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Quantitative Environmental Analysis, LLC

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Hudson River PCBs Site

Phase 2 Dredge Area Delineation Report

Prepared for:

General Electric Company

Albany, NY

Prepared by:

Quantitative Environmental Analysis, LLC

Glens Falls, NY

December 17, 2007

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List of Abbreviations

BBL	Blasland, Bouck & Lee, Inc.
CD	Consent Decree
CDE	Critical Phase 1 Design Elements
CL	Confidence Level
CY	Cubic Yards
DAD	Dredge Area Delineation
DGWP	Data Gap Work Plan
DoC	Depth of Contamination
DSR	Data Summary Report
EGIA	East Griffin Island Area
ESI	Environmental Standards, Inc.
FDR	Final Design Report
FS	Feasibility Study
FSP	Field Sampling Plan
GE	General Electric Company
GIS	Geographic Information Systems
GPS	Global Position System
IDL	Interactive Data Language

IDW	Inverse Distance Weighting
MDL	Method Detection Limit
MPA	Mass per Unit Area
NTIP	Northern Thompson Island Pool
OC	Organic Carbon
OSI	Ocean Surveys, Inc.
PCB	Polychlorinated Biphenyl
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
QEA	Quantitative Environmental Analysis, LLC
RA CD	Remedial Action Consent Decree
RCRA	Resource Conservation and Recovery Act
RD	Remedial Design
RD AOC	Remedial Design and Cost Recovery Administrative Order on Consent
RI/FS	Remedial Investigation/Feasibility Study
RL	Reporting Limit
RM	River Mile
ROD	Record of Decision
SDG	Sample Delivery Group
SDS	Supplemental Delineation Sampling
SDSR	Supplemental Delineation Sampling Program Data Summary Report
SEDC	Supplemental Engineering Data Collection
SOW	Statement of Work
SSAP	Sediment Sampling and Analysis Program
SSS	Side Scan Sonar
USEPA	United States Environmental Protection Agency

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

This Phase 2 Dredge Area Delineation (DAD) Report has been prepared pursuant to the Administrative Order on Consent for the Hudson River Remedial Design and Cost Recovery and in accordance with the Remedial Design Work Plan (RD Work Plan), which is a part of that Administrative Order. The Record of Decision for the Hudson River (ROD) covers three sections of the Upper Hudson River: River Section 1 (from the former location of the Fort Edward Dam to Thompson Island Dam); River Section 2 (from Thompson Island Dam to Northumberland Dam); and River Section 3 (from Northumberland Dam to the Federal Dam at Troy). It divides the dredging project into two phases. Phase 1 dredging, which is defined by the Phase 1 Dredge Area Delineation Report approved by the United States Environmental Protection Agency (USEPA) in 2005, will take place in two regions of River Section 1: the northern portion of Thompson Island Pool; and the east channel at Griffin Island. The remaining 37+ river miles of the Upper Hudson River are the subject of this report.

In accordance with the RD Work Plan, the objective of Phase 2 DAD is to identify those sediments within the Phase 2 Areas that meet the USEPA established criteria for removal as interpreted by USEPA. The dredge area delineation method relies on a weight-of-evidence approach, based primarily on the mass and concentration of polychlorinated biphenyls (PCBs) in the sediments, supplemented by consideration of the other physical characteristics of the river.

Mathematical interpolation was used, at least initially, to establish horizontal (areal) dredge area boundaries in Phase 2 Areas, except in areas where interpolation was infeasible because there were not enough data to establish spatial correlation or spatial correlation was too poor to support interpolation. The interpolation results were then reviewed, in conjunction with USEPA, to assess whether those results were reliable in terms of whether they captured cores that met the dredging criteria and did not capture cores that did not meet those criteria. Based on discussions with USEPA in 2007, quantitative criteria representing the performance of the interpolator, combined with professional judgment, were used to determine whether the areal interpolation results in a given area were reliable. For areas where the interpolation results were judged to be reliable, minor adjustments were made to the dredge area boundaries to include or exclude particular cores. For areas where the interpolation results were judged to be unreliable, areal delineation was performed manually. When manual delineation was conducted (either because interpolation was not feasible or because the interpolation results were judged to be unreliable), boundaries were drawn using a set of objective guidelines pertaining to bathymetry, sediment type and distances between cores. Vertical delineation was based on interpolation of Total PCB concentrations at depth, except in areas lacking sufficient data for such interpolation. In the latter types of areas, vertical delineation was based on a statistical analysis of the depth of contamination data.

One hundred fifty-nine separate dredge areas were initially delineated within the Phase 2 portion of the Upper Hudson River. These areas range in size from less than 0.1 to over 50 acres. One of these delineated dredge areas is located more than half a mile from any other dredge area and was determined to meet the ROD's criteria for exclusion of "isolated" areas less than 50,000 ft^2 that would require a separate mobilization of equipment to reach them. After exclusion of this area, there remain 158 delineated dredge areas within the Phase 2 Areas. In addition, there are 10 dredge areas included in this report that were previously delineated during the Phase 1 delineation, which has been approved by USEPA. Overall, approximately 400 acres are targeted for dredging in Phase 2 and contain a sediment volume of 1,531,400 cy and about 92,800 kg of PCB. The average depth of contamination is less than 3 ft. in most of these dredge areas, although a few areas extend to depths of 5 ft. or more.

A summary of the delineation for the entire project was compiled by combining the results of the Phase 2 delineation presented herein and the dredge prisms presented in the Phase 1 Final Design Report. Within River Section 1, the Thompson Island Pool, about 60,600 kg of PCBs have been targeted for removal. This constitutes about 98% of the Total PCB inventory in River Section 1. For comparison, the estimated remedy that USEPA outlined in the Feasibility Study (FS) and the ROD targeted about 36,000 kg of PCBs, which was estimated to account for about 80% of the PCB mass in River Section 1 based on the data available at that time. Thus, the delineation targets almost twice as much PCB in River Section 1 as the FS estimated would be removed by the selected remedy. This removal is achieved by targeting 310 of the 537 acres of

River Section 1, whereas the FS remedy targeted 266 acres. Thus, the project targets 8% more area in River Section 1 and removes a much greater percentage of the PCB inventory.

In River Section 2, about 364,000 cy of sediment and 28,500 kg of PCB are targeted for removal from 86 acres. The comparative statistics from the FS are, 565,000 cy, 23,600 kg of PCB, and 74 acres. In River Section 3, 491,000 cy of sediment and 24,000 kg of PCB are targeted to remove from 95 acres. The comparative statistics from the FS are, 393,000 cy, 6,700 kg of PCB, and 92 acres.

Combining Phase 1 and Phase 2, the overall project targets almost 113,000 kg of PCBs that would be removed by dredging about 490 acres of the Upper Hudson River. The ROD indicates that the chosen remedy would remove 66,300 kg of PCBs by dredging about 430 acres. Thus, the project will target about 14% more area than was specified in the ROD and will remove almost 70% more PCBs. This will be accomplished by dredging about 1,795,000 cy of sediments, substantially less than the about 2,450,000 cy estimated by USEPA (not counting the volume targeted for navigational dredging). The volume difference is attributable to the finding from the massive pre-design sampling program that PCB concentrations greater than 1 mg/kg do not reach as deeply into the sediments as was estimated in the FS.

In summary, the dredge area delineation process has produced a dredging project that is substantially more efficient than that specified in the ROD. It removes a higher percentage of PCBs present in the Thompson Island Pool (98%), while removing much less sediment. In addition, for River Sections 2 and 3, it is projected to remove more mass than what was estimated in the FS.

SECTION 1

SECTION 1
INTRODUCTION

This Phase 2 Dredge Area Delineation (DAD) Report has been prepared on behalf of the General Electric Company (GE) as part of the remedial design to implement the Record of Decision (ROD) (United States Environmental Protection Agency [USEPA] 2002) for the Hudson River PCBs Superfund Site issued by the USEPA in February 2002.

In August 2003, GE and USEPA entered into an Administrative Order on Consent for the Hudson River Remedial Design and Cost Recovery (RD AOC; USEPA and GE 2003; Index No. CERCLA 02-2003-2027), under which GE agreed to conduct the Remedial Design (RD) for the remedy selected by USEPA in the ROD. That RD AOC provided for the conduct of the RD in two phases to correspond to the two phases of the Remedial Action specified in the ROD – Phase 1 consisting of the first year of dredging (at a reduced rate) and Phase 2 consisting of the remainder of the project. Subsequently, GE and USEPA entered into a Remedial Action Consent Decree (RA CD) relating to the performance of the remedy (USEPA and GE 2005); this RA CD was approved by federal district court on November 2, 2006, in *United States v. General Electric Company* (Civil Action No. 05-cv-1270, N.D.N.Y.).

This report focuses on the areas within the Upper Hudson River that fall within Phase 2 of the dredging program specified in the ROD (Phase 2 Areas). The areas that will be dredged in Phase 1 of the dredging program are identified in the Phase 1 Final Design Report (Phase 1 FDR), which was submitted to USEPA on March 21, 2006 (Blasland, Bouck & Lee, Inc. [BBL] 2006), subsequently modified by revisions of numerous plans and specifications that were part of that report, and approved by USEPA through several letters, the latest dated November 30, 2007. The delineation of these areas had previously been set forth in the revised Phase 1 DAD Report (Quantitative Environmental Analysis, LLC [QEA] 2005a), which was submitted to USEPA on February 28, 2005 and approved by USEPA on March 30, 2005.

This Phase 2 DAD Report has been prepared pursuant to the RD AOC and in accordance with the RD Work Plan (BBL 2003), which is a part of that RD AOC. This report represents a revision of a review draft initially submitted on March 29, 2006, and resubmitted in accordance with the RA CD on November 16, 2006 for final USEPA review. The delineation presented here conforms to the following:

- the pertinent requirements set forth in the RD Work Plan;
- the applicable criteria and requirements that were specified in USEPA's March 2004 comments (USEPA 2004a) on the initial Phase 1 DAD Report and that GE did not dispute;
- the parties' agreements on resolution of disputed issues relating to the Phase 1 DAD Report (GE 2004, Attachment A; USEPA 2004b, Attachment 1);
- the requirements set forth in USEPA's Final Decision Regarding General Electric Company's Disputes on Draft Phase 1 DAD Report and Draft Phase 1 Target Area Identification Report (USEPA's Final Decision; USEPA 2004b), insofar as relevant to the Phase 2 dredge area delineation;
- the data treatments set forth in the approved Phase 1 DAD Report, insofar as relevant to Phase 2 dredge area delineation;
- the procedures specified in Attachment A (Critical Phase 1 Design Elements [CDE]) to Appendix B (Statement of Work [SOW]) to the RA CD, insofar as relevant to Phase 2 dredge area delineation; and
- agreements reached during discussions between GE and USEPA in 2007 regarding the reliability of the results produced by the areal delineation method required by the resolution of the Phase 1 DAD dispute (i.e., kriging) and regarding the manual delineation of dredge area boundaries in cases where those results were judged to be unreliable.

1.1 BACKGROUND

The ROD covers three sections of the Upper Hudson River: River Section 1 (from the former location of the Fort Edward Dam to Thompson Island Dam); River Section 2 (from Thompson Island Dam to Northumberland Dam); and River Section 3 (from Northumberland

Dam to the Federal Dam at Troy). Phase 1 dredging will take place in two regions of River Section 1 (see Phase 1 FDR): the northern portion of Thompson Island Pool (referred to as NTIP); and the east channel at Griffin Island (referred to as the East Griffin Island Area or EGIA). The remaining 37+ river miles of the Upper Hudson River, as shown in Figure 1-1, are the subject of this Phase 2 DAD Report. For convenience, the Phase 2 Areas have been divided into 11 separate areas as labeled on Figure 1-1. Details and the spatial extent of each area are presented in Sections 3 and 5.

Pursuant to the Administrative Order for the Sediment Sampling and Analysis Program (SSAP) (Index No. CERCLA 02-2002-2023), GE initiated a sediment sampling program in October 2002 to provide information to delineate the areal extent and depth of sediments meeting the criteria for removal set forth in the ROD. The details of the SSAP are described in a Field Sampling Plan (FSP; QEA 2002), a Supplemental FSP (QEA 2003a), and a Quality Assurance Project Plan for the SSAP (QAPP; Environmental Standards, Inc. [ESI] and QEA 2002). The SSAP was designed to provide data for the evaluation of the following sediment parameters, which are required to delineate the dredge areas:

- Mass per Unit Area (MPA) of PCBs with three or more chlorine atoms (Tri+ PCB or PCB_{3+});
- surficial sediment PCB concentrations (Tri+ and Total);
- depth of PCB-containing sediments;
- sediment texture;
- sediment stratigraphy, including location of underlying rock or gravel, when encountered;
- river bathymetry;
- profile of PCB concentration (Tri+ and Total) and sediment type with depth; and
- erosion potential, for River Section 3 only.

The sediments in River Section 1 that were identified as “target” areas were sampled at an 80 ft. spacing and areas identified as “screening” areas were sampled at a 160 ft. spacing. By contrast, in River Sections 2 and 3, the sampling was limited to areas of fine-grained sediment and, in some cases, sandy or “transitional” sediments bordering fine-grained sediments.

Consequently, some areas in River Sections 2 and 3 (as well as a few localized areas in River Section 1) are isolated and do not have sufficient data (or spatial correlation) to support the statistical interpolations of MPA and surficial sediment PCB concentration specified in the Final Decision (USEPA 2004b), and thus required special consideration. The approach to dredge area delineation in these areas is included in Section 3.

Sampling in Phase 2 Areas was conducted in four years. The first round of sampling in the SSAP was completed in 2002. In winter 2002-2003, the data collected in 2002 were reviewed to identify data gaps. Sampling locations were identified to fill the data gaps and sediment cores were collected from these locations in 2003 as a continuation of the SSAP. Data collected in 2003 were evaluated upon receipt to identify additional data gaps and, to the extent practical, samples were collected from these locations during the 2003 field season. The data collected in 2002 and 2003 are documented in the Data Summary Report for Phase 2 Areas (Phase 2 DSR; QEA et al. 2004b).

Following USEPA's Final Decision, GE submitted the Additional Phase 2 Supplemental Engineering Data Collection (SEDC) Work Plan (Phase 2 Data Gap Work Plan [DGWP]; QEA 2004a), accompanied by a set of figures (QEA 2004b), describing additional data gaps in Phase 2 Areas and proposing sampling and other field investigations to eliminate the data gaps. This sampling was conducted during the 2004 field season (as part of the program referred to as the Supplemental Delineation Sampling Program). These data are documented in the Supplemental Delineation Sampling Program Data Summary Report (SDSR; QEA and ESI 2005). Finally, based on review of the data, further sampling to fill additional data gaps identified in Phase 2 Areas was proposed in the SEDC Work Plan for 2005 Data Gap Sampling (QEA 2005b). These data were collected in the 2005 field season and are summarized in the 2005 Data Gap Data Summary Report (2005 Data Gap DSR; QEA and ESI 2006). The 2004 and 2005 data are jointly referred to herein as the Supplemental Delineation Sampling (SDS) data.

1.2 PROJECT OBJECTIVES

In accordance with the RD Work Plan, the objective of Phase 2 dredge area delineation is to identify those sediments within the Phase 2 Areas that meet the criteria for removal specified in the ROD, as interpreted by USEPA, as well as those specified in the USEPA's Final Decision. The ROD specifies that removal of sediments shall be based primarily on MPA_{3+} of 3 g/m^2 or greater in River Section 1 and 10 g/m^2 or greater in River Section 2, and on removal of selected sediments with high PCB concentrations and high erosional potential (i.e., certain "hot spots") in River Section 3. In addition, the RD Work Plan specifies that, in River Section 3, sediments with an MPA_{3+} exceeding 10 g/m^2 in areas where burial has been a significant ongoing process may be left in place consistent with the ROD criteria for that river section. The Final Decision requires that, in addition to evaluating the MPA_{3+}, the delineation must identify for dredging those sediments having a measured or estimated PCB_{3+} concentration anywhere in the top 12 in. (30 cm) that meets or exceeds 10 mg/kg in River Section 1 or 30 mg/kg in River Sections 2 and 3.

As required by the USEPA's Final Decision, the dredge area delineation method relies on a weight-of-evidence approach, based primarily on MPA_{3+} and PCB_{3+} concentration in the top 12 in. of sediment and supplemented by consideration of the other information listed in Section 1.1 of this report and Section 2.4 of the RD Work Plan. More specifically, the project objectives include identification of:

- areas to be dredged within the Phase 2 Areas;
- depths of removal required to capture the PCB-containing sediments meeting the removal criteria within those dredge areas; and
- PCB concentrations within the delineated sediments.

1.3 REPORT OBJECTIVES

The principal goal of this report is to provide a description of the dredge area delineation process and to present the delineation of specific areas within the Phase 2 Areas that meet the criteria for removal in accordance with the requirements imposed by USEPA. This report provides detailed descriptions of:

- the logic used for dredge area delineation;
- the data analyses used to characterize the river sediments and the associated PCBs;
- the rationale used for targeting specific sediment areas; and
- the methodology for establishing the horizontal and vertical boundaries of those areas meeting the criteria for removal, volume of contaminated sediments, and PCB inventory within those areas.

1.4 REPORT ORGANIZATION

Section 2 details the data used for the dredge area delineation. Section 3 describes the general methodology employed in the areal and vertical delineation approach. Section 4 presents the specific interpolation methods used in the delineation process. Section 5 presents the results of the dredge area delineation for the Phase 2 Areas. Finally, Section 6 presents a summary and conclusions from the dredge area delineation effort for these areas.

SECTION 2

SECTION 2
DATA ANALYSIS

2.1 INTRODUCTION

The delineation of specific dredge areas within the Phase 2 Areas of the Upper Hudson River generally follows the approach used for Phase 1 dredge area delineation (QEA 2005a). It relies principally on PCB data from the 2002-2003 SSAP and on the 2004 and 2005 SDS data. This delineation is based on the March 6, 2006 version of the SSAP/SDS database.[1] Historical data are also included if their location and data help to refine a dredge area boundary that is uncertain due to a lack of SSAP/SDS data. Side scan sonar (SSS) mapping, sediment type, probing data, and bathymetric data (i.e., river bottom elevations and contours) also factor into the establishment of dredge area boundaries (RD Work Plan; BBL 2003). The subsections that follow provide an overview of the data sets used in the dredge area delineation and the manner in which the data were treated. The Phase 1 DSR (QEA et al. 2004a), Phase 2 DSR (QEA et al. 2004b), 2004 SDSR (QEA and ESI 2005), the 2005 Data Gap DSR (QEA and ESI 2006), and USEPA Feasibility Study (USEPA 2000) should be consulted for a more detailed description of the SSAP data, the 2004 and 2005 SDS data, and the historical data, respectively. A small subset of the SSAP/SDS data set was rejected for use in delineation based on uncertainty considerations (i.e., 18 inconsistent data cores in the Phase 2 Areas). These data and the logic used in their evaluation are presented in Section 2.7.1.

The RD Work Plan indicates that dredge area delineation will consider deposition and the proximity of the sediments to tributaries. Deposition that has caused substantial burial of the PCB inventory is justification for excluding sediments from dredging. The RD Work Plan also indicates that sub-bottom profiling results will be considered in delineation. However, this is not possible because sub-bottom profiling was unsuccessful in providing data useful in establishing the interface between contaminated and clean sediments (Ocean Surveys, Inc. [OSI] 2003a).

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[1] No additional data relevant to the Phase 2 dredge area delineation have been collected since that time. However, as discussed in Sections 5 and 6, a relatively small number of additional cores, plus additional probing, have been identified to satisfy data gaps in the delineation described in this report. GE has proposed, and USEPA has approved, those additional investigations. This additional sampling and probing will be conducted in 2008, and the results will be incorporated into the Phase 2 design.

The RD Work Plan notes further that the organic carbon (OC) content of the sediment will be considered in the delineation. However, the parties agreed in the Phase 1 DAD dispute resolution that, "[s]ince the PCB data and organic carbon (OC) data come from the same cores, GE shall use the PCB data, not the OC data, from those cores in dredge area delineation," and that GE would include in the Phase 1 DAD Report a further explanation of its evaluation of the OC data (GE 2004, Attachment 1). In the Phase 1 DAD Report, GE presented an analysis of the OC data for the Phase 1 Areas, which indicated that while there were general patterns of correlation of OC with sediment type, strong gradients that would assist in dredge area delineation were absent. In these circumstances, no further analysis of the OC data in the Phase 2 Areas was completed. Instead, the Phase 2 delineation focuses on the PCB data within each core.

In accordance with the RD Work Plan, an electronic map (i.e., an ArcReader "published map file") of the key data used in the Phase 2 dredge area delineation is included on a CD-ROM (Appendix F) accompanying this report. This electronic map includes Geographic Information Systems (GIS) layers showing bathymetry contours, sediment type, core penetration depth, core probing depth, core recovery depth (lab and field), and Total PCB concentrations (in all depth intervals sampled). Directions for viewing these data are on the CD-ROM.

2.2 SSAP/SDS PCB DATA TREATMENTS

SSAP/SDS data collected from the Phase 2 Areas were incorporated into the dredge area delineation.[2] There were 8,081 locations that provided MPA_{3+} (including 187 abandoned locations with probing depths less than 6 in.) and 8,008 locations that provided maximum PCB_{3+} concentrations in the top 12 in. As discussed further in Section 2.4, many of the SSAP cores were not sectioned at 12 in., but at 2 in. and 24 in. The 8,022 locations that provided maximum PCB concentrations in the top 12 in. include 259 grab samples and 1,542 locations where the maximum concentration was derived using USEPA's length-weighted adjustment equation

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[2] The data counts provided in this section and in all tables in this report (except for Tables 5-3 and 5-4) include a number of cores in areas that were previously considered to be Phase 1 Areas in the Phase 1 DAD Report (QEA 2005) but are not scheduled to be dredge in Phase 1 and thus are now considered to be in Phase 2.

(described in Section 2.4) to estimate a concentration within the top 12 in. (e.g., in the 2-12 in. segment) from the measured concentration in a longer segment (e.g., the 2-24 in. segment). Further discussion on the certainty and confidence of the data used in the dredge area delineation is provided in Section 2.5.

The project-specific PCB Aroclor Method GEHR8082 was used to quantify Aroclor concentrations for the SSAP and SDS data (ESI and QEA 2002, Appendix 5). In addition, homolog PCBs were measured on a subset of the SSAP sample extracts using Method GEHR680 (ESI and QEA 2002, Appendix 8) to develop a relationship between the Aroclor equivalent concentrations (Total PCBs) and the PCB_{3+} metric specified in the ROD (Section 2.2.2).

2.2.1 General Data Treatments

2.2.1.1 Non-Detects in SSAP/SDS Data

Non-detect Aroclor concentrations were assigned values of zero for purposes of computing PCB_{3+} concentrations. This assignment is consistent with the manner in which Total PCB concentrations typically are calculated from Aroclor data[3] and with the treatment of non-detects in the data set used to develop the PCB_{3+} – Aroclor PCB regression equations.

2.2.1.2 Blind Duplicates in SSAP/SDS Data

The SSAP/SDS database contains the results from a number of blind duplicate samples analyzed for Quality Assurance/Quality Control (QA/QC) purposes. These QA/QC samples were split samples created in the core-processing lab in order to assess precision based on the field processing and analytical testing of the samples. Duplicate samples used in the MPA_{3+} calculations were treated according to the following rules:

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[3] The historical data used by USEPA in crafting the Upper Hudson River remedy are largely Aroclor data in which non-detect Aroclor concentrations were treated as zero values in the computation of Total PCB and PCB_{3+}.

- if both the blind duplicate and parent sample had detected PCB concentrations greater than or equal to the method detection limit (MDL), the average of the two values was calculated;
- if one of the two samples had a PCB concentration reported as non-detect and the other had a detected concentration, the detected concentration was used; and
- if both PCB values were non-detect, a value of zero was used.

In addition, if the blind duplicate and/or parent sample contained blank contamination for any of the Aroclor values or Total PCB value, the sample was adjusted as described in Section 2.2.1.3 and the above criteria were then applied.

2.2.1.3 Consideration of Blank Contamination when Determining PCB_{3+} and Total PCB Concentrations

When PCBs were detected in the associated blank samples for a given sample delivery group (SDG), indicating the possibility of external contamination of the samples in the SDG, the Total PCB concentrations of the SDG were adjusted. In accordance with the data validation Standard Operating Procedures in the Sediment Sampling Design Support Quality Assurance Project Plan (SSAP QAPP; ESI and QEA 2002), any sample Aroclor result that was less than or equal to 5x the associated blank Aroclor result was considered to be potentially attributable to external contamination not indigenous to the sample location. Each such Aroclor result was given the validation qualifier "U*" and changed to a "not-detected" result, and the associated Aroclor MDL was raised to the original detected value (the Reporting Limit [RL] was also raised if the original positive result was greater than the RL). There were 353 samples in the Phase 2 Areas used in the delineation with Aroclor results qualified due to blank contamination (Table 2-1). In addition, the Total PCB concentrations in these samples were adjusted to the sum of the positive Aroclor results for each sample, excluding any Aroclor results qualified due to blank contamination. If all Aroclors detected in a sample were qualified due to blank contamination, the associated Total PCB result was given the validation qualifier "U*" and changed to a "not-detected" result, and the associated Total PCB MDL was raised to the highest Aroclor MDL (including the MDLs raised due to blank contamination).

These adjusted Aroclor values were used in the calculation of PCB_{3+} using Equation 2-1 (set forth in Section 2.2.2). Table 2-1 summarizes the samples in the Phase 2 Areas that were adjusted due to blank contamination. Some samples with blank contamination were reanalyzed and provided measurements of PCB concentrations without blank contamination. These samples were not adjusted and therefore are not shown in Table 2-1. The samples that were reanalyzed (144 samples), along with the new results, are listed in Table 2-2. If a sample that was reanalyzed had blank contamination, as well as the parent sample, the two samples were adjusted and averaged for use in Equation 2-1 and are included in Table 2-1.

2.2.1.4 Treatment of Bulk Density Outliers and Missing Bulk Density Values for SSAP/SDS Cores

Dry bulk density was analyzed in the analytical laboratory for the surface sample of each core and for grab samples. For subsurface core samples, the dry bulk density was calculated from the moisture content measured in the analytical laboratory and wet bulk density, which was calculated using field measurements obtained during sample processing.

The accuracy and precision of calculated dry bulk density values depend on the accuracy and precision of moisture content and the wet bulk density of the sediment. The moisture content, wet bulk density, and calculated dry bulk density data sets were reviewed to identify spurious data or what are termed "outliers". An "outlier" is defined as an extreme value in a data set that is not representative of the data set itself due to errors in its determination. In order to identify outliers in an objective way, a classification based on statistical and physical criteria was performed.

GE evaluated the measured moisture content to ensure that reported values: 1) fell between physical limits (i.e., 0 – 100%) during data verification; and 2) did not include statistical outliers. There were no moisture content values outside of the physical limits. Wet bulk density values were reviewed to determine: 1) outliers based on the range of values that might reasonably be observed in different sediments; and 2) statistical outliers. Wet bulk density values were rejected as "unreasonable" if the calculated value was less than or equal to 0 g/cm^3, greater than or equal to 2.5 g/cm^3, or less than or equal to 1.0 g/cm^3 for all samples other than those containing a primary component of silt or organics. Calculated dry bulk density values of 2.5 g/cm^3 or more were rejected. Any samples failing these criteria were flagged as outliers. Subsurface samples passing the reviews above were tested for statistical dry bulk density outliers.

The statistical outlier tests were completed using the procedures identified in Appendix 5 of the Phase 1 DSR (QEA et al. 2004a). The procedure was modified based on comments provided by USEPA to GE on December 22, 2004 (USEPA 2004c) such that only the primary sediment texture description of each individual sample was used, as opposed to using both the primary and secondary texture description. This test identified 891 outliers (250 statistical outliers and 641 unreasonable values) out of 40,219 calculated dry bulk density values.[4] Probability plots of dry bulk densities and flagged outliers for each sediment type are presented in Figure 2-1.

The bulk density values for samples missing bulk densities (there were two cores missing measured dry bulk density) or identified as outliers were replaced with the following values (in order of decreasing preference):

- bulk density value for the segment below, provided it is not an outlier;
- bulk density value for the segment above, provided it is neither a surface sample nor an outlier; or
- average bulk density value for the primary sediment classification grouping.

The dry bulk density values replaced by values from adjacent segments were then re-tested for statistical dry bulk density outliers. This test was needed because the sediment type of the original sample may not match the sediment type of surrounding core segments. If the replaced dry bulk density value was still an outlier, the average bulk density value for the

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[4] In response to a comment on the Phase 1 DAD Report by USEPA (2005), we explored the use of a non-parametric outlier test (i.e., Walsh's Test). This test identified many fewer values as statistical outliers (24 versus 250 out of 40,219 samples). However given the low frequency of outliers identified by either method (i.e., 0.06% or 0.62% of the data), we expect the delineation results would be insensitive to the choice of the outlier statistical test.

primary sediment classification grouping was used. Twenty-six of the replaced values from samples in Phase 2 Areas were identified as outliers. Table 2-3 presents summary statistics for the dry bulk densities of each sediment type before and after outlier removal. Table 2-4 lists the samples for which the bulk density values were identified as outliers, the original bulk density value, and the replacement value.

2.2.1.5 Abandoned Locations and Grab Samples

Abandoned locations with probing depths less than 6 in. were considered areas with little or no sediment for purposes of dredge area delineation. The data treatment for these 187 locations was the same as in the Phase 1 DAD Report – namely, MPA_{3+} set to 0 g/m^2, surface PCB_{3+} concentration considered as unavailable or "no data," and depth of contamination (DoC) set to probing depth. Abandoned locations with probing depths greater than or equal to six in. were designated as locations with no data and resampled during the 2004 or 2005 field season if they were in a location that would impact the delineation. The treatment of the data from these locations is described in Section 2.7.3.

At locations where the field crews were not able to collect a core and the sediment probing depth was less than or equal to six in., a grab sample was attempted with a Ponar dredge. There were 155 such locations in Phase 2 Areas. There were also 28 locations in Phase 2 Areas with probing depths equal to six in. and 101 locations with probing depths greater than six in. at which grab samples were collected. The data treatments for grab samples were the same as in the Phase 1 DAD Report. Specifically, for the grab samples with probing depth less than or equal to six in., MPA_{3+} was based on probing depth, surface sediment concentration was considered as measured, and DoC was set to the probing depth. For the grab samples with probing depth greater than six in., the samples were considered to have no data for MPA_{3+} and DoC calculations and the surface sediment concentration was considered as measured.

2.2.2 Estimation of PCB_{3+} Concentrations from SSAP/SDS Aroclor Concentrations

As noted above, the SSAP/SDS samples were analyzed for PCB Aroclors using Method GEHR8082. For use in applying the applicable MPA_{3+} and surface sediment removal criteria, these results needed to be converted to PCB_{3+} concentrations. Consistent with the Phase 1 DAD, PCB_{3+} concentrations were calculated from the Aroclor results using a regression equation developed by USEPA contractors (USEPA 2004b, Appendix E). The equation, which USEPA directed GE to use (USEPA Final Decision), is as follows:

$$[PCB_{3+}]_i = 0.03 \cdot [Aroclor1221]_i + 1.16 \cdot [Aroclor1242 + Aroclor1254]_i \qquad (2\text{-}1)$$

where:

$[Aroclor1221]_i$ = the reported Aroclor 1221 PCB concentration (mg/kg); and

$[Aroclor1242 + Aroclor1254]_i$ = the sum of the reported Aroclor 1242 and Aroclor 1254 PCB concentrations (mg/kg).

2.2.3 Estimation of PCB Concentrations in Sediments Beneath Incomplete Cores

Cores containing a Total PCB concentration (based on the Aroclor results) greater or equal to 1 mg/kg in their bottom segment have been termed incomplete cores. In such cores, either the entire column of soft sediments contains PCBs, or the core did not recover the full column of contaminated sediments (possibly due to an obstruction that stopped core penetration or to the loss of sediments as the core was retrieved). For the subset of these cores that was retained for dredge area delineation (i.e., those that were not replaced by a paired data gap core obtained by resampling), an estimate was made of the PCBs in sediments beneath the sampled sediments.

To provide a basis to estimate the PCB concentrations beneath the sampled sediments, the PCB patterns in complete cores were examined. This examination indicated that in cores with an evident peak PCB concentration at depth, the PCB concentrations beneath the peak tended to decline in an exponential fashion. Work conducted by Kern Statistical Services (2004), details of which can be found in Appendix A of the Phase 1 DAD Report, indicated that the following simple exponential model provided a conservative approximation of the decline (i.e., over-estimated the distance to reach 1 mg/kg in complete cores simulated as incomplete cores in 65% of cases):

$$c(z) = c(0)e^{-0.186z} \tag{2-2}$$

where:

$c(z)$ = the extrapolated Total PCB concentration z inches below the mid-point of the bottom segment; and

$c(0)$ = the Total PCB concentration in the bottom segment.

The rate constant of -0.186 per inch was determined by minimizing the mean squared error between the true PCB concentrations and the modeled concentrations using the peak concentration, the known distance to 1 mg/kg, and the paired PCB concentration at depth for the bottom and second from bottom intervals of the artificially-truncated cores.

Equation 2-2 was applied to those incomplete cores containing an evident peak PCB concentration and a decline below the peak that either persisted to the bottom core segment or terminated with an insignificant increase in concentration between the last two segments. An increase was judged to be insignificant if the relative percent difference was less than 40% or the bottom two sections had Total PCB concentrations less than 25 mg/kg. In addition, a visual inspection of the cores meeting these criteria was conducted to determine if the extrapolation may be applied. If the core profile was sporadic and it was difficult to determine if the peak was reached, the core was not extrapolated, even if it met the above criteria: there were six such cores in the Phase 2 Areas.

For cores that were extrapolated using Equation (2-2), the Total PCB concentrations were extrapolated to a maximum depth of twice the core recovery measured in the laboratory. This depth was used to truncate the extrapolation because PCBs typically do not extend beyond about twice the depth of the peak concentration. Because the peak PCB concentration in cores subject to extrapolation occurs at a depth shallower than the depth of recovered sediment, the constraint on extrapolation is conservative, i.e., it is likely that PCBs at this location do not persist to twice the depth of recovered sediment.

The extrapolation was terminated at a shallower depth if either: (a) the extrapolation reached a Total PCB concentration of less than 1 mg/kg; or (b) the field notes indicated that rock, gravel, cobbles, or Glacial Lake Albany clay was encountered.

PCB_{3+} concentrations in the extrapolated depth intervals were calculated from the extrapolated Total PCB concentrations. The PCB_{3+} fractions used to determine PCB_{3+} from Total PCB are those determined by the USEPA's Tri+ PCB–Aroclor PCB regression model and the paired Total PCB data analyzed by Aroclor GEHR8082; these fractions were provided by USEPA (Hess 2005). The PCB_{3+} fractions are listed in Table 2-5. PCB_{3+} concentration was calculated by multiplying the appropriate mean PCB_{3+} fraction by the extrapolated Total PCB result.

This extrapolation method was applied to only the subset of cores that met the criteria described above. For incomplete cores that did not fall into any of the above categories, Total PCB profiles, and consequently PCB_{3+} concentrations, were not established for sections below the last measured section. For those incomplete cores, the PCB_{3+} mass per unit area (MPA_{3+}) and DoC were established using a specific set of procedures, depending on the core's PCB profile and the presence of Glacial Lake Albany clay, rock, or cobble. These procedures, which involved setting the MPA_{3+} and DoC by applying specific ratios to the unextrapolated MPA_{3+} and lab recovery depth, respectively, are discussed further in Section 2.5.

2.3 MASS OF PCB PER UNIT OF SEDIMENT SURFACE AREA

One of the criteria for identifying sediments to be targeted for removal is MPA_{3+}. This metric, which defines the inventory of PCB_{3+} within the sediments, is calculated from the measurements of PCB_{3+} concentration (on a dry weight basis) and sediment dry bulk density. The MPA_{3+} criteria specified in the ROD and the RD Work Plan for sediment removal are 3 g/m^2 or greater for River Section 1, 10 g/m^2 or greater for River Section 2, and 10 g/m^2 or greater for River Section 3.

The MPA_{3+} is expressed as grams of PCB_{3+} per square meter of sediment surface area and is calculated for each sediment core according to the formula:

$$MPA_{3+} = \sum_{i=1}^{n} [PCB_{3+}]_i \cdot BulkDensity_i \cdot SectionLength \tag{2-3}$$

where:

n = the number of sections in the core;

$[PCB_{3+}]_i$ = the concentration of PCB_{3+} in section *i* (mg/kg, dry weight);

$BulkDensity_i$ = the dry bulk density (kg/m^3) of sediments in section *I; and*

$SectionLength_i$ = the length of section *i* (m).

For purposes of calculating MPA_{3+} for cores with PCB concentrations estimated by extrapolation, the bulk density associated with the extrapolated PCB_{3+} concentrations was assumed to be the value measured in the bottommost sampled segment.

2.4 SURFICIAL SEDIMENT PCB_{3+} CONCENTRATIONS

In addition to MPA_{3+}, the ROD and the RD Work Plan indicate that the delineation of sediments to be removed is to consider surficial sediment PCB_{3+} concentrations, as well as sediment texture, bathymetry, and depth at which the PCB contamination is found. The USEPA's Final Decision specifies that any sediment sample collected in whole or in part within the top 12 in. (30 cm) must be considered surficial sediments. The Final Decision further directs that, in delineating dredge areas, the PCB_{3+} concentration in any such surface sediment sample must be compared to the applicable numerical criterion, which in River Section 1 is 10 mg/kg and in River Sections 2 and 3 is 30 mg/kg.

Under the SSAP sampling protocol approved by the USEPA prior to the Final Decision, more than half of the cores collected were not sectioned at 12 in. (Most of these cores were sectioned at 2 in. and 24 in.). In consideration of this fact, the USEPA's Final Decision includes a length-weighted average calculation procedure to assign PCB concentrations to the portion of such sections within the top 12 in. (e.g., the 2-12 in. section). This procedure relies on a comparison of the PCB concentrations measured in the section that straddles the 12-in. depth horizon (e.g., 2-24 in.) and the section underneath it. If the deeper section's concentration equals or exceeds that of the straddle section, the concentration measured in the straddle section was assigned to the portion of the section within the top 12 in. Otherwise, this upper portion was assigned a calculated concentration based on the assumption that the upper portion contains the Total PCB mass measured in the straddle section less the mass that would be in the portion deeper than 12 in. if its concentration equaled that of the immediately underlying section. In addition, where the core section straddling the 12-in. depth horizon was the last available section in the core, the PCB mass in that straddle section was assigned to the portion of the section within the top 12 in. of the core. The calculated concentrations were combined with concentrations measured in grab samples and core sections wholly within the top 12 in. to produce a data set for comparison to the surface concentration removal criterion.

All PCB_{3+} concentrations within the top 12 in., including directly measured concentrations and the calculated concentrations for the portions of straddle sections within the top 12 in. (except where additional data were collected, as described below), were compared to the applicable surface concentration dredge criterion in order to determine whether a location should be targeted for removal. For some cores where the 2-12 in. adjusted PCB_{3+} concentration exceeded the dredge criterion, additional data were collected to measure the 2-12 in. PCB_{3+} concentration at that location. In these cases, the adjusted 2-12 in. PCB_{3+} concentration was dropped and the comparisons to the surface concentration criterion were made using the new core's 0-2 in. and 2-12 in. measurements. However, if the maximum surface PCB_{3+} concentration in the original core occurred in the 0-2 in. interval, that value was kept along with the new core's surface PCB_{3+} maximum. More information on this process is provided in Section 2.7.5.

2.5 CONFIDENCE LEVELS

SSAP and SDS cores, as well as sample locations where cores could not be collected, were assigned to one of two "data confidence" levels – Confidence Level (CL) 1 or 2. The term "Confidence Level," as used in this report, is an indicator of the relative certainty of the calculated MPA_{3+}. CL1 cores are complete cores – i.e., those with a Total PCB concentration less than 1 mg/kg in the bottom section (thus indicating that the complete PCB inventory was captured). CL2 cores include all other cores. CL1 MPA_{3+} values have greater certainty than CL2 MPA_{3+} values. Cores falling into CL2 were further classified into a number of categories based on the types of cores or samples. With the exception of CL2P (discussed below), detailed descriptions of the CL categories and the corresponding data treatments were presented in the Phase 1 DAD Report.

The CL categories and the manner in which they have been used for understanding the certainty of a predicted MPA_{3+} value and in delineating dredge areas are summarized in Table 2-6. Tables identifying the cores within each CL for Phase 2 Areas are presented in this section (Tables 2-7 through 2-20), but specific details on the data treatments for each CL (except CL2P) can be found in the Phase 1 DAD Report.

It should be noted that incomplete cores with PCB profiles in which the DoC could be extrapolated based on a consistent decline (or near-consistent) in PCB concentrations below the peak were divided into four CLs; CL2A, CL2B, CL2F, and CL2G. The extrapolation of the data in those cores was limited to a maximum of twice the core recovery. If the concentration in the last extrapolated section above that maximum depth was less than or equal to 10 mg/kg, the core was classified as CL2A; if the concentration in that section was above 10 mg/kg, the core was classified as CL2B. The latter indicates a somewhat lower degree of confidence in the extrapolated DoC representing the actual DoC. Hence, this division allowed for the degree of certainty concerning the DoC to be considered in the vertical delineation of the areas that were not subjected to kriging.

It should also be noted that incomplete cores that could not be extrapolated as discussed in Section 2.2.3, their Total PCB concentrations below the last measured section were left unknown. MPA_{3+} and Depths of Contamination (see Section 2.6) for these cores were established using the ratio methods described in Table 2-6.

Confidence Level 2P

The Phase 1 DAD Report did not contain a CL for cores having at least two consecutive sections that were less than 1 mg/kg (i.e., 10 in. or more of "clean" sediment) below the segment with the peak Total PCB concentration, but with deeper sections marginally above 1 mg/kg (i.e., between 1 mg/kg and 5 mg/kg). These cores were assigned to CL2P in this Phase 2 DAD Report. For these cores, the DoC (discussed further in Section 2.6) was set at the top depth of the first section below the peak that went below 1 mg/kg, effectively disregarding the slightly higher Total PCB concentrations in lower section(s). A list of these cores is provided in Table 2-19. It should be noted that, regardless of the DoC set for these cores, all available Total PCB concentrations were used in interpolation of Total PCB at depth (discussed in detail in Sections 3 and 4) and in the manual evaluation of Total PCB concentrations when considering vertical dredge depths.

2.6 DEPTH OF CONTAMINATION FOR INDIVIDUAL CORES

As in the Phase 1 DAD Report and with the exception of CL2P cores, the DoC at a location was defined as the bottom of the deepest core section that had a Total PCB concentration greater than or equal to 1 mg/kg (i.e., all samples beneath that depth had Total PCB concentrations less than 1 mg/kg). For incomplete cores where DoC and MPA_{3+} were extrapolated based on a PCB profile (considered to be in CL 2A, 2B, 2F, or 2G), this was the depth at which the extrapolated Total PCB concentration reached less than 1 mg/kg. The procedures for determining the DoC for grab samples and cores not amenable to extrapolation are given in Table 2-6.

2.6.1 DoC Class

The accuracy of the DoC differs among cores. Complete cores are likely to have more accurate DoC than incomplete cores. Complete cores with finely-sectioned sampling lengths have a more accurate DoC than coarsely-sectioned complete cores. The bottom of a DoC-defining core section becomes a less accurate measure of the actual depth at which Total PCB concentration falls below 1 mg/kg as the average concentration in the section approaches 1 mg/kg (see Figure 2-2). To provide a convenient means to account for the variations in accuracy of the established DoC values, each Phase 2 core was assigned a "DoC Class." As indicated in Table 2-21, there are 10 different DoC Classes, with the most certainty in DoC Class 1 and the least certainty in DoC Class 10. These classes were used in the establishment of DoC in those areas where interpolation could not be used due to data limitations, as discussed in Section 3.4.2. Table 2-22 separates out the Phase 2 cores by DoC Class and Confidence Level.

Complete cores were segregated into six DoC Classes (Classes 1-3 and 5-7) depending on the thickness and Total PCB concentration of the DoC-defining core section. Three categories were established based on the principal segmentation scheme for the samples in the data set – i.e., less than 10 in. (mostly 6 in.); 10 to 15 in., and greater than 15 in. (mostly 22 in.). Based on professional judgment, a Total PCB concentration division at 2 mg/kg in the section above the DoC or the last measured section was used to further divide cores within each of the three thickness categories. This value was used as an indicator of the relative accuracy of the DoC established from the data treatment compared to the actual DoC in the core; as noted above. As PCB concentrations in that section fall below 2 mg/kg and approach 1 mg/kg, it becomes more likely that estimated DoC is greater than the actual DoC (see Figure 2-2).

Incomplete cores with DoC estimated by extrapolation of the Total PCB concentration profile were segregated into four DoC Classes. Similar to the complete cores, their DoC Class was defined by Total PCB concentrations (in this case, the concentration in the last measured section) and the thickness of the last measured section. Cores that were nearly complete (i.e., having a bottom section less than 10 in. thick and a Total PCB concentration less than or equal to 2 mg/kg) were assigned to a class (Class 4) whose accuracy fell within the classes for complete cores. The other three DoC Classes for incomplete cores had lower accuracy than the classes for complete cores. Cores having a Total PCB concentration less than or equal to 2 mg/kg in a bottom section greater than or equal to 10 in. thick were assigned Class 8. Incomplete cores with Total PCB concentrations in the bottom section between 2 and 25 mg/kg were assigned Class 9, regardless of the section thickness. Those cores with Total PCB concentrations in the bottom section greater than 25 mg/kg were assigned Class 10, regardless of section thickness. Cores whose DoC could not be estimated by extrapolation (i.e., CL2D cores) were not assigned a DoC Class.

The DoC Classes were used in establishing DoC in areas for which the data were too limited to support interpolation (see Section 3.4.2). The classes were irrelevant in areas in which DoC was established by interpolation of the Total PCB concentration at depth.

2.6.2 Consideration of Reporting Limits when Calculating Depth of Contamination

The parties agreed in the Phase 1 dispute resolution that for core sections having less than 1 mg/kg Total PCB concentrations to be used to determine DoC, the RL must be less than or equal to 0.5 mg/kg unless an elevated RL is justified with a technical rationale (USEPA 2004b, Attachment 1). RLs can exceed 0.5 mg/kg if the sample has an elevated sample moisture content (above 60%), dilution prior to analysis, or the presence of PCBs in an associated blank sample. Base (unadjusted) RLs are directly proportional to sample moisture content and are calculated using the following equation as per Table B-6a of the SSAP QAPP (ESI and QEA 2002):

$$RL = \frac{A * (LCS) * (V)}{DW * (1 - MC)} \tag{2-4}$$

where:

RL = reporting limit (mg/kg);
A = number of Aroclors (4);
LCS = low calibration standard (0.02 μg/ml);
V = pre-injection final extract volume (25 ml);
DW = sample dry weight (10 g); and
MC = moisture content.

This equation has been used to evaluate whether a core section with an RL greater than 0.5 mg/kg but less than 1 mg/kg, as calculated by the sum of Aroclor 1221, Aroclor 1242, Aroclor 1254, and Aroclor 1260, can be used to establish the DoC. As long as the moisture content of a sample is above 60%, the equation above will yield an RL above 0.5 mg/kg. For these samples with a Total PCB concentration less than 1 mg/kg, the RL greater than 0.5 mg/kg is considered justified due to the high sample moisture content. Thus, the core section with this RL can be used to establish the DoC, as long as: 1) the sample does not have blank contamination; 2) the sample does not have a dilution factor above 1; and 3) the RL remains below 1 mg/kg. If the RL exceeds 0.5 mg/kg because of blank contamination or extract dilution, the sample cannot be used to establish DoC. Finally, as discussed in Section 2.2.1.3, there are a number of samples where laboratory detections of one or more Aroclors were negated due to contamination in an associated blank sample. The individual Aroclor results, Total PCB concentrations, RLs, and MDLs for these samples were adjusted to account for these detections. For samples that cannot be used to set DoC, the next "clean" section down-core with Total PCBs less than 1 mg/kg was used. In the case where the deepest sample in the core had an RL issue, the DoC was set by extrapolating, starting at the midpoint of the bottommost core section. A list of the cores whose DoCs were affected by RL issues is provided in Table 2-12.

2.7 RESAMPLED LOCATIONS WITH PAIRED LOCATIONS

A number of locations were resampled in 2004 or 2005 because the original core did not yield a confident estimate of MPA_{3+} or DoC. Paired data now exist at these locations. The treatment of these data varied depending on the deficiency of the original sample (grouped in specific categories) and the result achieved with re-sampling. The details of these treatments are discussed below.

2.7.1 Inconsistent Data

A number of SSAP cores had a PCB concentration profile inconsistent with other measurements or atypical of Hudson River sediments or had length measurements in the processing laboratory that are inconsistent with length measurements made in the field (e.g., high PCB concentration in the clay layer or a core recovery length that exceeded the penetration depth by more than could be attributed to measurement error, which was defined as 5 in.). These cores are termed "inconsistent." Misidentification of the core or of particular sections was suspected and these cores were considered not representative of the actual conditions at the locations associated with them. There were 18 such "inconsistent" cores in the Phase 2 Areas. Resampling was attempted at nine of these locations; cores were collected at eight locations, but could not be collected at the other location because the resampling criteria were not met. The remaining nine locations were either not needed for the delineation or had already been reattempted in a previous year.

Table 2-23 identifies the 18 cores in Phase 2 Areas that were not used in the delineation because of their "inconsistent" classification. These cores are not assigned a CL, nor are they shown on the figures in Section 5. At the eight resampled locations where cores were collected, the cores collected during resampling were not "inconsistent," and the data from those cores were used in the delineation. These new cores are identified with asterisks in Table 2-23.

2.7.2 Previous Incomplete Core Locations

Locations at which an incomplete SSAP core was obtained such that DoC could not be confidently extrapolated and did not meet the criteria specified in the dispute resolution and Final Decision to be excluded from resampling were targeted for resampling in 2004 or 2005. There were 279 incomplete SSAP locations in Phase 2 Areas that were resampled in 2004 or 2005. These cores are identified with an "IN" designation in the core ID and are listed in Table 2-24.

Surface PCB concentrations for both the previous incomplete core and the new core collected in 2004 or 2005 (called the "data gap core") were used in the delineation. In addition, all measured Total PCB concentrations were used in the interpolation of Total PCBs at depth. MPA_{3+} and DoC estimates as follows:

Case 1: The data gap core is complete (CL1A) (or the data gap core was abandoned with probing depth of six in. or less [CL2J or CL2K]) and its DoC exceeds the recovery depth of the original core.

In this case, the complete data gap core provides a local estimate of DoC and MPA_{3+} and was used for purposes of dredge area delineation. The MPA_{3+} and DoC derived by extrapolating or doubling the original core were not used in the dredge area delineation. This approach reflects the fact that the complete core confirms the finding from the incomplete core that PCBs exist to the depth sampled by the incomplete core and provides relatively accurate estimates of MPA_{3+} and DoC. In contrast, extrapolation or doubling of the incomplete core provides estimates of MPA_{3+} and DoC whose reasonableness cannot be assessed and have been shown to be highly uncertain by simulation of the extrapolation and doubling methodologies using complete cores. In addition, it should be noted that, as indicated in the analysis performed by USEPA consultants (Kern 2004, Appendix A of the Phase 1 DAD Report), the extrapolation overestimates DoC 65% of the time, indicating that the extrapolation is a conservative estimate of the DoC. Therefore, the use of the complete core in place of the incomplete core, even when the incomplete core is extrapolated, is more certain and representative of the data at that location.

Case 2: The data gap core is complete (CL1A) (or the data gap core was abandoned with probing depth of 6 in. or less [CL2J or CL2K]) and its DoC is less than or equal to the recovery depth of the original core.

In this case, when the original incomplete core could be confidently extrapolated, its extrapolated MPA_{3+} and DoC were included in the delineation (and assigned a CL of 2A, 2B, or 2F) along with those of the data gap core. The MPA_{3+} and DoC of the incomplete cores that could not be confidently extrapolated were not used in the delineation.

Case 3: The data gap core is incomplete.

In this case, if the data gap core and original core could be confidently extrapolated, the MPA_{3+} and DoC estimates for both cores were used in delineation (and assigned a CL of 2A, 2B, or 2F). If neither core could be confidently extrapolated, both cores were doubled and treated as CL2D (see Table 2-6 in Section 2.5) in dredge area delineation. If only one core could be confidently extrapolated, the MPA_{3+} and DoC for that core were used in the dredge area delineation.

2.7.3 Previously Abandoned Locations

Abandoned SSAP locations where the probing depth was greater than or equal to 6 in. and field notes indicated that recoverable sediment may exist were targeted for resampling in 2004 or 2005. There were 143 abandoned locations in Phase 2 Areas that were targeted for resampling. These cores had “AB” as part of the core ID and are listed in Table 2-25. The resampling achieved the following: 73 complete cores were collected, 23 incomplete cores were collected, 33 grab samples were collected, and 14 locations were abandoned a second time. The locations that were abandoned again in 2004 or 2005 are not listed on Table 2-25.

Abandoned locations with probing depths greater than or equal to 6 in. that were not resampled or did not yield a sample in the resampling effort were treated as having no data for the delineation (see description of CL2K and CL2L cores in Table 2-6).

2.7.4 Previous Grab Samples

Twenty-two SSAP grab sample locations in Phase 2 Areas with a probing depth greater than six in. were targeted for resampling in 2004 or 2005. The resampling achieved the following: nine complete cores were collected, two incomplete cores were collected, four grab samples were collected, and seven locations were abandoned because a core meeting the recovery requirements could not be collected. The PCB_{3+} concentration from the original grab sample was used for the maximum PCB_{3+} surface value, but no MPA_{3+} or DoC was calculated from that sample.

2.7.5 Previously Adjusted 2-12 in. Samples

As noted above, many of the cores collected in 2002 and 2003 were sectioned in 2-24 in. depth intervals. As a result, these cores were subject to the length-weighted average adjustment discussed in Section 2.4. A subset of these locations was resampled in 2004 or 2005 to either provide a refined estimate of DoC or replace the adjusted 2-12 in. PCB_{3+} concentration (paired data gap locations, termed "TT" and "LW" cores, respectively). These resampled locations had a section that ended at 12 in. These cores thus yielded a PCB_{3+} concentration measurement in the 2-12 in. layer, as well as a PCB_{3+} measurement in the 0-2 in. layer. For these locations, the previous core's adjusted concentration data (i.e., the calculated 2-12 in. data) were not used in the evaluation of the maximum PCB_{3+} surface concentration. Instead, the new core's surface concentration data (for both the 0-2 in. and 2-12 in. intervals) were utilized to establish the maximum PCB_{3+} concentration in the 0-12 in. layer. In addition, if the old core's surface PCB_{3+} maximum occurred in the 0-2 in. interval, that value was used, along with the newly determined surface PCB_{3+} maximum. Data from both cores were used for MPA_{3+} and for the interpolation of Total PCB concentration at depth. For the "TT" cores, the new DoC provided a refined estimate of DoC for that location. The surface PCB_{3+} concentrations and refined DoC information for these locations are shown in Table 2-27. There were 308 cases of these types of data gap locations in Phase 2 Areas.

2.8 ANALYSIS OF "SELECT" CRITERION

As indicated in the ROD, areas determined to be depositional in nature may be excluded from dredging if certain criteria are met. These criteria require that Total PCB concentration anywhere in the top 12 in. be less than 5 mg/kg and that the peak Total PCB concentration occur below 24 in. For the evaluation of the Total PCB concentrations in the top 12 in., cores sectioned at 2-24 in. were adjusted using USEPA's length-weighted adjustment equation, when applicable (see discussion in Section 2.4). Cores exceeding the MPA_{3+} and surface PCB dredging criteria while also meeting the exclusion criteria were termed “select” cores. For the Phase 2 Areas, 300 cores were determined to be select cores. The use of this information in delineation is discussed in Sections 3 and 5.

2.9 HISTORICAL DATA IN PHASE 2 AREAS

PCB data from historical sediment sampling programs were not incorporated into the statistical interpolation or other procedures used to establish initial dredge area boundaries. Given the trend in PCB concentrations documented in the USEPA Remedial Investigation/Feasibility Study (RI/FS) documents (USEPA 1997; USEPA 2000) and the GE modeling report (QEA 1999) and the ROD’s conclusion that “[s]ome PCB-contaminated sediment may be buried by deposition of cleaner sediments at some times, but in other places and at other times, they may be redistributed by scouring” (ROD at page 27), older data may not be representative of contemporary conditions. Moreover, the technologies used to determine the location of sample collection were less precise than the differential global positioning system (GPS) used for the SSAP/SDS. These surveying and GPS technologies had positioning errors on the order of 1 m, whereas the SSAP/SDS GPS system is accurate to ± 1 cm. Finally, the compatibility of the PCB_{3+} concentrations measured in the historical data with the Tri+ PCB concentrations calculated for SSAP data using Equation 2-1 is unknown. The extent to which the historical data are biased high or low has not been assessed.

Despite the obvious limitations of the historical data, they provide some perspective on PCB levels that can be of use as part of a weight-of-evidence evaluation in situations in which dredge boundaries are uncertain due to a lack of SSAP/SDS data. For this reason, the historical data were reviewed and a subset of the data was judged adequate for use in resolving uncertain dredge area boundaries, as discussed below.

Data collected in the 1970s and 1980s were not used in the weight-of-evidence evaluation because of their age and uncertainty of estimated PCB_{3+} concentrations. Similarly, the 1991 GE Composite and 1998 GE Broad Scale Sampling Programs were not used because the entire depth of PCB-containing sediments was not sampled and samples from multiple coring locations were combined to form composite samples.

The following other historical data sets were considered in the delineation process:

- 1992 USEPA High Resolution Coring Program;
- 1994 USEPA Low Resolution Coring Program;
- 1998 GE Sediment Sampling Programs;
- 1999 GE Sediment Sampling Program; and
- 2001 GE Lignin Core Sampling Program.

While data from sediment cores collected during these historical sediment sampling programs were not incorporated into the initial delineation, they were used when they provided PCB data from locations near an uncertain dredge area areal boundary to aid in the delineation of the dredge area boundary. However, appropriate care was taken when incorporating these data, including individual review of each core to determine its usability. Each core was analyzed individually to determine its appropriate MPA_{3+} and surface PCB concentrations.

For the historical data sets accepted for use in delineation, PCB_{3+} concentrations were calculated directly because PCB concentrations in these samples were analyzed utilizing techniques that distinguished individual PCB congeners, from which homolog concentrations were calculated. PCB_{3+} concentrations were computed by adding the Tri- and greater homolog results. Consistent with past treatment of these data by USEPA, homologs reported as non-detects were treated as zero in the summation. Duplicate PCB data in the historical data sets were handled in the same manner as duplicates in the SSAP/SDS data set. In addition, missing bulk density values, when needed, were replaced with the average bulk density of that particular data set. Historical core data from three locations, each of which exceeded the surface PCB_{3+} criterion, were used to adjust or set dredge boundaries in the Phase 2 Areas and are discussed further in Section 5.1.4.

2.10 ANCILLARY DATA

Certain physical and other ancillary data were also used in defining dredge boundaries; the following subsections provide an overview of these data and how they were used in the delineation.

2.10.1 Surface Sediment Type Classification

PCBs adsorb preferentially to the organic matter in sediments. As a result, PCB concentrations tend to be highest in fine-grained, organic-rich sediments and lowest in sediments composed of coarse sand and gravel. Fine-grained, organic-rich sediments typically are found in areas of net deposition. The combination of these factors tends to result in a significant correlation between PCB MPA and sediment type (see further discussion in the Phase 1 DAD Report [QEA 2005a]). Fine-grained, organic-rich sediments typically have the highest PCB MPA, while coarse sand and gravel sediments typically have the lowest PCB MPA. Consequently, in a case where cores collected in one sediment type exceed the removal criteria and cores collected in an adjacent sediment type do not exceed the removal criteria, the boundary between the sediment types forms a logical boundary for delineating a dredge area so long as the data are sufficient to make such a conclusion (i.e., 80-ft. grid on both sides of boundary or 160 ft. grid that fulfills certain "performance criteria"). This is consistent with the resolution set forth in USEPA (2004b, Attachment 1), which states:

> *Physical boundaries shall only be used to adjust PCB contamination boundaries developed by the interpolator(s) at locations where:*
>
> *i. PCB data from both sides of the boundary support the use of the physical boundary to demarcate the areal extent of contamination. In such cases, the physical boundary can only be employed where the PCB data are present at a sufficient spatial resolution (i.e., typically 80-foot triangular grid spacing and up to 160 feet where performance criteria have been satisfied – refer to page 32 of 182 of the SSAP QAPP, or as otherwise agreed by EPA), or*
>
> *ii. [a] Type III (gravel/cobble) or Type V (rock) sediment boundary is not overlain by 6 inches or more of finer (i.e., Type I, II or IV) sediment.*

The surface sediment types used for these adjustments were derived from the SSS surveys performed as part of the SSAP to map the river bottom. These surveys identified the following five surficial sediment types:

- Type I (clay, silt, fine sands): smooth, generally featureless bottom; principally composed of soft aqueous silty sediments;
- Type II (sands): smooth to mottled bottom; principally composed of semi-compact to compact sand deposits;
- Type III (coarse gravel and sand mixtures): irregular bottom; principally composed of compact gravel and cobble deposits intermixed with sand;
- Type IV (mixed sediments): smooth and irregular bottom; a varying assemblage of sediments typically associated with Types I, II, and III; and
- Type V (rocky): extremely irregular bottom; principally composed of bedrock, cobbles, and/or boulders that are often overlain by a variable thickness of unconsolidated sediments.

The sediment type mapping was conducted using the SSS acoustic results, sediment probing, confirmatory grain-size analysis, and visual textural classification of surficial 2-in. sediment samples from each SSAP core. The SSS Data Interpretation Report for River Sections 1 and 3 (OSI 2003b) was presented as an appendix to the Supplemental FSP (QEA 2003a). The SSS Data Interpretation Report for River Section 2 was submitted to the USEPA in October 2003 (OSI 2003a). Supplemental analyses and field investigations were performed in late 2003 in response to USEPA's concerns that the original interpretation may not have identified all of the fine-grained sediment deposits. These included: 1) a re-evaluation of SSS data in select areas of River Section 3 where additional fine-grained sediment was suspected to exist based on conflicting groundtruthing or alternative processing by USEPA consultants; 2) probing in areas of the river where SSS coverage was not possible in 2002 and where aerial photos indicate navigable conditions and the possibility of fine sediment; and 3) the collection of additional confirmatory grain-size samples. The findings from these investigations were presented to USEPA in a supplemental report in December 2003 (QEA 2003b). A summary of the major findings for the SSS surveys for Phase 2 Areas is presented in Section 6 of the Phase 2 DSR

(QEA et al. 2004a). In areas determined to be potentially fine-grained after further data review, additional sediment cores were collected in 2004 and 2005. The results from these cores collected in 2004 are summarized in the SDSR (QEA and ESI 2005), and the results from the 2005 cores are summarized in the 2005 Data Gap DSR (QEA and ESI 2006). The details of how the surface sediment types were used in the delineation are discussed in Section 3.3.

2.10.2 2004 and 2005 Probing Data

Probing of sediments was conducted in areas where refined information on sediment thickness and sediment type was needed to aid in data gap core locations and confirmation of the boundary between fine, sandy, or transitional sediments, and gravel or rock (QEA 2004a, b, and QEA 2005b). Sections 3 and 5 discuss the application of the probing results to dredge area delineation. In general, the sediment type determined by probing was consistent with the SSS mapping. Table 2-28 shows the percentage of probing results where the sediment type determined by probing was consistent with the SSS interpretation. These estimates are based on the primary description in the probing results given by the field staff and do not take into account the secondary or qualitative descriptions of the probing effort. In addition, it should be noted that the primary purpose of probing was to differentiate sediment Types I and II from sediment Types III and V. If these types are grouped together (i.e., I and II and III and V), the percent correct would increase to 81% correct for Types I and II and 65% correct for Types III and V. These statistics support the use of probing to define dredge boundaries between these sediment types.

2.10.3 Bathymetric Data

Riverbed elevation data (determined through bathymetric surveys) identify steep slopes, shoals, and the channel in the river. Sediment and PCB accumulation is likely to vary among these different physical conditions, and their delineation can guide the location of dredge boundaries in a manner similar to that of sediment type boundaries. For example, if cores in a shoal exceed the MPA_{3+} dredge criterion and cores in an adjacent slope or channel do not exceed the criterion, the edge of the shoal forms a logical boundary for the dredge area so long as the data are sufficient to make such a conclusion (i.e., 80-ft. grid on both sides of boundary or 160-ft. grid that fulfills certain "performance criteria"). This is consistent with the resolution quoted in Section 2.10.1.

Bathymetry surveys of Phase 2 Areas were conducted in 2001, 2003, 2004, 2005, 2006, and 2007 (Table 2-29). Some areas, such as part of the west side of Griffin Island, are missing bathymetry data. In River Sections 1 and 2, transect data from 2001 and 2003 surveys were reprocessed and contoured at 1-ft. intervals to support the dredge area delineation. These contours were also used as an indicator of the location of the current navigational channel. The limited data from 2004 was not contoured. Multi-beam data from the 2005 survey were contoured at 0.5-ft. intervals. Data from River Section 3 and data collected in 2006 and 2007 were not contoured for the delineation and therefore, bathymetric data from these areas were not available for use in setting dredge area boundaries.

More details on how the bathymetric information was used in the dredge area delineation are provided in Sections 3.3.2 and 3.4.2.

2.10.4 Shoreline Geometry

At times, the shoreline geometry provided a logical boundary for dredge areas that were delineated. This occurred when data closest to shore were above the dredging criteria. The shoreline used in the dredge area delineation is the GIS layer that was digitized from aerial photography of flow conditions in spring 2002 (approximate flow rate of 5,000 cfs at the Fort Edward United States Geological Survey gauge station).

2.10.5 Probing Depth

Probing depth is the depth below the surface of the river bottom to which a steel rod can be manually advanced into the sediments. Such probing was conducted at each SSAP and SDS sample location, typically within five ft. of the sediment sampling location. Probing depth was used as a basis for MPA_{3+} assignment only at abandoned SSAP/SDS sampling locations (including those that were abandoned and not resampled and those that were abandoned a second time after a resampling attempt). At these locations, probing depth was used in MPA_{3+} assignment in the following manner: 1) at abandoned locations with a probing depth less than 6 in., the MPA_{3+} was assumed to be zero; and 2) abandoned locations with a probing depth greater than or equal to 6 in. were treated as unsampled locations during dredge area delineation (see Section 2.7.3).

2.11 DIOXINS, FURANS, AND METALS

Data on dioxins, furans, and Resource Conservation and Recovery Act (RCRA) metals in the sediments were not used for dredge area delineation. These data are summarized in Appendix E. The selection of core sections for analysis of dioxins, furans, and metals was governed by the availability of sections for analyses within a given holding time and the probability of the core being in an area to be dredged. The MPA_{3+} for each core available for dioxins, furans, and metals analyses was estimated from available PCB data. If the core had an estimated MPA_{3+} above the dredging criterion for a particular river section, it was evaluated for potential lab analysis. In order to assess the presence of these constituents in sediments that would be “left behind” after dredging, the section below the DoC in complete cores (i.e., the section below the deepest section with a measured Total PCB concentration greater than or equal to 1 mg/kg) was analyzed for those other constituents. Efforts were made to collect data that provided spatial coverage of all three river sections.

SECTION 3

Quantitative Environmental Analysis, LLC

SECTION 3
DREDGE AREA DELINEATION GENERAL METHODOLOGY

3.1 BACKGROUND

As discussed in Section 1, the ROD specifies that removal of sediments shall be based primarily on MPA_{3+} of 3 g/m^2 or greater in River Section 1 and 10 g/m^2 or greater in River Section 2, and on removal of selected sediments with high PCB concentrations and high erosional potential (i.e., certain “hot spots”) in River Section 3. The RD Work Plan specifies that, in River Section 3, sediments with an MPA_{3+} exceeding 10 g/m^2 in areas where burial has not been a significant ongoing process may be left in place consistent with the ROD criteria for that river section. Additional considerations specified in the ROD and RD Work Plan include surficial sediment PCB_{3+} concentrations, sediment texture, bathymetry, and depth at which the PCB contamination is found. The USEPA’s Final Decision specifies that surficial sediments consist of the top 12 in. of sediment and that the numerical criteria for removal are PCB_{3+} concentrations anywhere in the top 12 in. that are at or above 10 mg/kg in River Section 1 and 30 mg/kg PCB_{3+} in River Sections 2 and 3. Sediment texture and bathymetry are to be considered in accordance with the requirements that were agreed upon during the dispute resolution proceeding (USEPA 2004b, Attachment 1) quoted in Section 2.10.1.

This report delineates dredge areas solely by physical and chemical characteristics of the river and sediment bed (i.e., MPA_{3+}, PCB_{3+} concentration in the top 12 in. of sediment, sediment type, and bathymetry) in the manner described herein. Dredging feasibility, design optimization, or other practicability issues were not considered in this report. Nor has there been any consideration of side slope stability, discontinuities in dredging depths between delineated dredge areas, differences between individual cores’ DoCs set by the data treatment and the DoC surface set through the vertical delineation procedure (described below), or removal that may be needed to facilitate dredging operations (e.g., for access or navigational purposes). Further, implications associated with the presence of sensitive habitats and cultural resources in potential dredge areas were not assessed. All these factors will be considered and addressed as part of engineering design in the Phase 2 Intermediate and Final Design Reports and may result in removal volumes different from those indicated in this report. To support the engineering assessment of dredge areas, the delineation makes a distinction between veneers and deeper pockets of sediment within the areas targeted on the basis of the dredge area delineation methodology. Modified dredge area delineations, including revised dredge prisms and cut lines to account for the engineering factors identified above, will be presented in the Phase 2 Intermediate and Final Design Reports. The procedures for modifying the dredge area delineations are set forth in Attachment A (Critical Phase 1 Design Elements) to Appendix B (SOW) to the RA CD (USEPA and GE 2005). This attachment is referred to herein as the CDE.

The purpose of Section 3 is to identify the Phase 2 Areas in the river and to provide an overview of the approaches for the areal and vertical delineations. Further details regarding the interpolation methods used, including the mathematics and statistics involved in those methods, are provided in Section 4.

It should also be noted that the ROD states that "[t]arget areas for remediation were defined as approximately 50,000 ft^2 (a little over an acre) or greater, due to practical limitations on the number of separate remediation zones that could be accomplished for a project of this size" (USEPA 2002, page 55). USEPA's Final Decision in the dispute resolution specifies that this 50,000 ft^2 criterion shall be applied to exclude areas "in limited instances where there would otherwise need to be a mobilization of equipment to reach an isolated area" (USEPA 2004b, page 18). As discussed further below, one dredge area below the 50,000 ft^2 criterion was determined to be "isolated," the area has been identified with unique shading on the maps presented in Section 5 and justification for its exclusion is provided in Section 5.1.4.

3.2 SECTIONING OF PHASE 2 AREAS BASED ON DELINEATION APPROACH

As required by the resolution of the Phase 1 DAD dispute (USEPA 2004b, Attachment 1), mathematical interpolation using a geostatistical interpolator, namely kriging, was used to make an initial determination of horizontal dredge area boundaries in Phase 2 Areas, except in areas where kriging was infeasible because the spatial structure of the data (e.g., a single line of cores) or poor or erratic spatial correlation precluded development of a meaningful semivariogram. In these areas, boundaries were drawn using a set of objective guidelines that are discussed in Section 3.3.2.

For areas where kriging was performed, the results were evaluated for reliability in capturing within the dredge area cores above the criteria and not capturing within the dredge area cores below the criteria. In all kriged areas, some cores meeting the criteria for removal are outside the kriging-based dredge area boundary and some cores not meeting the criteria for removal are inside the kriging-based dredge area boundary. This fact is not problematic in cases where the contradictory cores are isolated, but it was a concern in cases where several adjacent cores are contradictory to the kriging conclusions or where the kriged dredge area boundary excludes adjacent cores that meet the criteria for removal. Consequently, based on discussions with USEPA, quantitative criteria representing the performance of the krig, combined with professional judgment, were applied to evaluate whether the kriging results in a given area were reliable. In areas with a relatively poor percentage capture of cores above the dredging criteria or percentage non-capture of cores below the dredging criteria, kriging was deemed unreliable. In such cases, based on agreement with USEPA, the interpolator was abandoned, and the areal delineation was performed manually, using the objective guidelines described in Section 3.3.2. In addition, in areas where the krig performance was deemed reliable, minor boundary adjustments were made to include or exclude particular cores (see Section 3.3.1.3 for a discussion of the types of minor adjustments performed).

Further, kriging was not used on the west side of Griffin Island and the area behind the islands on the east shore near Snook Kill because the PCB data support targeting the entirety of each of those areas for dredging. Finally, kriging was not performed for the areas south of Lock 7 (from approximately River Mile [RM] 193.1 to 192.4) and east of Griffin Island, on the western shore, because those areas had been subject to delineation in the Phase 1 DAD Report (QEA 2005a), as approved by USEPA; hence, the areal delineation from the approved Phase 1 DAD Report was used for those areas.

In areas where kriging was the initial or final basis for the areal delineation or where kriging was not used because the entire area was targeted for dredging, vertical delineation was based on Inverse Distance Weighting (IDW) interpolation of Total PCB concentrations at depth (also referred to herein as "1 mg/kg interpolation"), in accordance with the procedures specified in the CDE, as discussed in Sections 3.4.1 and 4.3. Similarly, for the areas south of Lock 7 and east of Griffin Island on the western shore, which were addressed in the Phase 1 DAD Report, the vertical delineation was established using an IDW interpolation of Total PCB concentrations at depth, which was the vertical delineation method used for all Phase 1 Areas in the Phase 1 Final Design Report. Where the areal delineation was made manually from the outset due to the inadequacy of the data to support kriging, a manual method was used for vertical delineation, as discussed in Section 3.4.2.

Table 3-1 identifies the Phase 2 Areas of the river, by section based on changes in river direction, locations of dams, and the presence of clusters of sampling locations. Figure 3-1 provides an overview of the available data and the boundaries of these Phase 2 Areas sections. For each section, Table 3-1 indicates the approach used for the areal and vertical delineation. For the areal delineation approach, five possible categories have been used in this table: 1) kriging with minor adjustments ("Krig with Adjustments"); 2) manual delineation because kriging was infeasible due to insufficient data or poor spatial structure of the data ("Manual - Kriging Infeasible"); 3) manual delineation due to unreliable krig performance ("Manual – Unreliable Krig Performance"); 4) areas of bank-to-bank dredging ("Manual – Whole Area to be Dredged"); or 5) previously delineated Phase 1 dredge areas that are not included in the Phase 1 Final Design and will now be dredged during Phase 2 ("Phase 1 Approved Delineation"). For the vertical delineation, there were two possible categories: 1 mg/kg interpolation and manual. Sections of the river designated as non-dredge in Table 3-1 do not have sediments meeting the criteria for removal.[5]

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[5] Although occasional isolated cores meeting the dredging criteria may be found, the preponderance of data in these areas supports the conclusion that the overall PCB levels in these areas are below the criteria for removal.

3.3 AREAL DELINEATION

3.3.1 Delineation by Mathematical Interpolation

3.3.1.1 Determination of Kriging-Based Dredge Area Boundaries

The identification of areas meeting the removal criteria began by establishing contours at the MPA_{3+} and surface PCB_{3+} concentration criteria values. These contours were determined by ordinary kriging of MPA_{3+} and maximum PCB_{3+} concentrations in the 0-12 in. depth interval, using methods that are described in Section 4.2. These contours were established by using the optimal estimate of the krig, which, when back-transformed (as discussed in Section 4.2.4), yields the median or 50th percentile estimate or MPA_{3+} or surface PCB_{3+} concentrations. Dredge areas were formed by the outer boundary of overlain MPA_{3+} and maximum surface PCB_{3+} concentration contours at the criteria values.

3.3.1.2 Determination of the Reliability of Kriging

Kriging's interpolation is a form of weight-of-evidence analysis and can be relied on so long as model-data disagreements occur infrequently. As mentioned above, kriging was initially performed in all areas that had sufficient data and spatial correlation to apply the interpolator. Upon determining the dredge areas from these kriging results (i.e., the 50th percentile estimate described in Section 3.3.1.1), capture efficiency was evaluated. Quantitative results of the capture efficiencies for each kriged area are given in Section 5. Based on visual inspection of the dredge area delineation maps, kriging was judged to be adequate when greater than 90% of the cores meeting the criteria for removal are inside of the kriging-based dredge areas and greater than 75% of the cores not meeting the criteria for removal are outside of the kriging-based dredge areas (although minor adjustments to the boundaries were made where appropriate [see Section 3.3.1.3]). Kriging was abandoned for areas in which less than 70% of the cores meeting the criteria for removal are inside of the kriging-based dredge areas and delineation of those areas was conducted using the manual delineation procedures described in Section 3.3.2. The remaining areas were evaluated on a case-by-case basis using professional judgment. The decisions on basis of delineation for all of the kriged areas were agreed upon by GE and USEPA in discussions in spring 2007.

3.3.1.3 Minor Adjustments to Kriging-Based Dredge Area Boundaries

In areas where the kriging results were deemed sufficiently reliable for use in the delineation, minor adjustments were made to the kriging-based dredge area boundaries. These types of adjustments are described in this section.

If the dredge area encompassed a cluster of cores meeting the “select” exclusion criterion set forth by USEPA (described in Section 2.8), the dredge boundary was adjusted to approximately half-way between the outer band of this cluster and the next line of cores within the dredge area. The “select” exclusion criterion specifies that “any area where the maximum PCB concentration is below a depth of 24 in. and that has 12 in. or more of relatively clean surface sediment (i.e., 5 mg/kg Total PCBs or less)” may be excluded from dredge areas (USEPA 2004b, Attachment 2, page 1). To the extent that this new boundary results in a new dredge area that is near a “select” area and dredging in this nearby area may expose higher levels of PCBs at depth in the select area, this situation will be addressed in a manner to be determined in the cap and backfill design in the Phase 2 Intermediate Design Report.

Small “islands” that the interpolator carved out of larger areas above or below the removal criteria because of the presence of single isolated cores locations whose PCB data disagree with the bulk of the local data were included with the larger areas. That is, such “islands” of isolated cores below the removal criteria within a larger area that was above the criteria were included in the dredge areas, while such “islands” of isolated cores above the criteria within larger areas below the criteria were not identified as dredge areas. This adjustment reflects the view that isolated instances of contrary findings are overwhelmed by the preponderance of data. In addition, boundaries were adjusted to capture cores that were above the dredging criteria but were located immediately outside of a dredging boundary. These adjustments also reflect consideration of the uncertainty in the SSAP/SDS analytical data, which was required by the USEPA’s Final Decision.

Sediments mapped as Types III (gravel) and V (rock) and not overlain by 6 in. or more of finer sediments were excluded from the delineation because MPA_{3+} rarely exceeds the dredging criteria in these types of sediment (see discussion in Section 2 of the Phase 1 DAD Report). In accordance with the USEPA's Final Decision, probing was conducted during 2004 and 2005 in areas where: 1) dredge boundaries abut Type III or V sediments and are based on sediment type; 2) PCB data did not exist at an 80 ft. linear spacing on the sediment Type III or V side of the boundary; and 3) previous probing data did not exist at the density specified by USEPA in the Final Decision. The probing data were evaluated after collection to determine the need to collect additional cores. Core samples were collected at locations where the probing indicated that an area of fine-grained sediment with a thickness of 6 in. or greater (Types I, II, or IV) extended into areas that had been mapped as gravel or rock (Types III or V). The locations of the cores typically corresponded to the 80 ft. triangular grid spacing. Occasionally, target core locations were selected to provide data at a more appropriate location. The results of the 2004 probing program are described in Section 6.1.1 of the SDSR (QEA and ESI 2005), and the results of the 2005 probing are described in the 2005 Data Gap DSR (QEA and ESI 2006). The PCB results, as well as the results of the probing, have been incorporated into the current dredge area delineation so that dredge boundaries accurately follow the demarcation between areas above the removal criteria and rocky or gravelly areas that have little or no sediment. These probing results are shown on the maps in Section 5.

In some instances, kriging included within dredge areas, areas where the probing data indicates 6 in. or less of sediment. These areas were typically included in dredge areas either because the interpolator was not constrained by data (i.e., because the data treatment for abandoned locations with probe depths of 6 in. or less does not allow the surface sediment PCB_{3+} concentration to be set to zero) or because the surface sediment PCB_{3+} concentrations in grab samples or shallow cores met or exceeded the removal criteria. In the former case, the lack of data typically is the result of the inability to collect a core or a grab sample with a Ponar dredge. These areas are typically composed of rocks and cobbles and underlain by bedrock. It is anticipated that the determination of dredge prisms during design will exclude areas with 6 in. or less of contaminated sediment unless they are isolated within larger dredge areas of deeper contamination. The evaluation of these areas will rely on the local data rather than the interpolated DoC because the DoC interpolation (discussed in Section 3.4.1) does not accommodate a break at 6 in. (i.e., interpolation was done for intervals of 0-2 in. and 2-12 in.).

3.3.2 Manual Delineation

In areas where the data were insufficient or had inadequate spatial structure to support kriging (i.e., kriging was infeasible) or where kriging was deemed unreliable (see Section 3.3.1.2), physical features were used, to the extent practical, to establish the areal boundaries of dredge areas. In cases where cores collected in one sediment type exceed the MPA_{3+} and/or surface sediment PCB_{3+} concentration dredging criteria and cores collected in an adjacent sediment type do not exceed either dredging criterion, the boundary between the sediment types was used as the dredge area boundary, provided that the PCB data from both sides of the sediment type boundary were sufficient to confidently support the conclusion that the feature separates sediments above and below the removal criteria (i.e., typically, data spaced at 80 ft. horizontal intervals). Bathymetric features were used in a similar manner. For example, if cores in a shoal exceed the MPA_{3+} and/or surface sediment PCB_{3+} concentration removal criteria and cores in an adjacent slope or channel do not exceed either criterion, the dredge area boundary was established at the edge of the shoal, subject to the same condition stated above for sediment type. In the absence of a physical feature coincident with a transition from cores above to below the dredging criteria, the boundary was established as approximately half-way between the neighboring core that did not meet the dredging criteria and the core within the dredge area that did meet the dredging criteria. In addition, if cores in a cluster were found to meet the "select" exclusion criteria (see Section 2.8), the dredge area boundary was drawn approximately half-way between the cores meeting the select criteria and the cores within the dredge area, so that the cores meeting the select exclusion criteria lie outside of the dredge area. In the absence of any data to establish the areal extent of dredging, the preliminary boundary was drawn 40 ft. from the core exceeding the criteria, and in most cases, a location outside of this boundary was identified as a data gap.

3.4 VERTICAL DELINEATION

3.4.1 Delineation by Mathematical Interpolation

In areas where kriging was the basis for areal delineation or was used initially but later abandoned as unreliable and in areas where kriging was not used because the entire area was targeted for dredging, the vertical extent of dredging was established through an interpolation of Total PCB concentrations at depth, using IDW, in accordance with the procedures specified in the CDE. IDW interpolation of Total PCB concentrations at depth was also used for vertical delineation in the area south of Lock 7, in which the areal delineation was presented in the Phase 1 DAD Report.

In these vertical delineations, the thickness of sediment below which the Total PCB concentration is less than 1 mg/kg was developed by interpolating Total PCB concentrations (using IDW) for the following layers: 0-2 in., 2-12 in., 12-24 in., 24-30 in., and every 6 in. thereafter until the maximum DoC in a given area was reached. The DoC for each 10 ft. by 10-ft. grid cell was set at the bottom depth of the deepest layer with a Total PCB concentration equal to or greater than 1 mg/kg, thereby forming a contoured DoC surface. In conducting the interpolation, data treatment for each core was dependent on the core. The procedures used for these vertical delineations, including the data treatments, are described in more detail in Section 4.3.[6]

3.4.2 Manual Delineation

Vertical delineation in areas that were not kriged due to lack of a meaningful semivariogram or spatial structure of the data not amenable to kriging was based on the assumption that the variation in DoC within a dredge area has both organized spatial variability and random variability. To account for any organized spatial variability, the dredge area was divided into "homogenous" regions. Based on the observation that DoC tends to be similar

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[6] As discussed in Section 5.2.1, there are some differences between the DoC in individual cores (as established by the data treatment) and the interpolated DoC surface. These differences are listed in tables referenced in Section 5.2.1 and will be addressed in the Phase 2 design.

within a defined bathymetric area (i.e., shoal, slope, or deep water) and not across bathymetric features, bathymetric zones were initially defined by dividing the dredge area, if possible, into shoal, slope, and deep water regions. These regions were further sub-divided if there appeared to be a correlation in the DoC or sediment profile in adjacent core locations.

The DoC values within a final "homogeneous area" were treated as a sample set from a continuous, randomly varying DoC surface within the region. As a means of quality control, highly uncertain DoC values were discarded from the sample set so long as doing so did not reduce sample set size by more than 20%. To facilitate this data culling, each DoC value was assigned a certainty class as described in Section 2.6.1 and identified in Table 2-22. Cores with DoC certainty classes of 1 and 2 were not discarded in any case, while those from more uncertain classes (with higher numbers) were subject to discarding on a class-by-class basis, starting with the most uncertain class, up to a maximum of 20% of the data. This 20% limitation prevented any reduction in the data set for areas with less than five cores. Moreover, in several other homogeneous areas, the requirement to use at least 80% of the data meant that all of the data from the area had to be used, since dropping any DoC class would have resulted in discarding more than 20% of the data. These limitations restricted the removal of data to a minority of the areas.

The distribution of DoC values for all cores deemed appropriate for the analysis based on DoC class was plotted for each homogeneous region. The 60th percentile of this distribution was used as a starting point to establish the depth of dredging for a homogeneous area. This percentile was chosen because it most often captured nearly all of the PCB mass in the homogeneous areas initially analyzed using this method. The 60th percentile value was rounded up to the closest 6-in. interval. The Total PCB concentrations in the 6-in. layer below this depth (as defined by the full sample set, including the samples excluded from the DoC distribution) were then calculated. The Total PCB concentrations in these 6-in. layers were established using the same data treatments as were used in the IDW-based vertical delineation (which, as described in Section 4.3.2, are based on the CLs of the cores). The Total PCBs concentrations in these 6-in. layers were then averaged over a given homogeneous area using Thiessen polygons to establish the "area of influence" of each core. If the area-weighted mean Total PCB concentration for this 6-in. section (i.e., the 6-in. section below the dredge depth estimated from the 60th percentile) was less than 1 mg/kg and the maximum Total PCB concentration in this layer was less than 7 mg/kg, the 60th percentile was used to set the depth of dredging in that homogeneous area. If the concentrations exceeded these criteria, the area-weighted mean Total PCB concentration and maximum Total PCB concentration were calculated for the next deepest 6-in. segment and compared to the above criteria. The process was extended in 6-in. increments until the area-weighted average and maximum Total PCB concentration criteria identified above were met.

For dredge areas in manual vertical delineation areas that contained only two cores, the depth of dredging for that dredge area was set at the maximum DoC of the two cores, so long as both cores were not CL2D. If one core was CL2D, the dredge depth was set to the DoC of the non-CL2D core. In addition, a few special cases of dredge areas in rocky areas or with data gaps were exceptions to this procedure and are specifically discussed in Section 5.2.

For this analysis, the Total PCB concentration profile below the last measured section in incomplete cores was defined by extrapolation for cores subject to extrapolation. However, only the measured data were used in cores whose DoC could not be estimated with any confidence (i.e., CL2D cores). The DoC for incomplete cores in which Glacial Lake Albany clay was encountered was set at the top of the glacial clay, provided that the Total PCB concentration in the bottom measured section of the core was less than 10 mg/kg. If the Total PCB concentration in that section was greater than 10 mg/kg, the DoC was set at the bottom of the last measured section, which was below the top of the glacial clay. The DoC for incomplete cores that had field notes indicating the presence of rock or gravel at the bottom of the core was set to the lesser of the extrapolated depth (if applicable) or the maximum of the penetration or probing depths. A Total PCB concentration of 0 mg/kg was used below the DoC for these cores if there were no measured data available. If the core could not be extrapolated and probing indicated the presence of rock at a depth deeper than the bottom of the last measured section, the DoC was set at the greater of the penetration or probing depth and the depth interval between the last measured section and the DoC was treated as a location lacking data in any analyses of PCB concentration for that interval.

SECTION 4

SECTION 4
INTERPOLATION METHODS

4.1 BACKGROUND

As discussed in Section 3, in most Phase 2 Areas, kriging was used, at least initially, to interpolate MPA_{3+} and maximum surface PCB_{3+} concentrations for areal delineation purposes (as required by the resolution of the Phase 1 DAD dispute), and IDW was used to interpolate Total PCB concentrations at depth in order to set the DoC.[7] This section describes in detail the interpolation methods used for areal and vertical delineation in areas where interpolation was used. (The discussion of kriging in this section includes the areas where kriging was initially used but later abandoned as unreliable.) Interpolation results discussed in this section reflect analyses performed using the January 17, 2006 version of the SSAP database. Even though alternative data treatments were applied after that date to some cores, the changes were considered too minor and isolated to warrant re-interpolation. However, any boundary adjustments were made using the most recent data treatments and the March 6, 2006 SSAP database. The most recent data treatments and database are reflected in the data points shown on all maps in this report.

As discussed in Section 3.2, areal delineation was performed for subareas of the river termed variogram areas (Figure 3-1 and Table 3-1). Where kriging was used, the interpolation analysis was fine-tuned by the choice of area-specific values for each of the key parameters contributing to the kriging analysis. Section 4.2 describes the approach to areal kriging, including the data treatments, data transformations, variogram areas, semivariogram development, and general selection of kriging parameters. An overview of IDW and a description of how it was applied to determine DoC are provided in Section 4.3.

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[7] As also noted in Section 3, for areas in which kriging was infeasible because of insufficient data or orientation of the sampling (i.e., single line of cores), a manual method was used for both areal and vertical delineation.

4.2 INTERPOLATION FOR DEVELOPMENT OF AREAL BOUNDARIES

4.2.1 Kriging Overview

Kriging is a statistical predictor, producing for each location an estimate of the parameter of interest and the uncertainty of that estimate (i.e., the prediction error). The estimate has the property of having the minimum variance among all estimates that are linear functions of the data. Kriging has been described many times (e.g., Cressie 1993; Chilès and Delfiner 1999; Isaaks and Srivastava 1989; Goovaerts 1997), and thus the underlying method will be described here only in broad outline.

The basic ordinary kriging model for Gaussian data is:

$$Z(s) = \mu(s) + W(s) + \varepsilon(s) \tag{4-1}$$

where:

s = a spatial location;

$Z(s)$ = the value to be predicted, in this case, depth of contamination;

$\mu(s)$ = the mean (which is unknown and assumed constant throughout the area);

$W(s)$ = the signal (a stationary Gaussian random field with mean zero and a covariance function defined by a semivariogram); and

$\varepsilon(s)$ = independent Gaussian random variables with mean 0 and variance equal to the nugget (τ^2).

The results of the kriging analysis include an optimal or best estimate of the value for a given location and an error variance. Because the data are transformed to produce a data set whose marginal frequency distribution is reasonably close to a normal distribution (see Section 4.2.3), the optimal estimate must be back transformed to obtain the arithmetic equivalent of the kriging result. The back-transformation of the optimal estimate is the 50th percentile of the distribution of values that is defined by the optimal estimate and the error variance.

The kriging performed for the Phase 2 Areas comprised the following steps:

- delineation of variogram areas;
- data treatments;
- data transformation;
- development of the experimental semivariogram;
- parameter estimation;
- development of the model semivariogram; and
- kriging (including back transformation).

Each of these steps is described in the subsequent sections.

Geostatistical calculations were performed using Ribeiro and Diggle's (2001) geoR package for the R environment for programming, graphics, data analysis, and statistical computation (R Development Core Team 2005).

4.2.2 Delineation of Variogram Areas

Variogram areas were determined based upon river geometry, balancing the desire for homogeneity within each area (especially with respect to river direction), and the goal of maximizing the amount of data available for each semivariogram. Adjacent variogram areas overlapped by up to 280 ft. in cases where data near the boundaries were judged to be applicable to both variograms.

4.2.3 Data Treatments

Cores in the different CL groups provide estimates of MPA_{3+} and maximum surface PCB_{3+} with varying degrees of conservatism and uncertainty. To make the best use of the available information, while avoiding bias and minimizing uncertainty, cores were included in the analysis as discussed below.

MPA_{3+} variograms were developed using data having CLs 1, 2A, 2B, 2C, 2F, 2H, 2P, and 2R (see Table 2-6 in Section 2.5). Kriging was performed using these MPA_{3+} values plus CLs 2D, 2E, and 2J values (doubled cores, cores with RL concerns, and abandoned locations with probing depths less than 6 in., respectively). The CL2D and CL2E cores were not included in the semivariograms because uncertainty in the extrapolated MPA_{3+} at these locations may mask the spatial correlation that exists among more certain MPA_{3+} values. The CL2J locations were not included in the semivariograms because they would likely mask spatial correlation that exists at small spatial scales in deeper sediments or may artificially increase the apparent spatial correlation, depending on the pattern of their distribution. However, as noted, the CL2D, CL2E, and CL2J cores were used in the kriging.

All locations with maximum surface PCB_{3+} concentrations (CLs 1, 2A, 2B, 2C, 2D, 2E, 2F, 2H, 2I, 2P, and 2R) were used in both variograms and kriging. For the kriging, the maximum surface PCB_{3+} concentration in the 0-12 in. layer was used, including any calculated PCB_{3+} concentration for the 2-12 in. section (or other section within the top 12 in.) that was determined through the length-weighted average adjustment described in Section 2.4.

Statistics for MPA_{3+} and maximum PCB_{3+} surface concentrations used in variograms are presented in Table 4-1.

4.2.4 Data Transformation

The goal of data transformation is to improve the accuracy of the kriging interpolation by producing a data set whose marginal frequency distribution is reasonably close to the Gaussian standard (i.e., normal distribution). When kriging is applied to a skewed data distribution, the values from the longer tail of the distribution tend to exert disproportionate influence over the interpolator, thereby negatively impacting the accuracy of the interpolator. Section 2.8.1.2 of USEPA's initial comments on the January 2004 Phase 1 DAD Report (USEPA 2004a) provides a good example of this effect: "When interpolating chemical data, it is not uncommon to have a small 'hot spot' somewhere in the interior of the data where the measured concentrations are many orders of magnitude higher than the majority of the other concentrations. In such cases, the large values dominate the interpolation process, while details and variations in the low concentration zones are obliterated." Normalizing the data by transforming it addresses this problem by balancing the influence of large and small values in the data set.

Transforming the data also addresses another potential problem, the relationship between residuals and predicted values. "Residuals" refers to the differences between data values and their associated model predictions (i.e., kriging results). Ideally, residuals should exhibit no relationship with the predicted value. Transformation to normality has the advantage of weakening any relationship that may exist between residuals and predicted values.

4.2.4.1 Transformation of MPA_{3+} and PCB_{3+}

In an effort to normalize the data distribution, the data were transformed using the widely-used Box-Cox transformation. The transformation changes the original variable (*X*) into the transformed variable (*Y*):

$$\begin{aligned} Y &= \frac{X^{\lambda}-1}{\lambda}\, for\, \lambda \neq 0 \\ Y &= \ln(X)\, for\, \lambda = 0 \end{aligned} \tag{4-2}$$

where:

λ = the transformation parameter.

Note that when $\lambda \leq 0$, only positive non-zero values can be transformed. This situation was encountered in the Phase 2 data set. Therefore, epsilon (half the smallest positive value in the data set for that parameter) was added to all the data prior to transformation to eliminate zero values. This added value was accounted for during back-transformation (see below).

4.2.4.2 Optimizing the Box-Cox Transformation Parameter (λ)

A value for λ was selected independently for each parameter in each variogram area so as to produce transformed data that were approximately normally distributed. λ values between -1 and 1 were used to transform the data set for each variogram area.

To obtain the optimal value for λ, the data were transformed several times using a range of values for λ. The resulting distributions of transformed data were then compared using frequency plots and cumulative probability plots along with the Shapiro-Wilk statistic (Shapiro and Wilk 1965; see Figures A-1 through A-2 provided in Appendix A of the CD-ROM accompanying this report). The value of λ associated with the highest value of the Shapiro-Wilk's test statistic was selected as optimal. A complete discussion of the Shapiro-Wilk's statistic was provided in Section 3 of the Phase 1 DAD Report.

The optimal λ value (indicated on Figures A-1 through A-2) generally resulted in a distribution visually closest to linear on a normal probability scale. The optimized λs for each PCB parameter and variogram area are summarized in Table 4-2.

4.2.4.3 Back-Transformation of Interpolation Results

MPA_{3+} and maximum surface PCB_{3+} semivariogram development, kriging, and related analyses were performed using transformed data. The kriging prediction (50th percentile; see Section 4.2.1) was translated back into the original scale of measurement, as follows:

$$X = \left(\lambda Y + 1\right)^{\frac{1}{\lambda}} \tag{4-3}$$

The back-transformation is valid because the transformation (and its inverse) are monotonic and hence preserve the percentile's rankings. After the kriging results were back-transformed, epsilon (ε), half of the smallest positive value for each parameter was subtracted from the result. This subtraction compensated for the addition of epsilon (ε) to all data prior to the initial transformation.

4.2.5 Semivariograms

Semivariograms describe the extent, strength, and directionality of spatial correlation, in effect the "zone of influence" of individual data values, on predictions at nearby locations. They take the form of a curve relating variance[8] to distance: near a data point, variance is generally smaller due to the influence of the data value; farther from the data point its influence declines, i.e., the variance increases.

For the kriging calculation, it is necessary to develop a mathematical equation relating variance to distance; this is termed the model semivariogram. The model semivariogram is developed by fitting the equation to the data-based experimental semivariogram, which is a graphical representation summarizing the statistical analysis of the data.

Associated with the semivariogram are several parameters that describe its properties. The "range" refers to the distance over which spatial correlation is exhibited.[9] The "sill" refers to the variance exhibited at great distances, i.e., beyond the range. The "nugget" refers to the variance at very small separation (smaller than the minimum separation in the data). It quantifies small-scale spatial correlation.

4.2.5.1 Experimental Semivariogram

The experimental semivariogram is a statistical summary of the relationship between variance and distance. It is developed by analyzing the data in pairs. First, all possible pairs of

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[8] The word "variance" is used here informally in our qualitative description of the kriging process. The function plotted in a semivariogram is actually equal to one-half of the variance, or the semivariance, which is why the resulting curve is generally called the semivariogram (Isaaks and Srivastava 1989). The value plotted in a semivariogram is inversely related to the correlation between pairs of points at each specified distance: nearby points exhibit greater correlation, which translates to a lower variance; more distant points exhibit very little correlation, and thus, pairs of values separated by long distances exhibit a larger variance.

[9] The particular mathematical definition of range depends on the type of equation used to model the variogram.

data points within a given variogram area are created. Then, the pairs are grouped, or binned, according to the distance between them. Finally, the pairs in each group are used to calculate the specific statistic used in the variogram (the semivariance; Isaaks and Srivastava 1989). This results in a figure relating distance to variance, containing a series of points, each representing one bin of pairs of data points.

The development of the experimental semivariograms requires the estimation of several parameters: the bin size, the directionality (angle of anisotropy and the anisotropy ratio), and the tolerance.

Bin size. Data pairs were grouped in bins according to the distance separating the members of the pair, subject to two competing criteria: 1) bins must be small enough to ensure that there are a sufficient number of points on the semivariogram; and 2) bins must be large enough to ensure a sufficient number of data pairs in each bin to reliably estimate the correlation. Bin sizes within each semivariogram were equal. Based on professional judgment, bin size was set equal to the minimum possible value that could populate each bin with at least 15 pairs of data points, with the exception that bins with less than one pair were not represented on the semivariogram. This is the same methodology used in the Phase 1 DAD kriging of DoC.

Directionality. In the Upper Hudson River, sediment PCB data suggest that spatial correlation is stronger in the direction of flow than in the cross-flow direction. Directional semivariograms use only data pairs oriented within a specified tolerance of the specified angle. In contrast, omnidirectional semivariograms incorporate all pairs of points, regardless of direction. The strategy taken here involved first developing both omnidirectional and anisotropic experimental semivariograms for all Phase 2 Areas. Then, for each area, either the omnidirectional or the anisotropic semivariogram was selected for final kriging, based upon the shoreline geometry, the appearance of the variograms, and the anisotropy analysis presented in Appendix B.

Anisotropy, the variation in spatial correlation with direction, is expressed in kriging through two parameters, the angle of anisotropy and the anisotropy ratio. The angle of anisotropy refers to the direction at which the data exhibit the strongest spatial correlation. It was chosen based on visual assessment of a series of semivariograms developed for every 10 degrees (Figures A-9 through A-10).[10] In general, the semivariograms with the most data and the most clearly defined spatial correlation roughly corresponded to the direction of flow and the angle of anisotropy from the rose diagrams. Slight variations in angle (+/- 20 to 30 degrees) did not significantly impact overall quality of the semivariograms based on visual inspection.

The anisotropy ratio describes the strength of the anisotropy, that is, the extent to which the spatial correlation in the flow-direction differs from the spatial correlation in the cross-flow direction. Specifically, the anisotropy ratio represents the ratio of the ranges of the semivariograms in the flow and cross-flow directions and is used to calculate the final kriging weights. The anisotropy ratio was determined based upon an analysis of the series of semivariograms produced at 10-degree intervals, as described in Appendix B.

Tolerance. The tolerance is the range of directions between pairs of points that are included in an anisotropic experimental semivariogram. Tolerance was evaluated based upon visual examination of experimental semivariograms that were developed using tolerances of 10, 20, 30, and 40 degrees (Figures A-5 through A-6).[11] The tolerance was established by balancing two competing criteria, maximizing the number of pairs included in a given semivariogram, while honoring any directionality (anisotropy) that may be evident. Increasing the tolerance increases the number of pairs that are included in the semivariogram and thus its statistical power; however, it dilutes the extent of directionality in the semivariogram. Based primarily on the overall appearance of the semivariograms and secondarily on the rose diagrams in Appendix B, the tolerances listed in Table 4-2 were chosen.

Mathematical details. The estimator of the semivariogram that was adopted for the Phase 2 areal delineation was suggested by Hawkins and Cressie (1984). The ordinary kriging model was fitted using function krige.conv of the geoR package for R. This provides a robust alternative to the classical estimator, insofar as it achieves kriging inferences that remain stable

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[10] For the anisotropy analysis, the bin size was set at approximately 60-ft. in all semivariograms for comparability.

[11] This analysis used the reduced maximum distances as described below.

when the data do not fully comply with the conventional validating assumptions (in particular that the data should be like outcomes of a Gaussian random field). The validity and general usefulness of the robust estimator are established in the publication that originated it (Hawkins and Cressie 1984), and are discussed in great detail by Cressie (1993). This is the same methodology as used in the Phase 1 DAD Report.

Clearly, the data of interest are not Gaussian in their raw expression. Even after re-expression using the optimal Box-Cox transformation, it still is prudent to rely on an estimator that is not unduly influenced by outliers. Previously, in Phase 1 Areas, several trial cases using the classical estimator for DoC produced nonsensical results, which the robust estimator avoids automatically.

4.2.5.2 Model Semivariogram

To perform kriging, it is necessary to summarize the experimental semivariogram with a mathematical function that can be used to compute spatial correlation as a function of distance. Such an equation can take many forms. The choice of equation is based upon its ability to provide good fits to the experimental semivariograms from each variogram area. Here, Matérn's (1960) form of the correlation function, also known as the K-Bessel model (Chilès and Delfiner 1999), was fitted to the experimental semivariograms. This model was chosen because it proved to be flexible enough to provide reasonably good fits to the empirical semivariograms. Furthermore, other models such as the Gaussian, exponential, and spherical models specify *a priori* the degree of local smoothness of the random field, and ignore what the data indicate in this regard. In contrast, the Matérn model permits tuning of the degree of local smoothness of the random field. For instance, the exponential model is a special case of the Matérn model when the smoothness parameter equals 0.5. The Gaussian model may be regarded as a limit of the Matérn class of models when the smoothness parameter goes to infinity. The Matérn model was used in DoC kriging in the Phase 1 DAD Report.

The Matérn model has four parameters: the nugget variance (τ^2); the smoothness parameter (κ); the partial sill (σ^2); and the range (φ). Geometric anisotropy is assumed. This requires that cross-flow and the flow-direction models differ only in the value of the range. Model fitting was performed using a weighted least-squares procedure, as implemented in geoR's "variofit" function; the weights were as suggested by Cressie (1985).

In fitting the model to the experimental semivariogram, it is important that the model represent the shape of the experimental semivariogram near the origin, that is, at short distances where spatial correlation is greatest. It was found that the maximum distance between pairs of data points used in the semivariogram can affect the shape of the fitted model at short distances. Initially, the maximum distance was set equal to half the length of the longest distance between pairs. However, using this maximum distance, the fitted semivariograms sometimes did not match the experimental semivariograms at short distances. Furthermore, the semivariograms often exhibited rises or dips at longer lags, suggesting that the stationarity assumption might not hold at longer distances[12] (see the Phase 1 DAD Report). Because the correlation at short distances is of great significance to the final results, and because stationarity is an assumption of the method, the maximum distance used in model development was often set smaller than the initial estimate. The maximum distance was set by visually assessing the distance at which the semivariogram first appeared to level off. In addition, the fit of the model semivariogram to the experimental semivariogram at short distances was taken into consideration. Uncut semivariograms are presented in Figures A-3 and A-4. The maximum distances used are presented in Table 4-2.

The model fitting was performed with one constraint: the value for the smoothness parameter (κ) was limited to values less than or equal to 0.5. It was found that when values greater than 0.5 were used, kriging resulted in behavior that was clearly unreasonable. In particular, "ghost" dredge or non-dredge areas were sometimes produced by the model. A "ghost" dredge area is a dredge area that does not contain any cores and is surrounded by cores below the criteria. A model was fitted to each empirical semivariogram, either directional or omnidirectional, chosen from the previous step (Figures 4-1 through 4-2). It should also be noted that in general, the semivariograms in the cross-flow direction were poor.

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[12] The kriging analysis performed here relies on an assumption of stationarity, that is, the assumption that the mean of the modeled parameter does not exhibit a trend over the modeled area. Thus, for example, it is important that the average MPA does not increase or decrease consistently along the length of each variogram area.

The model semivariograms are presented in Figures 4-1 through 4-2, and the model parameters used in final kriging are listed in Table 4-2. With the exception of locations with poor cross-flow variograms, the estimates of the anisotropy ratio generally resulted in cross-flow semivariograms that are reasonable visual fits to the experimental semivariograms.

4.2.6 Kriging MPA_{3+} and Maximum Surface PCB_{3+} Concentration

MPA_{3+} and maximum surface PCB_{3+} concentration were calculated for the center points of a 10-ft. by 10-ft. grid. In grid cells falling within areas of overlap between adjacent variogram areas, the maximum predicted values from the two adjoining variogram areas were used. To ensure that kriging was not affected by a lack of data at the variogram area boundaries, kriging was performed including data within a buffer zone up to 200 ft. wide at the ends of each variogram area (i.e., beyond the overlap area discussed in Section 4.2.2). The size of the buffer zone was determined by the river geometry (Figure 4-3).

For each parameter, a contour line at the dredge criteria was created based on the back-transformed kriging results. Contour lines for each parameter were combined by taking the outer boundary of overlain MPA_{3+} and maximum surface PCB_{3+} concentration contours at the criteria values. Dredge areas were created from these contours as described in Section 3.

Cross-validation results for each area are presented in Figures 4-4 through 4-5. This process involved removing an individual data point from the data set, performing kriging, and comparing the results of the kriging calculation with the original data value. This was repeated for every core in turn. The relationship between the predicted value and prediction error (defined as the difference between cross-validation results and observed value on a core-by-core basis) is also presented in Figures 4-4 through 4-5. Type 1 and Type 2 errors, specificity, and sensitivity were calculated as described in Section 3 of the Phase 1 DAD Report.

The relatively flat slopes of the cross-validations demonstrate the general tendency of kriging to smooth spatial variation. Variability is relatively large, indicating the uncertainty associated with this tool. In general, modifying the assumptions of the analysis did not materially affect cross-validation results; that is, cross-validation did not provide a strong method of selecting alternative parameters (anisotropy ratio, Matérn model kappa value, etc.).

4.3 INTERPOLATION FOR THE DEVELOPMENT OF VERTICAL BOUNDARIES

4.3.1 IDW Overview

In areas where kriging was the basis for areal delineation or was used initially but later abandoned as unreliable, as well as in areas where kriging was not used because the entire area was targeted for dredging, the vertical extent of dredging was established through an interpolation of Total PCB concentrations at depth, using IDW, in accordance with the procedures specified in the CDE. IDW interpolation of Total PCB concentrations at depth was also used for vertical delineation in the area south of Lock 7, whose areal extent was delineated in the Phase 1 DAD Report.

Interpolations were performed to determine the areal extent of Total PCB concentrations at depth using the IDW deterministic interpolator with a specified optimization procedure. These interpolations are referred to as “1 mg/kg interpolations” because a Total PCB concentration of 1 mg/kg is the threshold that determines depth of contamination in a core. The steps involved in completing the 1 mg/kg interpolation include assigning Total PCB concentrations at depth, transforming the assigned Total PCB concentrations, delineating 1 mg/kg interpolation areas, optimizing the IDW parameters, and interpolating using IDW.

IDW was used rather than kriging because the Total PCB at depth data set was not amenable to the development of experimental variograms. The zero values in the data set, which constitute a significant portion at depth, tend to corrupt the semivariogram.

IDW is a deterministic exact interpolator that honors all data points. IDW assumes that each measured point has a local influence that diminishes with distance. It gives greater weight to the points closer to the prediction location than to those farther away, hence the name inverse distance weighting. The basic equation for IDW is:

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i) \tag{4-5}$$

where:

(s_0) = the value being predicted at location s_0;

N = the number of measured sample points in the search neighborhood of the location to be estimated;

λ_i = the weights assigned to measured points in the search neighborhood; and

$Z(s_i)$ = the observed value at the location s_i.

The formula to determine the weights is:

$$\lambda_i = d_{i0}^{-p} / \sum_{j=1}^{N} d_{jo}^{-p} \qquad where \quad \sum_{i=1}^{N} \lambda_i = 1 \tag{4-6}$$

where:

p = the power parameter that controls how much influence a data point has on the interpolation;

d_{i0} = the distance between the predicted location, s_0, and the measured locations, s_i; and

d_{j0} = the distance between the predicted location, s_0, and the observed location s_j within the search neighborhood.

As the distance between the predicted location and a measured location increases, the weight of the measured point will decrease exponentially according to the power parameter, p. The predicted value is the sum of the product of the data points within the search neighborhood and their assigned weights. The weights for the measured locations are scaled so that their sum is equal to 1.

"Nearest-neighbors" and "elliptical neighborhood" are two common methods used for defining the search neighborhood. "Nearest-neighbors" incorporates a preset number of data points that are closest to the predicted location into the interpolation. "Elliptical neighborhood" incorporates all data points within a prescribed elliptical area. The advantage of an elliptical neighborhood is that the geometry of the ellipse can be optimized to account for the distance and direction of correlation of the data. The disadvantage is that the direction of correlation has to be constant within the interpolation domain. The resolution of the Phase 1 DAD dispute required that elliptical neighborhood be used as the search neighborhood (USEPA 2004b, Attachment 1). The three parameters that define an elliptical neighborhood are:

1. azimuth - the orientation of the ellipse;
2. minor semiaxis - half the width of the ellipse; and
3. major semiaxis - half the length of the ellipse.

The anisotropy ratio is defined as the ratio of the major semiaxis to the minor semiaxis. During interpolation, this parameter governs how much influence the interpolator gives to data points along the orientation of the ellipse relative to data points across the orientation of the ellipse.

In the case where the elliptical neighborhood is too small to capture any data points for the interpolation, the interpolator is set to incorporate the data point closest to the prescribed neighborhood. This situation occurred sometimes in areas where the data points were sparse and the elliptical neighborhood was too small to capture enough data points.

Six steps were followed to generate a depth of contamination surface using IDW:

1. each core was subdivided into 18 individual depth intervals;

2. the length-weighted average Total PCB concentrations were calculated for each of the 18 depth intervals in each core;
3. Box-Cox transformations were performed on the length-weighted average Total PCB concentrations;
4. optimized IDW parameters were chosen for each of the 18 interpolations for each of the 36 interpolation areas;
5. interpolations were performed for each of the 18 depth intervals using the corresponding optimized IDW parameters within each of the 36 interpolation areas; and
6. each 10-ft. by 10-ft. interpolation grid cell was assigned the depth value of the bottom depth interval of the last interval equal to or above 1 mg/kg.

4.3.2 Assignment of Total PCB Concentrations to Depth Layers

All available data from the SSAP/SDS were incorporated into the interpolation method. In conducting the interpolation, data treatment was dependent on the CL of the core (see Table 2-6 in Section 2.5):

- CL1, 2A, 2B, 2E, 2F, 2G, 2P: The Total PCB concentrations for all measured and extrapolated sections were used to the maximum depth (two times recovery depth). The Total PCB concentrations below the maximum depth were set equal to 0 mg/kg.
- CL2C and 2R: The Total PCB concentrations for all measured and extrapolated sections were used to the depth to top of rock or clay unless the peak concentration occurred in the last measured section of the core, in which case the Total PCB concentrations between the last measurement section and the clay or rock layer reflects the absence of data (i.e., that depth is considered "no data available"). The Total PCB concentrations below the rock or clay layer were set equal to 0 mg/kg.
- CL2D: Total PCB concentrations for all measured sections were used. Below the last measured section, Total PCB concentrations equal no data.
- CL2H: No measured Total PCB concentrations were used. Below probing depth Total PCB concentrations equal 0 mg/kg.
- CL2I: These data are not used in the 1 mg/kg interpolator.

- CL2J: Below probing depth, Total PCB concentration equals 0 mg/kg.
- CL2K: Below probing depth, Total PCB concentration equals 0 mg/kg.
- CL2L: These data are not used in the 1 mg/kg interpolator.

The extrapolation applied to the Total PCB concentration in incomplete cores is described in Section 2.2.3. In addition, the Phase 1 DAD Report detailed the criteria for determining whether the original core, the data gap core, or both cores would be used in the dredge area delineation and subsequent design. However, these criteria assumed that the pertinent information for delineation and design was surface PCB concentrations, MPA_{3+}, and DoC. This method for determining a DoC surface does not directly consider each core's DoC. Instead, the focus of this method is on Total PCB concentrations within a pre-set number of depth intervals. As a result, in all cases, the measured Total PCB data for the original core and its paired data gap core were incorporated into the interpolation (except for inconsistent data, which were dropped). Only the measured sections for the previously "dropped" core were used, while all measured and extrapolated (if applicable) sections of the kept core were used as per the criteria described above.

Each core with CL 1, 2A, 2B, 2C, 2D, 2E, 2F, 2G, 2H, 2J, 2K, 2P, or 2R was partitioned into 18 vertical slices at 2, 12, 24, 30, 36, 42, 48, 54, 60, 66, 72, 78, 84, 90, 96, 102, 108, and 114 in. The length-weighted average Total PCB concentration for each slice was determined using the equation:

$$C_{lwa} = \sum_i \frac{TPCB_i \left(L_i\right)}{L_s} \qquad (4\text{-}7)$$

where:

C_{lwa} = length-weighted average of the Total PCB concentration of the slice;

$TPCB$ = measured or extrapolated Total PCB concentration of section I;

L = length of the portion of section i that is greater than or equal to the top of the slice and less than or equal to the bottom of the slice; and

L_s = length of the slice.

Where appropriate, the length-weighted average equation defined in USEPA's Final Decision, as described in Section 2.4, was used to calculate the Total PCB concentration in the portion above 12 in. of a core section whose top and bottom straddle 12 in. For cores that have a section straddling 12 in. (e.g., 2-24 in. section) and a Total PCB concentration in the section below the straddle section that is less than the straddle section, the Total PCB concentration in the portion of the straddle section above 12 in. was calculated assuming that all of the PCB mass in the straddle section was in that portion of the section. In these cases, correct mathematics requires that the Total PCB concentration in the portion of the straddle section below 12 in. be set to zero. However, to be conservative, the Total PCB concentration below the 12 in. horizon was set equal to the measured concentration in the straddle section. This results in "double counting" of Total PCB concentrations. For example, if a 2-24 in. section had a Total PCB concentration of 10 mg/kg that was adjusted to 20 mg/kg using USEPA's equation for the 2-12 in. layer, the 12-24 in. layer was assumed to still be equal to 10 mg/kg.

In addition to the data treatments and adjustments discussed above, some special conditions were applied when assigning the slice Total PCB concentration values:

- Core sections with Total PCB concentrations of non-detect were assigned concentrations of 0 mg/kg.
- Interpolation depth intervals whose start depths were greater than or equal to the depth to the confining layer in CL2C and CL2R cores were assigned concentrations of 0 mg/kg. The confining layer in CL2C cores is the Glacial Lake Albany clay layer, and the confining layer in CL2R cores is the rock, gravel, or cobble layer. These confining layers were determined by reviewing the field notes of those cores.
- Interpolation depth intervals in CL2D cores whose start depths were greater than the end depth of the last measured section in the core were considered to have no data.

- Interpolation depth intervals in CL 2H, 2J, and 2K cores whose start depths were above the depth of contamination were considered to have no data and those whose start depths were below the DoC were assigned concentrations of 0 mg/kg.
- All final depth interval concentrations between 0 and 0.0001 mg/kg were assigned a value of 0 mg/kg in order to avoid complications in the data transformation.

If a depth interval did not meet any of the above criteria, did not include a straddle core section, included sections with measured or extrapolated concentrations, and included sections with no data, then the concentration of the slice was calculated as the length-weighted average of the available concentrations.

4.3.3 1 mg/kg Interpolation Areas

Based on the variogram areas discussed in the kriging section (Section 4.2) and in Section 3, the Phase 2 Areas were divided into 36 1 mg/kg interpolation areas with approximately uniform flow direction. For all areas for which kriging was performed as the initial or final basis for determining the areal extent of dredging, the 1 mg/kg interpolation was applied to establish the vertical extent of contamination. In addition, the 1 mg/kg interpolation was applied to the area south of Lock 7 that was delineated in the Phase 1 DAD Report, and to the area on the west side of Griffin Island and the area behind the islands across the river from the confluence of Snook Kill, where kriging was not applied because the most of these areas were judged to meet the removal criteria. The 1 mg/kg interpolation areas are listed, along with the 1 mg/kg interpolation area flow direction, in Table 4-3. Interpolations were carried out separately for each depth interval in each 1 mg/kg interpolation area.

4.3.4 Data Transformations

The Total PCB concentration of each slice in each core was transformed using the same procedure as in the Phase 1 DAD Report: the Box-Cox transformation was applied in order to arrive at an optimal λ value that generally resulted in a distribution visually closest to linear on a normal probability scale. Normality was evaluated using the Shapiro-Wilk Test. The Box-Cox transformation and Shapiro-Wilk Test are described in detail in Section 3.3 of the Phase 1 DAD Report.

4.3.5 Optimizations

Using a similar procedure to that described in the Phase 1 DAD Report, the IDW parameters were optimized in an effort to minimize Type 2 errors while minimizing overall model errors. Each depth layer was optimized independently, around the decision criterion of 1 mg/kg (i.e., the accuracy of the model in predicting whether the point is above or below 1 mg/kg). The parameters that were optimized were:

1. azimuth;
2. IDW power;
3. major semiaxis; and
4. anisotropy ratio.

Optimization was performed using a computer program written in Interactive Data Language (IDL; a programming environment for statistical and graphical data analysis; www.rsinc.com/idl/) and is described in detail in the Phase 1 DAD Report (Section 3.4.1.3). The optimized parameters were chosen primarily to minimize the Type 2 errors (false negatives), with a secondary priority of minimizing total errors. In cases where multiple sets of parameters resulted in the same number of Type 2 and total errors, the set with the lowest anisotropy ratio was chosen. Also, no set of parameters was chosen if either the minor or major axis was equal to 80 ft., and a set where one of the axes was 90 ft. was chosen only if the set resulted in at least 2 fewer Type 2 errors than a set where the axes were both ≥ 100 ft. These criteria based on axis length were used to create a buffer for the general 80 ft. spacing between cores, thus maximizing the occurrence of cores within a given interpolation neighborhood. The optimized IDW parameters for the 18 slices in the 36 Phase 2 1 mg/kg interpolation areas are summarized in Table 4-4 through Table 4-6. The azimuth parameter for each area is the flow direction as given in Table 4-3. The plots generated from the optimization procedure for each layer within each variogram area are included in Appendix C.

4.3.6 Final Interpolation Parameters and Results

Interpolations were performed in each 1 mg/kg interpolation area for each of the 18 slices. Each cell within the 10-ft. by 10-ft. grid was assigned a depth equal to the bottom of the deepest slice for which the interpolated Total PCB concentration value was greater than or equal to 1 mg/kg. Final results of the 1 mg/kg interpolator are described in Section 5.2.1.

SECTION 5

SECTION 5
DREDGE AREA DELINEATION RESULTS FOR PHASE 2 AREAS

This Section 5 describes the results of the delineation process. Section 5.1 presents the areal delineation results. It includes the kriging results for all areas where that interpolator was applied, an evaluation of the krig performance, and a description of those areas for which the kriging was not used due to unreliable performance. Section 5.1 also describes the dredge area boundaries for: 1) areas where the boundaries were based on kriging with minor adjustments; 2) areas where the boundaries were based on manual delineations (due either to kriging infeasibility or manual due to unreliable krig performance); and 3) previously approved Phase 1 areas that are now subject to dredging in Phase 2. Section 5.2 presents the results of the vertical delineation, including the results of the 1 mg/kg interpolator (i.e., Total PCB interpolation at depth) and manual vertical delineation results for those areas where the 1 mg/kg interpolator was not applied. Section 5.3 summarizes the dredge area delineation.

5.1 AREAL DELINEATION

5.1.1 Kriging Results

As discussed above, in accordance with the resolution of the Phase 1 DAD dispute (USEPA 2004b, Attachment 1), kriging was initially applied to all areas that had sufficient data and spatial correlation to apply that interpolator. To display the kriging results, the portion of the river subject to kriging has been divided into 24 maps. Figures 5-1 through 5-24 show the MPA_{3+} kriging results as a color-coded surface on top of which are displayed the MPA_{3+} values of the cores. These figures also show the contour produced by the krig at the applicable MPA_{3+} criterion as a dark line. On these figures, the kriging results at the applicable MPA_{3+} criterion are grouped into the following categories: 0-2, 2-<3, 3-6, 6-<10, 10-50, and >50 g/m^2.

Similarly, Figures 5-25 through 5-48 show the kriging results for the maximum surface PCB_{3+} concentration in the top 12 in. as a color-coded surface on top of which are displayed the corresponding data. These figures also show the contour produced by kriging at the applicable surface PCB_{3+} concentration criterion as a dark line. The maximum surface PCB_{3+} concentrations are grouped into the following categories: 0-5, 5-<10, 10-20, 20-<30, 30-50, and >50 mg/kg.

The krig surfaces shown on the maps were generated with the January 17, 2006 version of the SSAP database. As mentioned in Section 4.1, the dataset shown for comparison is based on the March 6, 2006 version of the SSAP database and includes some minor adjustments to some cores' data treatments to address comments received from the USEPA on the March 29, 2006 Draft Phase 2 DAD, as well as agreements reached during discussions with USEPA and GE in spring 2007. The maps indicate the confidence level for each core by symbol shape, either a circle (CL1) or a diamond (CL2); grab samples are indicated by a triangle; and abandoned locations with probe depths less than 6 in. are shown as a square.

5.1.2 Evaluation of Krig Performance

Review of Figures 5-1 through 5-48 shows that the areas estimated by kriging to exceed the removal criteria sometimes omit cores meeting the removal criteria and sometimes include cores that do not meet those criteria. These results are due to the attributes of kriging, combined with the characteristics of the sediment PCB data, as discussed below.

Kriging uses a weighted average of values at nearby sampled locations as the estimate of the value at an unsampled location. Thus, interpolated values fall inside the range of the neighboring measured values, always greater than the lowest value and less than the highest value. The weighting factors that kriging applies to the neighboring values depend on the extent to which closely-spaced data covary and how quickly that covariance declines as distance between data points increases. The weaker the covariance of closely spaced (i.e., co-located) data (i.e., the larger the "nugget," which is the variance at very small separation – see Section 4.2.5) and the slower the decline in covariance with distance, the more kriging will tend to average among the neighboring values. These characteristics of kriging have two consequences: 1) the interpolated surface is smoother than the data from which it was derived; and 2) the interpolated values tend to exceed local measured values that are at the lower end of the distribution of measured values and to be less than local measured values that are at the upper end of the distribution of measured values. These consequences are most extreme when the nugget approximates the population variance and there is no overall increase in variance with distance – a condition known as a pure nugget model. Under this circumstance, kriging produces a simple average of the data as the best estimate everywhere over the interpolation domain.

When the above attributes of kriging are combined with the statistical properties of the sediment PCB data, the result is that kriging sometimes leaves cores meeting the criteria for removal outside of the areas that kriging indicates exceed the criteria, and includes cores below the dredging criteria within those areas. This was particularly true for kriging based on maximum surface PCB_{3+} concentration. In many variogram areas, maximum surface PCB_{3+} concentration yielded variograms with a large nugget and weak correlation between variance and distance. This behavior may be a consequence of the nature of the maximum surface PCB_{3+} concentration statistic. Because the top 12 in. of a sediment core likely includes sediments of varying age and PCB exposure, spatial correlation across cores is weakened by differences in the ages of the sediments being compared. For example, the top 12 in. of one core may include sediments deposited in the 1970s when PCB concentrations peaked, whereas the same interval in another core may include only sediments deposited since the 1980s. This inherent problem is not unique to the Hudson River. Brown et al. (1998) found that spatial correlation in Lavaca Bay and Matagorda Bay sediment mercury concentrations existed for the 0-0.8 in. layer but not for 4-8 in. or 8-20 in. layers. Another problem is that core sections of varying lengths are being compared (e.g., 0-2 in.; 0-6 in.; 2-6 in.; 2-12 in.; and a calculated 2-12 in. layer constructed from a measurement in a 2-24 in. segment). This means that the spatial analysis is being conducted over a population of values that has not been estimated in a coherent fashion. Finally, the use of the *maximum* surface concentration introduces an element of variability that is not present in an average or a sum such as MPA_{3+}.

Kriging performance for MPA_{3+} was generally much better than for maximum surface PCB_{3+} concentration. This appears to be due to better spatial correlation. Most of the model variograms for MPA_{3+} had a small or zero nugget and a strong correlation between variance and distance.

The differences in the performance of kriging for MPA_{3+} and maximum surface PCB_{3+} concentration are evident in the overall ability of the krig to place within the kriging-defined dredge areas cores meeting the removal criteria. Approximately 92% of the cores with a MPA_{3+} meeting the removal criteria are located inside the kriging-defined dredge areas. This capture efficiency exceeds that of the estimated remedy that USEPA outlined in the FS (USEPA 2000), which included 85% of such cores within the defined dredge areas. In contrast, about 79% of the cores with a maximum surface PCB_{3+} concentration meeting the removal criteria are located inside the kriging-defined dredge areas, whereas the FS included 87% of such cores within the defined dredge areas.

The areas estimated by the krig to exceed the removal criteria include approximately 10% of the cores that do not meet the criteria for removal. In some variogram areas, these cores are isolated within areas that clearly meet the criteria for removal or are located on the edges of dredge areas. In other cases, kriging has overrun groups of “clean” cores because of its tendency to average across cores. For example, in variogram area RM192a, which has a maximum surface PCB_{3+} concentration nugget equal to 22% of the population variance and a variance at 100 ft. separation that is 2.0 times the nugget, 38% of the clean cores (38 of 99) are located within the interpolated dredge area. This tendency to include clean cores appears to also be somewhat related to the average PCB concentration in the variogram area. In the RM192a variogram area, the average maximum surface PCB_{3+} concentration is about 34 mg/kg, substantially above the removal criteria of 10 mg/kg.

Variogram areas in which the kriged contours have the best conformance with the underlying data tend to be those in which neither MPA_{3+} nor maximum surface PCB_{3+} concentration has a nugget (although secondary factors such as structure of the variogram, (although secondary factors such as structure of the variogram, average concentration, the proximity of core MPA_{3+} and maximum surface PCB_{3+} concentration to the removal criteria, and the spatial pattern of cores above and below the criteria prevent global conclusions).

Cores values that are contradictory to the krig boundary (e.g., a cores meeting dredging criteria that are outside a krig-based dredge boundary, or vice versa) are is not problematic in cases where the contradictory cores are isolated, but have been identified as a concern in cases where several adjacent cores are contradictory to the kriging conclusions or where the dredge area boundary excludes adjacent cores that meet the criteria for removal. Table 5-1 presents, for each variogram area, the frequencies at which cores meeting the criteria for removal are inside of the kriging-based dredge areas and cores not meeting the criteria for removal are outside of the kriging-based dredge areas. Based on visual inspection of the Phase 2 dredge area delineation maps and discussions with USEPA, kriging was judged to be adequate when greater than 90% of the cores meeting the criteria for removal are inside of the kriging-based dredge areas (i.e., the second column in Table 5-1) and greater than 75% of the cores not meeting the criteria for removal are outside of the kriging-based dredge areas (i.e., the third column in Table 5-1). Eight variogram areas shown in Table 5-1 met these two criteria. Kriging was abandoned for 14 variogram areas in which less than 70% of the cores meeting the criteria for removal are inside of the kriging-based dredge areas, and for those areas, delineation was conducted using the manual delineation procedures described in Section 3.3. The remaining ten areas were evaluated on a case-by-case basis. For those areas, either kriging was either abandoned (five variogram areas) or the kriging-based boundaries were adjusted manually (five variogram areas) to achieve an accurate delineation. The last column in Table 5-1 indicates the final basis for delineation in each variogram area. The decisions on basis of delineation were agreed upon by GE and USEPA during discussions in spring 2007.

5.1.3 Dredge Area Boundaries Based on Kriging with Minor Adjustments

For those areas where kriging was judged to be reliable (as discussed in Section 5.1.2), the contours produced by the krig at the MPA_{3+} and maximum surface PCB_{3+} concentration criteria values which are shown in Figures 5-1 through 5-48, were combined as described in Section 3.3.1 to form the boundaries of dredge areas for those areas where kriging was judged to be reliable (see Section 5.1.2). However, in all cases, the kriging-based dredge area boundaries were adjusted, as described below.

For these areas, the results of the kriging as well as the adjustment made to the kriging-based boundaries are depicted on Figures 5-49 through 5-64. The contours produced by the krig are shown as thin green lines, and the adjusted dredge area boundaries are shown as red lines. These figures also show the PCB data relative to the dredge criteria as black and white symbols using the following symbols:

- locations that exceed both the MPA_{3+} and surface PCB_{3+} dredge criteria are shown as black circles;
- locations that exceed only the MPA_{3+} criteria are shown as circles that are black on the left side and white on the right side;
- locations that exceed only the surface PCB_{3+} criteria are circles that are black on the right side and white on the left side;
- locations that are below both criteria are shown as white circles;
- locations that exceed the removal criteria but also meet the select exclusion criteria (described in Section 2.8; designated as “meet select – above”) are shown as white or unfilled diamonds;
- locations that do not meet the removal criteria and also meet the select exclusion criteria (designated as “meet select – below”) are shown as white or unfilled pentagons; and
- abandoned locations with probing depth less than 6 in. are shown as white or unfilled squares.

The adjusted dredge area boundaries, shown as red lines on these figures, illustrate the specific locations where the dredge area boundary was adjusted off of a kriged contour, the adjusted dredge boundary is shown as a red line. Adjustments were made as follows:

- Small “islands” of isolated cores below the removal criteria within a larger area above the criteria were subsumed in the dredge area and small “islands” of isolated cores above the criteria within a larger area below the criteria were not delineated as dredge areas.
- Cores adjacent to the dredge area boundaries that met the dredging criteria but were located outside the kriged boundary were included within the dredge areas.

- Clusters of cores meeting the "select" exclusion criterion were excluded from the dredge areas.
- Rocky or gravelly areas that have little or no sediment, as indicated by SSS data and (when available) probing results, were excluded from the dredge areas.

To illustrate the manner in which adjustments to the krig-based dredge boundaries were made, detailed descriptions of these adjustments are presented here for dredge areas SK_01_KA, CSD_01, and CSD_02. Dredge area SK_01_KA is approximately 33 acres and is in variogram areas RM192a in the Snook Kill Area (Figures 5-49 and 5-50). It extends from the southern boundary with dredge area SK_01_KX, which was delineated in the approved Phase 1 DAD Report, to the mouth of Snook Kill. The majority of the areal dredge boundary follows the kriging results with the following exceptions: In the central part of the dredge area, within the center channel, the dredge area boundary was adjusted to exclude groups of cores not meeting the criteria but captured by the krig. In these cases, the boundary was drawn approximately half-way between the cores exceeding and not exceeding the criteria. This type of adjustment also occurred on the western shore, near RM 192. In addition, in one small area at the southern boundary of SK_01_KA, which contained only a single core above the criteria (RS1-9392-AR024), the kriging-based boundaries were redrawn to be approximately half-way between the core above the criteria and the ones below the criteria. Finally, the areal boundary in the south near the mouth of Snook Kill was modified to reflect the change in sediment type that was defined by probing data collected to confirm the SSS interpretation. The dredge boundary was pulled back where the probing data indicated that cobbles and gravel are present.

Figure 5-60 shows the two dredge areas in the variogram area RM177a – CSD_01 and CSD_02. Minor adjustments to the krig boundaries were made in and near these areas. For CSD_02, a majority of the cores in the northern portion of that dredge area met the "select" criteria (see Section 2.8) and therefore, were not targeted for dredging. In this case, the dredge boundary was drawn approximately half-way between the dredged cores and those meeting the "select" criteria. The krig also identified a small area north of CSD_01. The original core in this area was above the dredging criteria only because of the LWA equation and the data from the new core at this location showed that the measured concentrations in both the 0-2 and 2-12 in.

sections were below the dredging criteria. Therefore this area was not delineated as a dredge area.

5.1.4 Dredge Area Boundaries Based on Manual Delineation

As described in Sections 3.3.2 and 5.1.2, in areas with insufficient data or spatial structure to support kriging or where the krig produced unreliable results, physical features were used, to the extent practical, to establish the areal boundaries of dredge areas. Figures 5-65 through 5-113 are two-panel maps showing the MPA_{3+} of each core on the left-hand side of the map and the maximum surface PCB_{3+} concentration in the top 12 in. of each core on the right side. The data were grouped into the following categories: 0-2, 2- <3, 3-6, 6-<10, 10-50, and >50 g/m^2 for MPA_{3+}; and 0-5, 5-<10, 10-20, 20-<30, 30-50, and >50 mg/kg for maximum surface PCB_{3+} concentration. The manually delineated dredge boundaries are shown as black lines and the SSS interpretation is shown on both panels. The confidence level for each core is indicated by symbol shape, either a circle (CL1) or a diamond (CL2); grab samples are indicated by a triangle; and abandoned locations with probe depths less than 6 in. are shown as a pentagon with a small black dot in the center. The locations of the three historical cores that were used in setting the manual delineation dredge boundaries are shown by black stars on the maximum surface PCB_{3+} maps. There are no MPA_{3+} estimates for these three cores.

Figures 5-114 through 5-164 show the annotated horizontal dredge area boundaries, with black and white (or unfilled) symbols indicating whether a location exceeds given dredge criteria (see Section 5.1.3 for an explanation of these symbols). The dredge area boundaries are annotated using the following colors:

- black – non-kriging boundary that abuts a dredge area delineated by kriging;
- pink – non-kriging boundary that abuts another non-kriging dredge area;
- purple – boundary drawn based on SSS data supported by probing data;
- teal – boundary on SSS data only;
- red – boundary drawn approximately half-way between cores above the dredge criteria and those below the criteria;

- orange – boundary drawn approximately 40 ft. from the nearest core above the dredge criteria;
- blue – boundary based at the shoreline;
- bright green – boundary based on the location of a historical sample that exceeds the maximum surface PCB_{3+} concentration criterion;
- dashed black line – uncertain boundary;
- forest-green – boundary based on bathymetric data; and
- grey – boundary based on aerial photography information (Figure 5-152).

Similar to the descriptions of the kriged dredge area boundaries with minor adjustments (Section 5.1.2), detailed descriptions of the manual areal delineations are presented below for dredge areas GI_01_NK, GI_06_NK, and WD_10_NK to illustrate the manner in which the delineation was conducted.

Dredge area GI_01_NK is on the west side of the river at the northern end of Griffin Island and extends into the northern portion of the western side of Griffin Island (Figure 5-114). The dredge area is approximately 4.5 acres in size. The western and southwestern boundaries of this dredge area abut the shoreline. The western side of the northern boundary is drawn approximately half-way between a cluster of two cores below the dredging criteria (RS1-9190-TT229 and RS1-9190-WT111) and two cores above the criteria (RS1-9190-WT113 and RS1-9190-TT230). The remaining portion of the northern boundary and the majority of the eastern boundary were drawn using the SSS data, supported by the probing data. The dredge area boundary was extended into the Type III sediments in the north and brought into the Type II sediments in the center portion of the dredge area based on the probing data which were used to refine the data from the SSS coverages. The southeastern portion of the dredge area is in Type II sediments and the boundary was drawn approximately half-way between a core exceeding the dredging criteria (RS1-9190-CT145) and an abandoned location with probe depth of less than 6 in. (RS1-9190-AR045). The western portion of the southern dredge boundary was drawn based on the SSS and probing data, and the eastern portion of the southern boundary in Type I and II sediments was drawn approximately half-way between the cores above the dredging criteria and those below.

Dredge area GI_06_NK extends from south of Griffin Island to the northern portion of the Lock 6 land cut. (Figures 5-116 and 5-117). The dredge area is approximately 19.9 acres in size. The northernmost boundary connects with dredge area GI_03_KA and the northwestern boundary abuts dredge area GI-01_KX. The majority of the boundaries for this dredge area are drawn approximately half-way between cores above the dredge criteria and cores below the criteria (resulting in the honey-comb pattern). Portions of the western boundary are drawn on the shoreline because there are no cores below the dredge criteria between cores above the criteria and the shoreline. Portions of the eastern boundary (in the north) are drawn between Type II and Type V sediment types where probing confirms the SSS coverage. The eastern boundary in the south is drawn along the shoreline. The southernmost extent of this dredge area is drawn abutting the Lock 6 Land Cut wing dam.

Dredge area WD_10_NK is on the west side of the river in the Waterford Dam section near RM 158 (Figure 5-161). The dredge area is located at the mouth of a small backwater area and is approximately 0.6 acres in size. The eastern and southern boundaries are drawn based on the probing data collected to confirm the SSS coverage. The boundary encompasses the fine-grained and sandy probes with probe depths greater than 6 in., but does not include the probes that were described as predominately gravel and cobbles. The western boundary was drawn on the shoreline. The northern boundary of the dredge area was drawn approximately half-way between the two cores above the dredge criteria (RS3-5857-SS005 – above MPA_{3+} criteria, and RS3-5857-PR059 – above both criteria) and two cores that meet the select exclusion criteria (RS3-5857-SS003 and RS3-5857-SS004). There are a total of four cores in the cove (to the north of the dredge area) that met the select exclusion criteria and were not included in this dredge area.

As noted above, the data from three historical core were used in setting dredge area boundaries. Specifically, dredge area GI_05_NK's northern boundary was set using the information from a historical core that exceeded surface PCB_{3+} criteria (shown as a black star on Figure 5-115). In addition, one historical core that exceeded surface PCB_{3+} criteria is located under the vertical data gap (green dot) in LL_01_NK on Figure 5-119. Finally, dredge area

FMD_14_NK, which contains only one SSAP core was delineated because of the presence of a historical core that exceeded the surface PCB_{3+} removal criteria (Figure 5-131).

One small manually delineated dredge area (TD_01_NK) has been judged to meet the ROD's criteria, as explained in the USEPA's Final Decision, for exclusion of "isolated" areas less than 50,000 ft^2 that would require a separate mobilization of equipment to reach them. This area, which is approximately 0.4 acres (17,900 ft^2) is more than one-half mile from the closest dredge area and is denoted with grey shading on Figure 5-113 and diagonal hatching on Figure 5-164. Although this area has been delineated both areally and vertically, it is not targeted for dredging; and the summary statistics presented in this report show the totals without this area.

5.1.5 Dredge Area Boundaries for Previously Delineated Phase 1 Areas

Ten dredge areas that were previously delineated and approved in the Phase 1 DAD report (QEA 2005a). However, they are not scheduled to be dredged in Phase 1 and consequently, are included in this Phase 2 DAD Report. These consist of three dredge areas in the Northern Thompson Island Pool (NTIP) and seven in the Griffin Island area, east of the island (EGIA). The areal delineations of these areas are shown in Figures 5-165 through 5-167. The approved Phase 1 DAD Report (QEA 2005a) provides details on the setting of the dredge boundaries in these areas.

5.2 VERTICAL DELINEATION

This section describes vertical delineation for both vertical delineation categories: 1 mg/kg interpolator and manual. For these categories, vertical delineation was performed using the procedures described in Section 3.4.

5.2.1 1 mg/kg Interpolation Results

As previously noted, the 1 mg/kg interpolator was used for vertical delineation in areas where kriging was used at least initially for areal delineation, as well as in the areas south of Lock 7 and in East Griffin Island that were delineated areally in the Phase 1 DAD Report and in the areas behind the islands near Snook Kill (SK_01_NK) and West Griffin Island (GI_01_KX). Figures 5-168 to 5-216 display the interpolation of Total PCB concentration at depth for these areas. These DoC figures have two panels, with the left panel having a larger scale to show the location of the dredge area within the river. The right panel shows both the interpolator results as a gridded surface and the DoC data. The displayed data include cores that were used in the 1 mg/kg interpolation, colored to match their measured or extrapolated DoCs. For CL2D cores (shown as squares on the maps), only the measured data were used in the interpolation (see Section 4.3.2 for the data treatments for each CL), but the DoCs determined from doubling these cores are displayed on the maps. The circles on the maps also include abandoned locations with probing less than or equal to 6 in., where the DoC was set to the probing depth.

The interpolated DoC surfaces shown on these maps were generated with the January 17, 2006 version of the SSAP database. However, the dataset of cores shown for comparison is based on the March 6, 2006 version of the SSAP database and includes some minor adjustments to some cores' data treatments to address comments received from the USEPA on the March 29, 2006 Draft Phase 2 DAD, as well as agreements reached during discussions with USEPA and GE in spring 2007. In addition, the interpolated surfaces shown for the NTIP dredge areas (NTIP02H and NTIP02I) and East Griffin Island (EGIA01A, EGIA01B, EGIA02, EGIA03, EGIA04, EGIA01C, EGIA05, EGIA01B_2), which were Phase 1 approved dredge areas, reflect the 1 mg/kg interpolator results from the Phase 1 FDR (BBL 2006).

The DoC determined from the interpolation of Total PCB concentrations at depth range from 2 in. to greater than 60 in. The area-weighted average depth for all of the dredge areas is approximately 2.3 ft., and many of the dredge areas show interpolated DoCs in the range of 12 to 30 in. Some of the deeper DoCs occur in the following areas: the west shore near Snook Kill, just south of Galusha Island, near RM 186 (i.e., "Hot Spot 28"), near Northumberland Dam, near

RM 177, just north of the Mechanicville Dam, and southwest of Quack Island. Portions of some dredge areas indicate DoCs of 2 in. or less in the Snook Kill and East Griffin Island areas.

In some of the areas, there are discontinuities in the DoC when moving from one variogram area to another. For example, the DoCs determined from the interpolation in the southern portion of variogram area RM192a are about 42 in., compared to the depths of 30 in. in from the adjacent portion of variogram area RM192b. Although the data indicate a change in DoCs moving from the southern part of variogram area RM192a to the northern part of variogram area RM192b, the abrupt change from 42 in. to 30 in. is obviously a product of both the discretized nature of the 1 mg/kg interpolator and the change in variogram areas.

In addition, comparison of the DoC set by data treatment of individual cores and the DoC determined by the results of the 1 mg/kg interpolation shows that in some cases, the resultant interpolated surface is more shallow than the core data, and in other areas is deeper than the core data. For the cores within Phase 2 dredge areas where such differences exist, Tables 5-2 and 5-3 show a comparison of the DoC determined by data treatment of each core and the DoC resulting from the 1 mg/kg interpolated 10-ft. by 10-ft. grid cell on which the core is located for those cores that fall within the Phase 2 dredge areas.[13] Table 5-2 presents such comparisons for the cores where the DoC determined by data treatment exceeds the interpolated DoC in that area, and Table 5-3 presents such comparisons for the cores whose individual DoCs are less than the interpolated DoC. Of the 2,735 cores that fell within Phase 2 dredge areas, 55% of the cores had a data-determined DoC that was equal to its closest 10-ft. by 10-ft. interpolated cell DoC value. Another 10% of the cores had differences of less that 6 in. Approximately 19% of the cores (533 cores; 48 of which are CL2D) show individual DoCs that are 6 in. or more deeper than the interpolated DoC surface in that area (Table 5-2), indicating possible under-dredging using the 1 mg/kg surface. Approximately, 16% of the cores (430 cores) show individual DoCs that are 6 in. or more shallow than the interpolated DoC surface (Table 5-3), indicating possible over-dredging using the 1 mg/kg interpolated surface.

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[13] Tables 5-3 and 5-4 and the subsequent statistics presented in this section do *not* include a comparison of the cores to the interpolated surface for the following dredge areas: NTIP02H, NTIP02I, EGIA06, EGIA01A, EGIA01B, EGIA02, EGIA03, EGIA04, EGIA01C, EGIA05, EGIA01B_2. For these areas, the core DoC to DoC interpolated result comparisons were performed in the Phase 1 Final Design Report (BBL 2006).

This analysis should be considered preliminary and subject to change, because other processing to account for the presence of Glacial Lake Albany clay, shoreline, and other engineering considerations has not yet occurred. However, the issues of surface discontinuities when moving from one variogram area to another and difference between individual core DoCs and the interpolated surface will be addressed during the Phase 2 Intermediate and Final Design.

5.2.2 Manual Vertical Delineation

Manual vertical delineation was performed for all areas where kriging was deemed infeasible due to lack of data or lack of spatial structure in the data. Figures 5-217 to 5-239 display the results of the manual vertical delineation. These figures show the dredge areas that were subdivided into homogeneous regions and then subject to vertical delineation using the procedures described in Section 3.4.2. The figures show the DoC class of the cores as separate symbols and the CLs of the cores in different colors. The DoC determined by the data treatment for each core is posted in the center of the symbol. The DoCs established using the analyses of the mean Total PCB concentration in the segment below the DoC and the maximum Total PCB concentration in any segment below the DoC are also shown on these figures. The supporting graphs for the analyses and the bathymetry figures for the vertical delineation in the non-kriged areas are presented in Appendix D. The key inputs to, and the results of, the DoC analysis for these areas (based on the procedures described in Section 3.4.2) are summarized on Table 5-2.

The DoCs in these manually delineated areas range from 2 in. to 102 in. The area-weighted average DoC for all of the dredge areas is approximately 3.5 ft. The dredge depth in NDCA_02_NK was set at the depth of the last measured section for core RS3-8281-WS001 (54 in.) because the PCB criteria below the DoC were not met at shallower depths. A vertical data gap core is also located in this area and will refine the DoC estimate for this dredge depth (Figure 5-133). The depth in CSD_36_NK was set at 30 in., the deepest DoC in the two CL2R cores in that dredge area (Figure 5-230).

5.3 DATA GAPS

In cases where more information was needed to delineate a dredge area boundary, data gaps were sited and will be collected during Phase 2 design. Areal data gaps are shown on Figures 5-49 through 5-164 as red circles at 104 locations. Two data gap cores have been sited to obtain a measurement from the 2-12 in. section. These are shown as yellow circles on Figure 5-63 (near existing cores RS3-7170-WS015 and RS3-7170-WS504). Two vertical data gap cores are shown as green circles on Figures 5-19 and 5-133 in dredge areas LL_01_NK and NDCA_02_NK and will be used to confirm the DoC in these areas. In addition, four probing data gap lines were drawn near dredge areas FMD_13_NK, NDCA_04_NK, WD_07_NK, and LL_19_NK totaling approximately 600 linear ft. of probing.

5.4 SUMMARY OF DELINEATION

The results of the areal and vertical delineation of Phase 2 dredge areas are summarized in Table 5-4. In all, approximately 400 acres encompassing 1,531,400 cubic yards (cy) of sediment and 92,800 kg of Total PCB are targeted in the Phase 2 Areas. There are 168 total dredge areas (excluding one isolated area and including 10 areas previously delineated in the Phase 1 DAD Report). These areas range in size from less than 0.1 acre to close to 40 acres and range in volume from less than 100 cy to over 150,000 cy. The median size of the dredge areas is 0.7 acre, and the median volume is 2,400 cy.

SECTION 6

SECTION 6
CONCLUSIONS AND SUMMARY

The dredge area delineation methodology described in this report, which incorporates MPA_{3+} data, PCB_{3+} concentrations in the top 12 in. of sediment, and ancillary information such as SSS sediment type and bathymetry (where justified under the parties' agreement in the dispute resolution), was applied to the Phase 2 Areas. This methodology includes consideration of trends typically seen in PCB concentrations relating to sediment type, water depth, and bottom slope. The regions of the Phase 2 Areas in which the sediments contain PCBs at levels meeting the criteria specified by USEPA for removal were identified and their boundaries were defined. Some of the boundaries were defined by mathematical interpolation of contours at the USEPA-specified removal criteria. Some boundaries were set along the boundaries between soft sediment and rocky or cobbly sediments or were located midway between cores above and below the removal criteria. One boundary was defined by water depth or bottom slope. Within the regions meeting the removal criteria, the sediments containing PCBs were delineated from underlying strata in which PCBs were not detected or were present at Total PCB concentrations below 1 mg/kg.

6.1 SUMMARY OF PHASE 2 AREAS

One hundred sixty-nine separate dredge areas were initially delineated within the Phase 2 portion of the Upper Hudson River (including 10 dredge areas that were previously delineated during the Phase 1 delineation which had been approved by USEPA). These areas range in size from less than 0.1 to over 39 acres and comprise a total area of approximately 400 acres and a total sediment volume of 1,533,000 cy. One of these delineated dredge areas were judged to meet the ROD's criteria, as explained in the USEPA's Final Decision, for exclusion of "isolated" areas less than 50,000 ft^2 that would require a separate mobilization of equipment to reach them; this area TD_01_NK is more than ½ mile from the closest dredge area. After exclusion of this area, there remain 168 delineated dredge areas within the Phase 2 Areas. These areas cover a total of 400 acres and encompass a sediment volume of 1,531,400 cy.

The average DoC is less than 3 ft. in most of the dredge areas. A few areas have a much greater DoC, the most notable being seven areas – the west shore near Snook Kill, just south of Galusha Island, near RM 186 (i.e., "Hot Spot 28"), near Northumberland Dam, near RM 177, just north of the Mechanicville Dam, and southwest of Quack Island – where the sediments containing PCBs that meet the dredge criteria extend to depths of 5 ft. or more.

Table 6-1 summarizes for the 11 regions shown in Figure 1-1 the acreage and volume encompassed by the Phase 2 dredge areas (excluding the "isolated" area less than 50,000 sq. ft.). The volumes are presented separately for areas having DoC less than or equal to 2 in., DoC greater than 2 in. and less than or equal to 12 in., and DoC greater than 12 in. Table 6-1 also presents for these 11 regions statistics detailing the Total PCB inventory inside the dredge areas. In total, about 92,820 kg of Total PCB are contained within the dredge areas.

In addition to the delineated dredge areas, this report has identified the need for the collection and analysis of a number of additional cores, as well as additional probing to satisfy data gaps. These include 104 areal data gap cores, two vertical data gap cores, and two data gap cores needed to establish the PCB concentration of the 2-12 in. section. There are also four areas where the need for additional probing has been identified to confirm SSS sediment type boundaries. These additional data gap sample/analysis and proving activities, which have been approved by the USEPA, will be conducted in 2008, and the results will be incorporated into the Phase 2 design.

6.2 SUMMARY OF HUDSON RIVER DREDGING PROJECT

A summary of the complete delineation for River Sections 1, 2, and 3 is presented in Table 6-2. This summary combines the results of the Phase 2 delineation presented herein and the dredge prisms presented in the Phase 1 FDR, as modified by GE and approved by USEPA. Within River Section 1, the Thompson Island Pool, 60,600 kg of Total PCB have been targeted for removal. This constitutes about 98% of the total PCB inventory in River Section 1. For comparison, the estimated remedy that USEPA outlined in the FS targeted about 80% of the

Total PCB mass in River Section 1. Thus, the final delineation targets significantly more PCBs for removal in River Section 1. This removal is achieved by targeting 310 of the 537 acres of River Section 1. The FS remedy targeted 266 acres. Thus, the project targets 8% more area in River Section 1 and removes a much greater percentage of the PCB inventory.

In River Section 2, 28,500 kg of Total PCB inventory are targeted for removal over 86 acres. In River Section 3, 24,000 kg of Total PCB inventory are targeted over 95 acres. The FS targeted 74 and 92 acres in River Sections 2 and 3, respectively. The percentage removals on a PCB_{3+} or Total PCB inventory basis were not calculated due to lack of data in the non-dredge areas within River Sections 2 and 3.

Overall, the combined dredge area delineation for both Phase 1 and Phase 2 Areas covers about 490 acres in comparison to the remedy outlined in the FS, which delineated about 430 acres. In addition, the mass inventory estimated to be removed in the Phase 1 and Phase 2 Areas under this delineation consists of approximately 113,000 kg of Total PCB. This mass removal is greater than that estimated in the FS, which was about 66,300 kg of Total PCB. This mass removal can be accomplished with less overall volume removal of sediments (1,800,000 cy versus 2,500,000 cy), because the sediment data collected since the ROD show that overall PCB concentrations greater than 1 mg/kg do not reach nearly as deep into the sediments as was estimated in the FS.

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SECTION 7
REFERENCES

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