Hudson River
PCBs SUPERFUND SITE

Engineering Performance Standards

Technical Basis and Implementation of the Residuals Standard

April 2004

Volume 3 of 5

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ATTACHMENTS

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List Of Acronyms

AMN	Water treatment facility (*formerly known as* SRMT)
ARARs	Applicable or Relevant and Appropriate Requirements
ATL	Atlantic Testing Labs
CAB	Cellulose Acetate Butyrate
CAMU	Corrective Action Management Unit
Cat 350	Caterpillar Model 350
CDF	Confined Disposal Facility
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CF	cubic feet
cfs	cubic feet per second
CLP	Contract Laboratory Program
cm	centimeter
CPR	Canadian Pacific Railroad
CSO	Combined Sewer Overflow
CU	certification unit
CWA	Clean Water Act
cy	cubic yard(s)
DDT	Dichlorodiphenyltricholorethane
DEFT	Decision Error Feasibility Trials
DGPS	Differential Global Positioning System
DMC	Dredging Management Cells
DNAPL	Dense Non-Aqueous Phase Liquid
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DQOs	Data Quality Objectives
DSI	Downstream of the dredge area inside the silt curtain
DSO	Downstream of the dredge area outside the silt curtain
EDI	Equal Discharge Interval
EMP	Environmental Monitoring Plan
EPS	Engineering Performance Standards
EQUIL	Software model used to determine chemical equilibrium between the particle-bound solid and the water column or aqueous phase
ESG	ESG Manufacturing, LLC
EWI	Equal Width Interval
FIELDS	Field Environmental Decision Support
FISHRAND	USEPA's peer-reviewed bioaccumulation model

FJI	Fort James Water Intake
fps	feet per second
FRRAT	Fox River Remediation Advisory Team
FS	Feasibility Study
ft	foot
ft^2	square feet
GE	General Electric Company
GEHR	General Electric Hudson River
GCL	Geosynthetic Clay Liner
g/cc	grams per cubic centimeter
g/day	grams per day
GIS	Geographic Information Systems
GM	General Motors
gpm	gallons per minute
GPS	Global Positioning System
HDPE	High Density Polyethylene
HUDTOX	USEPA's peer-reviewed fate and transport model
IDEM	Indiana Department of Environmental Management
JMP	a commercial software package for statistical analysis
kg/day	kilograms per day
lbs	pounds
LWA	length-weighted average
MCL	Maximum Contaminant Level
MCT	Maximum Cumulative Transport
MDEQ	Michigan Department of Environmental Quality
MDS	ESG Manufacturing model #. For example, MDS-177-10
MFE	Mark for Further Evaluation
MGD	million gallons per day
ug/L	micrograms per liter
mg/kg	milligrams per kilogram (equivalent to ppm)
mg/L	milligrams per liter
MPA	Mass per Unit Area
MVUE	minimum unbiased estimator of the mean
ng/L	nanograms per liter
NBH	New Bedford Harbor
NJDEP	New Jersey Department of Environmental Protection
NPDES	National Pollution Discharge Elimination System
NPL	National Priorities List

NTCRA	Non-Time-Critical Removal Action
NTU(s)	Nephelometric Turbidity Units
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
OBS	Optical Backscatter Sensor
O&M	Operations and Maintenance
PAHs	Polycyclic Aromatic Hydrocarbons
PCBs	Polychlorinated Biphenyls
PCDFs	Polychlorinated Dibenzofurans
pcf	pounds per cubic foot
PL	Prediction Limit
ppm	part per million (equivalent to mg/kg)
PVC	Polyvinyl Chloride
Q-Q	Quantile-Quantile
QA/QC	Quality Assurance / Quality Control
QAPP	Quality Assurance Project Plan
QRT	Quality Review Team
RCRA	Resource Conservation and Recovery Act
RDP	Radial Dig Pattern
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
RM	River Mile
RMC	Reynolds Metals Company
ROD	Record of Decision
RS	Responsiveness Summary
Site	Hudson River PCBs Superfund Site
SLRP	St. Lawrence Reduction Plant
SMU	Sediment Management Unit
SOP	Standard Operating Procedure
SPI	Sediment Profile Imaging
SQV	Sediment Quality Value
SRMT	St. Regis Mohawk Tribe Water treatment facility (*former name for* AMN)
SSAP	Sediment Sampling and Analysis Program
SSO	Side-stream of the dredge area outside of the silt curtain
SVOCs	Semi-Volatile Organic Compounds
TAT	Turn-around Time
TDBF	Total Dibenzofurans
TG	turbidity generating unit
TI	Thompson Island
TIP	Thompson Island Pool

TM	turbidity monitoring
TOC	Total Organic Carbon
Tri+	PCBs containing three or more chlorines
TSCA	Toxic Substances Control Act
TSS	Total Suspended Solids
UCL	Upper Confidence Limit
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
USI	Upstream of the dredge area outside the silt curtain
USO	Upstream of dredge area outside the silt curtain
USS	US Steel
VOC	Volatile Organic Compound
WDNR	Wisconsin Department of Natural Resources
WINOPS	Dredge-positioning software system used to guide the removal of contaminated sediment
WPDES	Wisconsin Pollutant Discharge Elimination System
WSU	Wright State University

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1.0 Technical Background and Approach

1.1 Criteria in the Record of Decision

The United States Environmental Protection Agency's (USEPA) 2002 Record of Decision (ROD) states that the selected remedy includes the "removal of all PCB-contaminated sediments within areas targeted for remediation, with an anticipated residual of approximately 1 mg/kg Tri+ PCBs (prior to backfilling)." Based on the text of the ROD and USEPA modeling (as described later in this subsection), the primary objectives of the Residuals Standard are listed in the text box below.

Residuals Standard Objectives

- Affirmation of the removal of all PCB-contaminated sediment inventory in target dredging areas
- An arithmetic average Tri+ PCBs concentration in residual sediments of $\leq$ 1 mg/kg

The first objective of the Residuals Standard is the removal of all PCB-contaminated sediment from areas targeted for dredging. Sampling of residuals to verify achievement of the ROD's objectives will only begin after it has been verified that the dredging has met the design cut lines. It is assumed that the dredging cut lines will be designed to remove all PCB-contaminated sediments in a targeted area (*i.e.*, the cut lines will be set at an elevation below which sediment PCB concentrations are non-detect). The Residuals Standard incorporates sediment sampling to confirm the removal of PCB inventory and to determine the residual sediment contamination.

The Residuals Standard proceeds to build on the ROD's stated objective of "an anticipated residual concentration of approximately 1 mg/kg Tri+ PCBs (prior to backfilling)" by including a group of statistically derived action levels. The action levels are used to trigger specific responses (including redredging) from a range of responses appropriate for managing residual sediments. The use of statistics to generate the action levels is based on sound science, is a common approach for the interpretation of environmental datasets, and ensures that application of the action levels to evaluate residuals data will clearly indicate whether the ROD's criterion of approximately 1 mg/kg Tri+ PCBs has been achieved.

The following contingency actions are required if the objectives of the residuals standard cannot be achieved:

Engineering Contingency Actions

- Redredging
- Installation of a subaqueous cap
- Installation of backfill with a confirmed arithmetic average Tri+ PCBs surface concentration of $\leq$ 0.25 mg/kg (for areas with residual sediment concentrations greater than 1 but less than or equal to 3 mg/kg Tri+ PCBs).

Each of these contingency actions is applied to areas that do not meet the Residuals Standard criteria. The latter two are specifically intended to avoid multiple dredging passes in instances where inventory has been removed but residual concentrations are unacceptable. The tested backfill option is designed to address residual contamination just above the criteria but where inventory removal is complete. The contingency action for testing the backfill surface is based on the findings of previously conducted USEPA modeling to evaluate the recovery of fish tissue PCB concentrations following dredging and backfill placement. The model parameters included an assumption that the PCB concentrations in the backfill would be 0.25 mg/kg Tri+ PCBs for all dredged areas (areas outside the targeted dredging areas were modeled using existing Tri+ PCB surface concentrations as estimated from field sampling). The modeled PCB concentration in backfill was based on a conservative estimate of the potential mixing of a 1-foot-thick backfill layer with a dredged surface that had a residual concentration of 1 mg/kg Tri+ PCBs[1]. The modeled surface concentration also closely approximates the concentration that is estimated to result from recontamination of the backfill surface in the event of continued low-level releases from upstream sources.

While it was assumed for the purposes of the Residuals Standard that residuals could be completely encapsulated by carefully placed backfill, some case studies have shown that backfill placement can disturb and displace residuals, allowing them to resettle on top of

[1] Based on review of case study data, it is expected that the techniques available for placement of backfill will allow for efficient isolation of residuals; however, some mixing of residuals and backfill was considered in the FS to conservatively model the outcome of the remediation. If as much as the upper 4 inches of a residuals layer contaminated with 1 mg/kg Tri+ PCBs were to completely mix with a 1-foot thick "clean" backfill layer during backfill placement, the Tri+ PCBs concentration in the backfill would be 0.25 mg/kg Tri+ PCBs. This means of estimating the surface concentration of the remediated areas was a reasonable assumption that is not related to the selection of a residual sediment sampling interval (0-6 inches) or the requirements of the standard for the PCB concentration in that layer. The standard requires the residual sediment to be at 1 mg/kg or lower on average and calls for the placement of 1 foot of backfill. A mechanism that would completely homogenize the entire residuals layer with the backfill is not envisioned, considering that subsequent to backfill placement, bioturbation will typically be limited to the upper 6 inches of the backfill layer.

the backfill. The model indicated that fish tissue recovery trajectories are acceptable with a backfill Tri+ PCB concentration of 0.25 mg/kg or less; model runs using higher backfill PCB concentrations yielded more elongated (*i.e.*, slower) recovery trajectories. Therefore, the Residuals Standard must control Tri+ PCB concentrations in residuals to achieve compliance with the approximately 1 mg/kg Tri+ PCBs criterion stated in the ROD as well as to minimize the surface PCB concentration of backfill that is placed over non-compliant residual sediments (using the criterion of 0.25 mg/kg Tri+ PCBs). The Residuals Standard also dictates when the use of subaqueous capping is appropriate. Concentrations in areas where backfill is not to be placed (*e.g.*, the navigation channel) were modeled at 1 mg/kg Tri+ PCBs; therefore, this criterion is appropriate for such areas.

1.2 Placement of Backfill

Upon completion of sediment removal, there is likely to be some residual contamination along the river bottom due to the infeasibility of attaining a 100% removal efficacy and resettlement of sediments in the immediate work area. In addition to residual contamination, it is expected that the process of removing contaminated river sediments may result in adverse effects on the sediment surface topography, the hydraulics of the river channel, and the stability of the shoreline, and may reduce the ecological value of the river bottom substrate. In order to mitigate these impacts and substantially reduce the bioavailability of any residual contamination, restoration was included in the proposed alternative (USEPA, 2000a; page 4-7). Restoration consists of:

- Placement of clean backfill over remedial work areas.
- Stabilization of disturbed shoreline.
- Revegetation.

The appropriateness of eliminating the placement of backfill in targeted areas where deeper water conditions may be preferable *(e.g.*, the navigation channel and possibly in some shoreline fish habitats) was scheduled for assessment during the remedial design (Caspe, 2001). For example, near-shore fish habitat areas that have become silted-in over time may be better mitigated by not adding clean backfill and leaving a deeper water habitat.

The Feasibility Study (FS) described the placement of clean backfill material as fulfilling a number of important purposes in remediation of the river bed, including:

- Isolation of dredging residuals.
- Mitigation of potential bathymetric changes in shallow areas.
- Protection of impermeable capping materials.
- Habitat replacement (USEPA, 2000b; Section 5.2.6).

Of these purposes, habitat replacement was considered most likely to have the greatest influence on characteristics of selected materials.

Backfill in areas considered to be in the deep river habitat zone (6 to 12 feet [ft]) was proposed to be a 0.5-ft-deep layer of gravel over a 0.5-ft-deep layer of sand. The intention is to return the river bottom to a stable, well-sorted substrate, often a critical requirement for fish spawning and secondary production by aquatic insects (USEPA, 2000b; Appendices E.7, E.8, and F). For remediation occurring in the shallow river zone (0 to 6 ft), backfill would primarily consist of a 1-ft-deep layer of sand, with other materials used as needed (USEPA, 2000b; Appendices E.7, E.8, and F). Areas of the Hudson River with depths below 12 ft (considered to be the navigational channel) subject to the removal of PCB-contaminated sediments will not be capped or backfilled (USEPA, 2000b, Appendix F).

Backfill in deep river habitat zones is proposed to be a 0.5-ft layer of gravel over a 0.5-ft layer of sand.

USEPA will remain flexible regarding the most appropriate means for restoring dredged areas and will provide the state, other natural resource trustees, and the public an opportunity to provide input on this issue (USEPA, 2002), in accordance with the adaptive management approach that will be used for the habitat replacement and reconstruction program (GE, 2003b).

The ROD (USEPA, 2002) summarized the use of backfill at the Hudson River PCBs Superfund Site as follows (page 60):

> "Subsequent to removal, approximately one foot of backfill will be placed where appropriate over the dredged areas, which would cover residual PCBs thereby reducing the available PCB concentration at the surface and providing an appropriate substrate for biota. In addition, the backfill will help stabilize bank areas after dredging and minimize hydraulic changes to the river. During remedial design, the appropriateness of eliminating the placement of clean backfill in certain targeted areas will be assessed (e.g., near-shore fish habitat areas that have become silted in over time may be better mitigated by not adding clean backfill and leaving a deeper water habitat). EPA will remain flexible regarding the most appropriate means for restoring dredged areas and will provide the State, other natural resource trustees and the public opportunity to provide input on this issue. The source(s) of the backfill will be determined during the remedial design and construction."

The remedial design will be accomplished through an integrated systems design approach. This approach covers each individual design item while considering the potential interdependencies and associated effects on other components (GE, 2003a; Section 3). In-river activities, such as the dredging, backfilling, and habitat restoration, will be closely coordinated to allow for efficient operations. The preliminary, intermediate, and final design documents shall each include design of backfilling and capping to address the requirements and goals of the Engineering Performance Standards, including residual sediments. The design of subaqueous caps shall be integrated, as appropriate, with the design for habitat replacement and reconstruction.

The design process for the habitat replacement and reconstruction program will proceed in conjunction with the overall remedial design. The habitat replacement and reconstruction design will define acceptable backfill specifications based on the range of sediment structural characteristics determined during habitat delineation and assessment activities. Specifications will be provided on a parcel-specific basis (*i.e.*, within parcels of sediment for which dredging is planned) for inclusion as design criteria in appropriate design documents.

The adaptive management approach to be used for the habitat replacement and reconstruction program is described in the *Habitat Delineation and Assessment Work Plan* (GE, 2003b). The design for backfilling will be integrated with the dredging design, and will include:

- Materials specifications and availability.
- Vertical geometry of backfill/cap.
- Horizontal extent of backfill/cap.
- Identification and selection of material source(s).
- Evaluation and design of source material transport to the site and staging for installation.
- Methods for placement of backfill/cap materials.

The design methods for backfilling/capping are currently being developed as part of the *Preliminary Design Report*, using the draft *Engineering Performance Standard for Dredging Residuals* as a key basis of the design. Backfill/cap selection will be based on residual concentrations after dredging. The design process will continue during the dredging operations. Each dredge area will be evaluated based on the results of post-dredging residuals sampling and considerations for habitat replacement and reconstruction.

1.3 Case Studies

The development of the Residuals Standard included a review of residuals sampling programs previously designed or completed for other environmental dredging projects. Although the post-dredging sediment sampling protocol in the Residuals Standard is specific to the Hudson River PCBs Site, applicable information from other dredging projects was considered, including:

- Pre-dredging contaminant concentrations.
- Type of dredging (mechanical/hydraulic) conducted.
- Characteristics of the area.
- Presence of debris or boulders.
- Post-dredging contaminant concentrations.
- Number of samples collected (sample density).
- Depth of collected samples.

- Type of samples collected (*e.g.*, grab, core, composite).
- Sample location.
- Timing of collection (*i.e.*, length of time between completion of dredging and sampling).

The review performed for the Residuals Standard supplements the extensive literature search on post-dredging residual PCB concentrations prepared for the ROD, which can be found in Volume 5, *Appendix: Case Studies of Environmental Dredging Projects*. A brief summary of project information for the case studies reviewed is provided in Table 1-1.

1.4 Regulatory Guidance

Relevant guidance documents were identified and reviewed for development of the residual sampling strategy, including but not limited to:

- Guidance for Choosing a Sampling Design for Environmental Data Collection, EPA/240/R-02/005 (USEPA, 2002a), and hereafter referred to as the "Sampling Guidance."

- Guidance for the Data Quality Objectives Process, EPA QA/G-4 (USEPA, 1994).

- Requirements for the Preparation of Sampling and Analysis Plans, EM-200-1-3 (USACE, 1994).

- Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846 3rd Edition (USEPA, 1998).

- Methods for Evaluating the Attainment of Cleanup Standards, Volume 1: Soils and Solid Media (USEPA, 1989).

USEPA's manual, Guidance for Choosing a Sampling Design for Environmental Data Collection, available online at http://www.epa.gov/quality/qs-docs/g5s-final.pdf, describes several relevant basic and innovative sampling designs, as well as the process for deciding which design is appropriate for a particular application. Based in statistical theory, it explains the benefits and drawbacks of each design and describes relevant examples for illustration of environmental measurement applications. The information in this document is consistent with other USEPA guidance documents on sampling design, including the *Soil Screening Guidance* (USEPA, 1996) and SW-846 (USEPA, 1986). It also includes innovative designs not covered in earlier USEPA documents, including geostatistical studies.

USEPA's sampling guidance discusses two main categories of sampling designs: probability-based designs and judgmental designs. An essential feature of a probability-based design is that each member of the sample population has a known probability of selection. When a probability-based design is used, statistical inferences may be made about the target population from the data obtained from the sampling units. Judgmental sampling designs involve the selection of sampling units on the basis of expert knowledge or professional judgment. Key points from the USEPA's Sampling Guidance are included below.

1.4.1 Systematic and Grid Sampling

In the systematic and grid sampling method, samples are taken at regularly spaced intervals over space or time. An initial location or time is chosen at random, and then the remaining sampling locations are defined so that all locations are in regular intervals over an area (grid) or time (systematic). Examples of systematic grids include square, rectangular, triangular, or radial grids. Systematic and grid sampling typically is used to search for hot spots and to infer means, percentiles, or other parameters and also is useful for estimating spatial patterns or trends over time. This design provides a practical and easy method for designating sample locations and ensures uniform coverage of the site, unit, or process.

1.4.2 Soil Contamination Applications

For applications where the goal of sampling is to evaluate the attainment of cleanup standards for soil and solid media (including sediments), the guidance recommends collecting samples in the reference areas and cleanup units on a random-start equilateral triangular grid, except when the remedial action method may leave contamination in a pattern that could be missed by a triangular grid. In that case, unaligned grid sampling is recommended. If nothing is known about the spatial characteristics of the target population, grid sampling is efficient for finding patterns or locating rare events. If there is a known pattern or spatial or temporal characteristic of interest, grid sampling may have advantages over other sampling designs, depending on what is known of the target population and what questions are being addressed by sampling.

2.0 Supporting Analyses

2.1 Case Study Statistical Data Evaluation

2.1.1 Introduction

Case study data were acquired for a number of projects with contamination and remediation strategies similar to those at the Hudson River PCBs Superfund Site. These datasets were used to develop parameters for the Residuals Standard. Specifically, action levels for evaluation of the Hudson River PCBs residuals data and the number of samples required to assess the arithmetic average concentration of a dredged certification unit (CU) in the Upper Hudson River were derived using the case study data, as described below. As explained in Volume 1, certification units are defined as dredged areas five acres in size.

2.1.2 Description of the Case Studies

Case study data were used to determine action levels and other parameters for the Residuals Standard. Case studies with similar conditions and remedial operations were considered. For example, projects where the excavation was done "in the wet" were considered more relevant than those done "in the dry." Similarly, projects done more recently with newer technology are more relevant than projects completed ten or more years ago; sites with PCB contamination are preferred, but sites with other contaminants were considered.

Post-dredging residuals data were obtained for eight sites, described below. Table 1-1 contains project information for seven of these sites. The post-dredging sample data obtained are provided in Attachment A.

> *Sediments in the majority of target areas in the Upper Hudson are likely to be fine-grained, as were sub-bottom sediments in most of the case study sites.*

The sub-bottom sediments at these sites were fine-grained with some exceptions. The sediments at the sites located in the St. Lawrence River (General Motors Massena and Reynolds Metals) contained gravel and cobbles. The Grasse River removal had rocky conditions. The sediments in the majority of the target areas in the Upper Hudson River are likely to be fine-grained, but there are some coarse-grained sediment areas that will require dredging (excluding the rocky areas consisting of exposed bedrock exempted from dredging by the ROD).

All of the sites required multiple dredging attempts to achieve the clean up goals, except the New Bedford Harbor Pre-Design Test, where no concentration goal was set. It is possible that dredging technology incapable of meeting remediation goals in certain difficult areas was used at the sites where multiple redredging attempts were required. For example, at Reynolds Metals, the most contaminated area had dense non-aqueous phase liquid (DNAPL) contamination within a cobble stratum. This type of contaminated terrain would be difficult to remediate using conventional dredging technologies.

Most of the sites were sampled on a grid. The grid spacing varied from 40 to 100 ft. Core samples were collected from all sites at depths of collection from 4 to 12 inches (in) below the surface. Grab samples were also collected at three of the sites. The depth of the grab samples was specified for two of the sites at 0 to2 centimeters (cm).

All of the sites listed on Table 1-1 have PCB contamination. Of the sites examined only Marathon Battery has another type of contamination, which is cadmium. Six of the sites listed used Aroclors, usually USEPA Method 8082, to quantify the residual contamination. At New Bedford Harbor, 18 congeners were analyzed, and a relationship from a previous effort was used to calculate the concentration of Total PCBs. Two of the four sites that had a target post-excavation concentration were able to achieve the goal.

Figure 2-1 depicts the spatial distribution of the residual concentrations (derived by polygonal declustering analysis) for several of the sites. With the exception of a few locations of higher concentration, in most cases the distribution of the residuals concentrations was heterogeneous.

For Reynolds Metals, the “hottest” (most contaminated) quadrants were located in a small area relative to the entire site. This area was near an outlet and was the most contaminated area in the target area. It was underlain with cobbles and boulders, making the remediation more difficult. There were other sections of the target area with similar bottom conditions, but the sediments were remediated to below 10 mg/kg Total PCBs.

The target concentration for the residual sediment at the Reynolds site was set at 1 mg/kg Total PCBs. For the Hudson River, the Total PCB concentration associated with the Tri+ PCB goal of 1 mg/kg could be approximated as 2.2 mg/kg Total PCB. The average post dredge concentration at Reynolds Metals is 2 mg/kg, indicating that the goal set for the Hudson River remediation has been achieved at another site.

For the Marathon Battery site, most of the area had predredging cadmium concentrations between 3 and 30 mg/kg. The more contaminated samples (>30 mg/kg) were located along the boundaries of the dredging area, with two exceptions. The predredging samples were examined to determine whether there was a relationship between the pre- and post-dredging concentrations for the hotter residual areas (>30 mg/kg). There was a considerable range of predredging sample concentrations (45 mg/kg to 13,800 mg/kg) in the areas with high post-dredging sample concentrations. Other areas of the site having similar concentrations were remediated to concentrations below 30 mg/kg. Most of the residual sediment samples with high cadmium concentrations were located near or outside the boundary of the dredging area. This may indicate that the higher residual results are associated with the estimation and location of the dredging cut lines.

At the Fox River Deposit N site, most of the area was remediated to less than 3 mg/kg PCBs, with the higher residual concentrations coinciding with the areas of higher predredging concentrations. At General Motors (GM) Massena, the dredging successfully reduced the concentrations from greater than 500 mg/kg PCBs to less than 10 mg/kg PCBs in most locations. A portion of the GM Massena site had residual concentrations as high as 6,281 mg/kg and was capped. Both Cumberland Bay and the Fox River Sediment Management Units (SMUs) 56/57 site displayed a heterogeneous distribution of the residual concentrations.

At New Bedford Harbor, the majority of the highly contaminated sediment (>500 mg/kg PCBs) was removed. The few sections of higher contamination in the 0-to-1-ft residual layer appeared to coincide with the predredging hotter areas. The pattern and magnitude of contamination in the 0-to-2-cm residual layer (corresponding to approximately 0-to-1-in) is much different and higher than the 0-to-1-ft layer. This is probably a result of spillage during dredging and sloughing from the sides of the dredge cuts.

The Non-Time-Critical Removal Action (NTCRA) on the Grasse River, performed on only a portion of the site, successfully removed 27% of the contaminant inventory in the river. Dredging was hampered by unexpectedly rocky sub-bottom conditions and a boulder field that ran the length of the targeted area. A target residuals concentration was not specified as a project goal, but the average concentration in post-dredging samples was substantially reduced from the predredging conditions. Predredging core depth varied from 12 to 36 in. The length weighted average (LWA) concentration of the predredging cores gives a measure of the concentration removed by dredging. The average of the LWA values was 801 mg/kg PCBs, with concentrations in individual samples ranging from 12 mg/kg to 11,000 mg/kg. Following dredging, the concentration in the residual layer was 80 mg/kg PCBs on average, with sample concentrations ranging from 11 mg/kg to 260 mg/kg. On average, the contaminant concentration in the targeted sediment was reduced by 90%. A pattern relating the pre- and post-dredging concentrations is not evident.

2.1.3 Action Levels for Average and Individual Sample Concentrations

2.1.3.1 Overview

The Hudson River post-dredging CU residual sample PCB concentrations will be compared to action levels to determine whether the concentrations are within acceptable limits.

The Hudson River post-dredging CU residual sample PCB concentrations will be compared to action levels to determine whether the concentrations are within acceptable limits. Action levels were developed based on the case study residuals data. The ROD states that the anticipated residual concentration will be approximately 1 mg/kg Tri+ PCBs. This implies that the arithmetic average concentration and individual points may exceed 1 mg/kg Tri+ PCBs, and that it is appropriate to develop statistical action levels to evaluate the degree to which the ROD's objective has been achieved in a particular certification unit.

Two types of action levels were developed to assess the Upper Hudson River residuals data. The first type of action level specifies upper bounds on the certification unit's arithmetic average concentration. There will be two numerical action levels for the certification unit arithmetic average, in addition to the ROD's objective of approximately 1 mg/kg Tri+ PCBs, as listed below:

- An average concentration at or below 1 mg/kg Tri+ PCBs.

- An acceptable upper limit below which the area could be backfilled (with testing of the backfill surface concentration required) without requiring redredging.

- An unacceptably high limit, below which either redredging or construction of a subaqueous cap would be required, and above which redredging would be required.

The second type of action level is an upper bound concentration for an individual sample result. There will be two numerical action levels for individual samples (also referred to as sampling nodes).

- The lower of the two action levels can be exceeded at only one sampling node in a certification unit.

- The higher of the two action levels cannot be exceeded at any sampling nodes in a certification unit.

Non-compliant individual sampling nodes will be addressed by redredging or capping, based on the average concentration of the CU and the number of redredging attempts already conducted.

The action levels were calculated based on the case study data, using a variety of statistical approaches to determine interval estimates (upper confidence limits and prediction limits). The 95% upper confidence limit (95% UCL) on the mean (*i.e.*, arithmetic average) is the upper bound of the interval that would contain the true mean of the population 95% of the time if the sampling process could be repeated an infinite number of times. The 97.5% prediction limit (97.5% PL) considers the value of individual responses. This interval considers the relationship between the estimation of the true arithmetic average (mean) value of the certification unit and the variability of the individual responses around the mean. If a new observation comes from the same distribution as the previously collected data, there is only a 2.5% chance that it will be outside the 97.5% prediction level. In a similar manner, the 99% UCL and 99% PL values were also calculated.

These interval estimates will be the bases for the action levels set for the Residuals Standard. The intention is to establish action levels that, when exceeded in residuals sampling, clearly indicate that the ROD's objective of approximately 1 mg/kg Tri+ PCBs has not been achieved. The UCL represents the upper bound on the average concentration and the PL represents the upper bound for any individual concentration. The 95% UCL will be used as a limit for acceptable average concentrations in a target area. The 99%

UCL will be used to determine if a target area has an unacceptably high average concentration.

The 97.5% PL and 99% PL will be developed as additional checks on the true arithmetic average of the certification unit, using the individual sample results obtained. Finding samples in excess of the PL criteria indicate a significant probability that the ROD's objective of 1 mg/kg Tri+ PCBs has not been achieved because the data indicate that the distribution is more variable than anticipated. One point in a target area will be allowed to exceed the 97.5% PL value. These statistics indicate that 2.5% of the sampling locations (or 1 of 40 samples) could be greater than this value and the average concentration could still be in compliance. No points will be allowed to exceed the 99% PL.

As noted above, potentially applicable interval estimates were calculated from the case study data by a variety of means. The case study data were used to obtain estimated UCLs and PLs for evaluation of Upper Hudson River post-dredging residuals because no residuals data will be available from the Upper Hudson River until the dredging project commences. Final action levels were selected based on weight of evidence.

The first of multiple possible approaches to this weight of evidence analysis relies on analysis of the UCLs and PLs obtained in the individual case studies. The UCLs and PLs from each case study are not directly usable, as these values were obtained from a wide variety of sites with differing targets and different residual concentrations. To convert the individual case study results to a common basis, this approach assumed that the distribution of the residuals for the Upper Hudson River would be similar and proportional to the case study residual sample distribution; therefore, the UCL and PL action levels for the Upper Hudson River can be estimated using the following equation:

$$M_{cs} / M_{hr} = L_{cs}/L_{hr} \qquad (1)$$

where:

M_{cs} = the mean of the case study data,
M_{hr} = the mean of the Upper Hudson River data (the anticipated average concentration for the residuals is 1 mg/kg Tri+ PCBs),
L_{cs} = the limit (confidence or prediction) of the case study data, and
L_{hr} = the limit (confidence or prediction) of the Upper Hudson River data.

This approach is based on the observation that, in general, the mean and standard deviation of environmental data sets show some degree of proportionality. A problem with this approach is that both the UCL and PL equations have dependence on the sample size. As an alternative approach, the action levels were estimated by substituting the mean (1 ppm) and sample size (40) that are expected in the Upper Hudson River CUs and an estimate of variance from the case studies into the equations for the UCL and PL. Several variants on this approach are summarized below.

2.1.3.2 Analyses

The statistics were calculated using Pro-UCL (USEPA, 2001) for the assessment of the distribution and the UCLs. Statistics for each data set are presented in Table 2-1.

The Shapiro-Wilks W test was used to test normality and lognormality for data sets with 50 or fewer samples. The Lilliefors test was used to test normality and lognormality for data sets with more than 50 samples. The results are summarized in Table 2-2. Quantile-Quantile (Q-Q) plots were also used to test for approximate lognormality of the data distributions (Figure 2-2). These plots provide a simple graphical approach to test for approximate lognormality of the data distributions.

Pro-UCL was used to calculate the UCLs for the case study data using lognormal and nonparametric equations. A recommendation for the appropriate 95% UCL equation is given by Pro-UCL, depending on the number of samples and the standard deviation for the lognormal data sets. For the lognormal distributions, the 99% UCL Chebyshev (Mean, Std) equation for lognormal data was used. For the nonparametric UCLs, the 95% and 99% Chebyshev (Mean, Std) values for nonparametric data were used.

The following equations were used to estimate the UCLs and PLs when substituting the mean, number of samples, and variance. The Chebyshev (Mean, Std) UCL for non-parametric data is as follows:

$$UCL = \bar{x} + \frac{S_x \sqrt{((1/\alpha)-1)}}{\sqrt{n}} \qquad (2)$$

where:

$\bar{x}$	=	the arithmetic average
S_x	=	the standard deviation
α	=	defined such that 100*(1-α) is the confidence limit required
n	=	the number of measurements

An equation for the UCL, assuming the data are lognormal, is Land's method (Gilbert, 1987):

$$UCL = e^{\left(\bar{y} + 0.5 \cdot S_y^2 + \frac{S_y \cdot H_{1-\alpha}}{\sqrt{n-1}}\right)} \qquad (3)$$

where:

$\bar{y}$	=	the average of the log values
S_y	=	the standard deviation of the log values
$H_{1-\alpha}$	=	quantities found in the tables provided in Land (1975)
α	=	defined such that 100*(1-α) is the confidence limit required
n	=	the number of measurements

The prediction limit for nonparametric data is the percentile. For nonparametric data and α of 0.05, the prediction interval is the 95th percentile.

The parametric asymmetric prediction interval was computed assuming the data follow a lognormal distribution:

$$PL = e^{\left(\bar{y} + t(\alpha, n-1)\cdot\sqrt{s_y^2 + \frac{s_y^2}{n}}\right)} \qquad (4)$$

where:

$\bar{y}$	=	the mean of the log values
α	=	defined such that 100*(1-α) is the confidence limit required
s_y^2	=	the variance of the log values
n	=	the number of measurements
t	=	the Students t value from a table (Gilbert, 1987)

The central tendency for the lognormally distributed and nonparametric data required in Equation 1 was either the arithmetic mean or the minimum unbiased estimator of the mean (MVUE), depending on the amount of skew in the distribution. If the coefficient of variation was greater than 1.2, the MVUE was used; otherwise, the arithmetic mean was used (Gilbert, 1987). The sample geometric mean is not appropriate for Equation 1, because it is a biased estimator of the mean, tending to underestimate the true mean. The MVUE is calculated as follows:

$$MVUE = \left[\exp(\bar{y})\right]\Psi_n\left(\frac{s_y^2}{2}\right) \qquad (5)$$

where:

$\exp(\bar{y})$	=	the geometric mean of the data
s_y^2	=	the variance of the logarithms of the data
Ψ_n	=	the infinite series defined as:

$$\Psi_n(t) = 1 + \frac{(n-1)t}{n} + \frac{(n-1)^3 t^2}{2!\,n^2(n+1)} + \frac{(n-1)^5 t^3}{3!\,n^3(n+1)(n+3)} + \frac{(n-1)^7 t^4}{4!\,n^4(n+1)(n+3)(n+5)} + \ldots$$

t = $\dfrac{s_y^2}{2}$

All sample points were used from each case study except for areas of the Reynolds Metals and GM Massena sites. One sample from the Reynolds Metals site had a concentration of 5,941 mg/kg PCBs, which is 50 times higher than the next largest sample. This result can be reasonably omitted because the bottom conditions in that area, a boulder field with DNAPL contamination, are not representative of the Upper Hudson River, which is not expected to have DNAPL contamination.

Quadrant 3 of the GM Massena site had elevated concentrations and was capped. Samples from the capped area were not used in the development of the single estimate of variance based on the case studies because these data represent an extreme condition, with concentrations as high as 6,281 mg/kg PCBs. This level of residual contamination is not expected to routinely occur during remediation of the Upper Hudson River. These samples were included in the summary statistics for each of the multiple passes in order to provide an example of the effect of redredging passes on the concentration levels.

Summary statistics are provided for the New Bedford Harbor grab samples, but are not used to estimate action levels due to the interval sampled. These samples were collected to characterize the concentrations caused by spillage in the topmost layer (0 to 2 cm). Because the residual samples for the Upper Hudson River will be collected from the 0-to-6-in interval to characterize residual concentrations that are not merely a result of spillage (*e.g.*, sloughing, homogenization of the sediment, etc.), the New Bedford Harbor grab samples are not comparable. The 1-ft-thick core samples from the same New Bedford Harbor study were used instead.

Data from the Grasse River have been included in some of the calculations where the data have been lognormally transformed. The untransformed data were not included in the calculations because the residual concentrations differ greatly in magnitude from the other case study sites. The Mahalanobis jackknife distances test for outliers shows the mean and standard deviation to be possible outliers (Figure 2-3). The concentrations are not comparable to the other sites, because the bottom conditions were not conducive to conventional dredging and the primary goal of the remediation was inventory removal, not concentration reduction.

Variance in the case study samples appears to increase with mean concentration, a phenomenon commonly observed in environmental monitoring data (heteroscedasticity). Two approaches were used to obtain summary estimates of variability from the case study data. First, a simple linear regression analysis provided an estimate of the variance from the case study data as a function of the untransformed mean. With this estimate of the variance (S_X), the UCL can be calculated using the nonparametric Chebyshev equation (Equation 2). (The linear fit and 95% confidence curves on the line of fit were calculated using JMP software.)

The second approach follows from the observation that a lognormal transformation provides a better approximation to the observed distributions than the normal and also reduces the dependence of the variance on the mean. Therefore, the average of the standard deviation of the logarithms from the case studies can be used as an estimate of the expected standard deviation of logarithms (S_y) in the Upper Hudson River, and the upper confidence limit equation for lognormal data (Equation 3) and the parametric asymmetric prediction limit equation (Equation 4) can be applied.

2.1.3.3 Results

The statistics for each case study are summarized in Table 2-2. The site-specific UCL and PL values are presented for the distribution specified or for the nonparametric case if the data are not normal or lognormal. Examination of the Q-Q plots for the log-transformed data shows a somewhat linear pattern with high correlation coefficients. Of the Q-Q plots shown, seven of ten data sets have correlation coefficients greater than 0.95, which is indicative of data that are approximately lognormal (USEPA, 2001). The Grasse River is the only site that may be normally distributed.

Histograms of the untransformed data and the log-transformed data for each of the data sets are presented in Figure 2-4. For most of the sites, the log-transformed data show a more normally shaped distribution. Although most of the data sets were not lognormal according to Lilliefors Test, from review of the Q-Q plots and the histograms, most of the data sets appear to be approximately lognormal.

Residual concentration values following multiple redredging attempts at the GM Massena site show the effect on the average concentration with each additional redredging attempt. The difference in concentration between the first and second attempts was the most significant: 93.5 to 34.5 mg/kg on average. For the remaining attempts, the decrease was less pronounced, and from the fifth to the sixth attempt, the average concentration actually increased. The reduction in contamination experienced at the GM Massena site is associated with the type of dredge selected and the river conditions, which may differ at the Upper Hudson River site. It cannot be inferred that the Upper Hudson River residual concentrations will decrease in a similar manner, but this gives an indication of what might occur in portions of the river during the remediation.

Table 2-2 also contains UCL and PL estimates for the Upper Hudson River, and presents the value based on proportionality and the value based on substitution for each site. The Chebyshev nonparametric UCL equation (Equation 2) was chosen because most of the case studies are not strictly normal or lognormal based on the test for normality. The parametric asymmetric PL equation (Equation 4) was chosen because the data appear to be approximately lognormal for most of the sites and the nonparametric PL is calculated with the percentile, which would not be useable for substitution.

For the substitution approach, the controlling factor is the case study site standard deviation. The proportionality approach yields Tri+ PCB values ranging from:

- 1 to 3 mg/kg for the 95% UCL
- 2 to 6 mg/kg for the 99% UCL
- 3 to 15 mg/kg for the 97.5% PL
- 4 to 23 for the 99% PL

The substitution approach yields Tri+ PCB values ranging from:

- 3 to 24 mg/kg for the 95% UCL
- 5 to 54 mg/kg for the 99% UCL
- 7 to 25 mg/kg for the 97.5% PL
- 10 to 48 mg/kg for the 99% PL.

With this range of estimated values, it is difficult to select any single value to represent the expected post-dredging Upper Hudson River conditions. The substitution approach could be used most effectively if a best estimate of the standard deviation of the residuals is determined. A linear regression of the arithmetic mean and standard deviation provided this value. Scatter plots of the case study data are shown in Figure 2-5. The GM Massena data, including the uncapped area, and the New Bedford Harbor grab sample estimates are identified on the top graph. Most of the GM Massena attempts and the New Bedford Harbor grab samples are distant from the values for the other data sets. For this analysis, only one estimate of the mean and standard deviation will be used per site, in order to not heavily weight the results with the data from a single site. For the reasons given in Section 2.1.3.2, the New Bedford Harbor grab samples, GM Massena capped area, and Grasse River site data are not included in the regression.

The simple linear regression of these variables shows the mean and standard deviation to be related and have a good fit with a R^2 of 0.92. This is plotted in the lower graph of Figure 2-5. At a mean of 1 mg/kg Tri+ PCBs, the standard deviation based on the linear regression is 3. Substituting this standard deviation into the Chebyshev nonparametric UCL equation produces Tri+ PCB estimates of 3 mg/kg for the 95% UCL and 6 mg/kg for the 99% UCL.

A second estimate of expected variability was obtained using the standard deviation of the log-transformed data (S_y) from the case studies. A linear regression of the arithmetic mean and S_y was attempted, but was not found to be predictive. A plot of the mean vs. S_y is shown in Figure 2-6. These plots show that S_y has only a weak dependence on the mean. To estimate this value for the Upper Hudson River, the average of the S_y values for the eight sites will be used to get a second estimate of the action levels.

UCLs were calculated by substituting:

- The average S_y value, 1.3, 0 (the natural log of 1 mg/kg) for $\bar{y}$
- 40 for n
- The appropriate value for $H_{1-\alpha}$ (2.731 for $\alpha = 0.05$ and 4.560 for $\alpha = 0.01$) into the UCL equation for lognormally distributed data (Equation 3).

This produces Tri+ PCB values for the 95% UCL of 4 mg/kg and the 99% UCL of 6 mg/kg.

A value for the 97.5% PL can be estimated using the asymmetric parametric prediction limit equation (Equation 4) and substituting

- 1.3 for S_y, 0 for $\bar{y}$
- 40 for n
- 2.023 for t

This produces a 97.5% PL of 15 mg/kg Tri+ PCBs. For the 99% PL, t is 2.426, giving a value of 27 mg/kg Tri+ PCBs. Another, simpler approach will be taken for the PLs: the average PL of the seven sites was calculated using substitution. The individual PL values are shown on Table 2-2. The average 97.5% PL is 15 mg/kg Tri+ PCBs and the average 99% PL is 25 mg/L Tri+ PCBs.

Table 2-3 contains a summary of the UCL and PL values calculated using a single estimate of the variance from the case studies, where possible. The range of UCL and PL values estimated using the variance from the individual case studies is shown for comparison. Even with four different approaches to estimating the thresholds, the values are similar among these approaches for each statistic.

For the 95% UCL, Tri+ PCB values of 3 mg/kg and 4 mg/kg were calculated. The lower value of 3 mg/kg Tri+ PCBs was chosen to be conservative because, under specific conditions, a target area may be backfilled (with testing of the backfill surface concentration required) if the area weighted concentration is as high as the 95% UCL.

For the 99% UCL, both means of calculating this gave 6 mg/kg Tri+ PCBs. An average concentration less than 6 mg/kg should be attainable in most cases, considering the high percent reduction in inventory found at other sites (USEPA, 2002).

For the 97.5% PL, 15 mg/kg Tri+ PCBs was calculated using both approaches. For the 99% PL, values of 25 mg/kg and 27 mg/kg were calculated. The higher value of 27 mg/kg Tri+ PCBs was chosen to balance the Residuals Standard with dredging productivity goals.

2.1.3.4 Summary of Action Levels

The action levels that will be used to evaluate the Phase 1 residuals data for the Upper Hudson River are as follows:

Action Level	Value (mg/kg Tri+ PCBs)	Point of Compliance (1)
ROD's objective	1	CU arithmetic average
95% UCL	3	CU arithmetic average
99% UCL	6	CU arithmetic average
97.5% PL	15	Individual sample result
99% PL	27	Individual sample result

(1) Note that although the residual case study data are typically approximately lognormal, the arithmetic mean is the statistic on which to judge compliance with the standard. The arithmetic mean provides a measure that integrates the impact of the residual contamination whereas the geometric mean or median would provide the best estimate of the central tendency of the concentrations.

2.2 Relevance of the PL Criteria

The Residuals Standard is based on average Tri+ PCB concentrations in the certification unit. Because compliance with the Residuals Standard is based on a relatively small number of samples from a heterogeneous medium, the possibility exists that the mean calculated from the sampling results will meet the action level, but the true mean will not. The PL action levels were developed as additional checks on the true mean's compliance. Essentially, the PL action levels are individual sample values that have a low degree of probability of occurring if the true population mean is compliant. Finding samples in excess of the PL criteria indicates a significant probability that the ROD's objective of approximately 1 mg/kg Tri+ PCBs is not achieved, and is thus a rationale for focused redredging. A secondary benefit of the PL action levels is that their application will minimize the possibility for areas of elevated concentration to remain in the remediated area.

2.3 Estimate of Redredging Area by Percent Reduction in PCBs

Historical sediment sampling data can be used to estimate the Tri+ PCB concentrations in a hypothetical 6-in-thick residual sediment layer, assuming a certain percent reduction in PCB contamination (*e.g.*, 95% or 99% reduction) accomplished by the first dredging attempt, and also assuming that the residual layer contains the remainder of the PCB contamination. The estimated concentrations can be used to forecast the percent of the dredged area that will require redredging or capping. The NYSDEC 1984 sediment samples provide the most comprehensive coverage of the Upper River available prior to completion of the GE Sediment Sampling and Analysis Program (SSAP), with the samples concentrated in the TI Pool. These samples provide an estimate that can be applied to all river sections.

The 1984 samples were analyzed with a method that captured the Tri+ PCB fraction. Total PCB concentrations were estimated using the method outlined in the *White Paper - Relationship Between Tri+ and Total PCBs* in the *Responsiveness Summary to the ROD* (USEPA, 2002). Polygonal declustering was used to estimate the spatial extent of the contamination (USEPA, 1999). The area was further limited to the target areas defined in the FS for the remedy selected in the ROD.

Mass per unit area (MPA) is calculated with:

$$MPA(g/sq.m) = \sum_{i=1}^{n} C_i\left(\frac{mg}{kg_{DW}}\right)\cdot L_i(cm)\cdot SSW_i\left(\frac{g_{DW}}{cc}\right)\cdot\frac{1kg}{1000g}\cdot\frac{1g}{1000mg}\cdot\left(100\frac{cm}{m}\right)^2 \quad (6)$$

where:

C_i	-	the Total PCB concentration in the core segment in mg/kg dry weight (mg/kg)
L_i	-	the length of the core segment in cm
SSW_i	-	the mass of dry solids per unit wet core volume in $\frac{g_{dryweight}}{cc}$
n	-	the number of segments in the core analyzed for PCBs

Tri+ PCB concentrations representing a fraction of the inventory remaining were calculated by solving Equation 6 for concentration and substituting 6 inches for L, the length-weighted average solid specific weight (SSW) for that location, and the Total PCB MPA for each location multiplied by the percentage of the inventory remaining. The Tri+ PCB concentrations were calculated for 1%, 5%, and 10% contamination remaining in the residual layer. Figure 2-7 shows the spatial distribution of the concentration levels in the target areas for each percent inventory remaining listed above. Areas requiring additional redredging or capping are located throughout the target area and are not limited to a few hot spots.

The calculated percentages of dredged area expected to have Tri+ PCB concentrations that comply with the Residuals Standard's action levels are listed in Table 2-5. For a 6-in-thick residuals layer:

- If 99% removal can be achieved, only 9% of the area will require additional treatment (*e.g.*, re-dredging).
- If 95% removal can be achieved
  - 58% of the area will require no additional treatment.

– 25% of the area can be considered for backfilling (with backfill testing required).
– 5% could be capped immediately.
– 11% would require redredging.

A remedial goal of this project is removal of 95% to 98% of inventory (USEPA, 2002). Review of the case study data has shown that, generally, this level of removal has been achieved at other sites, some with more difficult environmental conditions than those expected in the Upper Hudson River (USEPA, 2002).

Case study data show that the remedial goal of this project, removal of 95% to 98% of inventory, has been achieved at other sites.

The tiered action levels in the standard provide flexibility in the approach to the remediation, with a mandatory redredging requirement (certification unit mean, *i.e.*, arithmetic average > 6 ppm) for only 11% of the targeted area if 95% of the contamination is removed by appropriately designing and subsequently meeting the design cut lines through the first dredging attempt. Capping or backfilling (with required testing of the backfill surface concentrations) are options for the remaining 30% of the target areas with average concentrations greater than 1 mg/kg Tri+ PCBs and less than or equal to 6 mg/kg Tri+ PCBs. Appropriate selection of the cut lines will be an important factor in minimizing the number of redredging attempts.

2.4 Estimate of Redredging Area Resulting from the PL Action Levels

The re-dredging area resulting from the application of the PL action levels in the Residuals Standard can be projected, because each 0-6 inch residual sample can be considered compliant or non-compliant depending on the measured concentration. If the concentration is less than the PL, it is compliant. If the residual concentrations conform to the desired distribution with a mean value of 1 mg/kg Tri+ PCBs, then there is a 97.5 percent probability of each sample to comply with the 97.5% PL (*i.e.*, the sample result is less than the 97.5% PL) and a 99 percent probability of each sample to comply with the 99% PL. The result of each sample is independent from the other samples. The binomial distribution can be used to estimate the probability that a number of samples will be non-compliant:

$$p(x) = p(y = n - x) = \frac{n!}{y!(n-y)!}\, p^{y} \left(1 - p\right)^{n-y} \quad \textbf{(7)}$$

where:

p = probability of compliance (0.975 or 0.99)

n = number of trials per CU (40)

y = number of samples less than the target

x = n – y, the number of non-compliant samples

Table 2-5 contains the probabilities for non-compliance of 0 to 40 nodes at the PL action levels, for both the 97.5% PL and the 99% PL. The probability for 1 to 40 non-compliant sampling nodes is shown even though more than 3 sampling nodes in a CU with concentrations at or above 97.5% PL will result in an estimated average concentration greater than 1 mg/kg Tri+ PCBs. The Residuals Standard permits one sampling node to exceed the 97.5% PL. According to the foregoing equation, there is a 73.6% probability (36.3% + 37.3%) that none or only 1 sampling node will exceed the 97.5% PL, and 27.0% of the areas with one exceedance of the 97.5% PL will fail for the 99% PL. This leads to the conclusion that 46.6% (73.6% - 27.0%) of the CUs with an areal average of 1 mg/kg Tri+ PCBs will not have exceedances of the PLs.

Conservative estimates indicate that exceedances of the PL action levels will require redredging or capping of 33 acres, or 8% of the total area targeted for removal.

Assuming that each non-compliant node will require dredging to the surrounding nodes that are located 80 ft away, the area of redredging for each node is 0.38 acres. Using the probabilities of the binomial distribution and assuming that a total of 100 CUs will be dredged, exceedances of the PL action levels will require redredging or capping of 33 acres. For the selected remedy, the area dredged for contaminant removal was estimated to be 432 acres. Thirty-three acres is equivalent to 8% of the total area targeted for removal. This estimate of the non-compliant area is conservative, because it assumes that there is no spatial correlation between the nodes.

2.5 Achievement of 1 mg/kg Tri+ PCBs Residual Concentrations

Removal of PCBs in a target area should be achievable if the design of the cut lines factors in a sufficient overcut, because the sediment deposition rates in the river are relatively low and the majority of the PCB contamination is located within a foot or so of the sediment surface. A means of determining the cut lines during design should take into account methods and reasoning described in the FS and the *White Paper – Post-Dredging PCB Residuals of the Responsiveness Summary* (USEPA, 2002). The goal of the remediation is a 96% to 98% reduction in PCB concentration. Reductions of similar magnitude have been found at other projects, some with more difficult environmental conditions. The reductions in concentration found at other dredging projects are:

- Grasse River 90%
- GM Massena 99%
- Fox River SMUs 56/57 90%
- Cumberland Bay 98 %
- New Bedford Harbor 97% (0-to-1-ft layer)

- Marathon Battery 99.6%
- Lake Jarnsjon 99%

Two of the sites, the Grasse River and Fox River, have comparatively lower percent reductions in contaminant concentration. For the Grasse River, inventory removal was the primary goal. For the Fox River, the goal was to reduce Total PCB concentration. While this goal was met (see Table 1-1), this translated to a relatively low percent reduction in concentration. The average Total PCB concentrations of *in situ* material in the targeted areas in River Sections 1 and 2 of the Upper Hudson River are estimated at approximately 27 mg/kg and 60 mg/kg, respectively, with the average concentration in River Section 3 similar to River Section 1. If a 96 percent reduction of concentration is achieved in these river sections, the Total PCB residual concentrations will be 1.4 mg/kg in River Section 1 and 2.4 mg/kg in River Section 2. Using a factor of 2.2 to convert the Total PCB concentrations to Tri+ PCBs (USEPA, 2002), the Tri+ PCB residual concentrations would be 0.6 mg/kg in River Section 1 and 1 mg/kg in River Section 2. Reduction of concentrations by percentages similar to those achieved at case study sites will result in residual concentrations that are in compliance with the ROD.

2.6 Size of Certification Units

The certification unit size was estimated in the FS based on the 45 known target areas. The average size of these areas is 5 acres. The size of the target areas ranges from 0.5 acres to 122 acres, but 34 of the 45 target areas have an area of 6 acres or less. Five acres was selected as the typical size for the CUs on this basis.

2.7 Number of Samples Per Certification Unit

The sampling frequency required to provide the best estimate of the central tendency of the residuals data was calculated using the variances from the case study residuals data. Estimates of the sampling frequency were made by:

- Determining the number of samples required to measure the central tendency with a degree of certainty.

- Determining the number of samples required to be confident that the contamination at depth had been identified.

- Using USEPA's Data Quality Objectives Decision Error Feasibility Trials Software (DEFT), (USEPA 2001b).

It was assumed that the residuals data from the Upper Hudson River are best approximated by a lognormal distribution.

For a lognormal distribution, the sample median is an estimate of the population geometric mean. The number of samples required to estimate the median value of a lognormal distribution can be determined if some measure of the variance can be made. The variances calculated from the case study data can be used in this calculation. From Gilbert (1987), the number of independent observations, n, required from a population (*i.e.*, the number of cores from a certification unit) equal to:

$$n = \frac{Z_{1-\alpha}^2 S_y^2}{\left[\ln(d+1)\right]^2 + Z_{1-\alpha}^2 S_y^2 / N} \qquad (8)$$

where:

S_y^2 = variance of the data

Z = the Z-score based on α

α = defined such that 100*(1-α) is the confidence limit required (Type 1 error probability)

N = total population

d = the error in the median which can be tolerated

Because the calculation is only concerned with exceedance of a threshold, a one-sided test was used. For a 95% confidence limit Z=1.65. The median is expected to be less than the arithmetic mean for a lognormal distribution, but a percentage error in estimation of the median is expected to yield a similar percentage error in estimation of the mean. A maximum 50% error in the estimate of the median is assumed to be tolerable, so d=0.5. Since N represents all possible cores from a certification unit (five acres), N is very large and approaches infinity.

Table 2-6 contains estimates of the number of samples required using this equation for each of the case studies. The number of samples ranges from 15 to 41, with a mean value of 34 for the selected data sets. The number of samples required for the data sets that were not used to develop the action levels, ranging from ranges from 34 to 92 samples, is also shown (GM Massena, including the capped area, and the New Bedford Harbor grab samples).

For comparison, using the standard deviation of 1.46 from the 1984 New York State Department of Environmental Conservation (NYSDEC) samples that were contained within the Expanded Hot Spot remediation areas defined in the FS, and assuming that the standard deviation of residuals will be similar, the number of samples is 36. Using the value of S_y for the eight sites of 1.31 as previously discussed, the resulting sample size is 28. Given the variability in estimates, a sample size of 40 is chosen to provide a safety factor on the tolerable error.

In the FS, the number of samples needed to properly characterize the existing conditions was estimated using the foregoing Equation (8) from Gilbert (1987) and a statistical analysis of the sampling requirements needed to assess depth of sediment removal. This second analysis was highly dependent on the method that will be used during design to select the cut line depths in the target areas.

USEPA's DEFT Software was also used to estimate the sampling frequency for this program. The results of this analysis are presented below.

Units: ppm	
Action Level (Mean)	1
Baseline Condition	Mean <= 1
Standard Deviation	3

Gray Area	1-1.5	1-1.5	1-2.4
False Rejection	0.1	0.3	0.1
False Acceptance	0.05	0.3	0.05
Number of Samples	**310**	**40**	**41**

The action level is the Residuals Standard. The baseline condition occurs when the mean is below or equal to the Residuals Standard. The standard deviation is the value calculated from the case study data. As defined in USEPA (2001b):

> The *gray region* is a range of true parameter values within the alternative condition near the action level where it is "too close to call." For the Residuals Standard, the gray region is between 1 and 1.5, values that will round to 1 ppm.
>
> A *false rejection* decision error occurs when the limited amount of sample data indicate that the baseline condition is probably false when it is really true.
>
> A *false acceptance* decision error occurs when the sample data indicate that the baseline condition is probably true when it is really false. False acceptances should be minimized because this is the more serious error.

In general, decisions that are critical, such as confirmation of exceedance of the Residuals Standard, which requires redredging or capping if the baseline conditions are not met, would need to have a large number of samples so that the decision can be made with certainty. For the residual sediment concentration measurements, a reasonable amount of certainty in these decisions is needed. For a false rejection rate of 10% and a false acceptance rate of 5%, 310 samples would be needed per CU. Approximately 40 samples are acceptable only if much lower false rejection and false acceptance rates are tolerable (30 percent) or if the gray region is increased (1 to 2.4 ppm).

Neither of these lower levels of certainty is acceptable, but it is not practical to collect 310 samples per CU. As a compromise, 40 samples will be collected per CU, but the additional restrictions requiring individual nodes to be below the prediction limits gives added certainty that the true mean does in fact meet the baseline conditions. A confident estimate of the average residual concentration can only be made by averaging the concentrations over a group of CUs. The standard provides this level of confidence by requiring consideration of joint evaluation areas. For Phase 1, joint evaluation of a 20-acre area will permit review of approximately 160 samples with a false rejection rate of 10% and a false acceptance rate of 21%. If the joint evaluation area is increased to 40 acres in Phase 2, approximately 320 samples will be collected allowing the mean to be measured with a high level of confidence (false rejection rate of 10% and a false acceptance rate of 5%).

Both the current assessment and that developed in the FS justify a sample size of approximately 40 samples per target area. Using the case study variances yields sample frequencies that are in a similar range. Within a 5-acre certification unit, the uniform triangular grid spacing is 80 ft on center. This is also in the range of sample grids spacing for the case studies shown on Table 2-1. Assessment of the case study data supports the use of 40 samples per 5-acre certification unit.

2.8 Case Study Data Geostatistical Analysis

The spatial correlation of residual data from the case study sites was evaluated to determine whether a correlation could be found that would support the development of an asymmetrical residual sediment sampling grid for the Hudson River PCBs Superfund project. To evaluate the spatial correlation of residual sediment data, semi-variograms of post-dredging sediment data from the following dredging projects were generated:

- Reynolds Metals
- Marathon Battery
- New Bedford Harbor (grab and sediment core samples)
- Cumberland Bay
- Fox River SMUs 56/57
- Fox River Deposit N
- GM Massena

A similar geostatistical analysis was performed on the Upper Hudson River historical data because hot-spot areas appeared elongated in the direction of the river flow, as opposed to perpendicular to the direction of the river flow. These depositional patterns indicated that PCB concentrations in hot spot areas might exhibit a directional correlation that could be quantified using a semi-variogram. The residual data from Reynolds Metals, Marathon Battery, New Bedford Harbor, Cumberland Bay, Fox River Deposit N, Fox

River SMUs 56/57, and GM Massena were evaluated using a similar approach to determine whether these data exhibited any directional or spatial correlation. It should be noted that some of the figures associated with this section of the document show only the relative sampling positions and detected concentrations for case study residual sampling datasets because base maps were not available.

2.8.1 Reynolds Metals

The Reynolds Metals site has a number of characteristics that are similar to the Hudson River PCBs site, among them the facts that the contaminants included PCBs and the spatial distribution of PCB data appeared to be similar to the Upper Hudson River hot spots. Figure 2-8 shows the distribution of total PCB concentrations in the residual sediments. The grid used for residual sampling was triangular, with 50-ft spacing in the hot-spot area and 70 ft on the periphery.

A directional semi-variogram analysis was conducted. A preferential direction was identified in the direction of the grid length, which was assumed to be in the direction of the river flow. The semi-variogram in the direction perpendicular to the assumed current showed no spatial correlation. As shown on Figure 2-8, the range of the semi-variogram in the direction of the river flow was approximately 130 ft.

Although the predredging data were not reviewed for this analysis, the post-dredging persistence of the river flow-related directional correlation at Reynolds may be due to difficulties experienced during dredging (*e.g.*, an inability to remove the contaminated material) or because residual contamination may be spatially correlated with the original contamination. Whatever the reason, the semi-variogram did show a preferential (directional) spatial correlation in the data, so such an analysis could be used to target additional dredging areas.

2.8.2 East Foundry Cove/Marathon Battery

Residual sediment samples were collected in the East Foundry Cove area where sediments containing elevated concentrations of cadmium had been dredged. Sediment samples were collected using coring devices on a 50 by 50-ft grid. One sample from the upper 6 in of each core was analyzed for cadmium. Figure 2-9 shows the distribution of cadmium concentrations in these shallow sediment samples. The highest residual concentration was located in the north-central portion of East Foundry Cove, and at least five other areas of elevated cadmium concentrations were identified. These areas appeared to be randomly distributed throughout the overall sampling area.

Directional semi-variograms were generated for this evaluation at 15-degree intervals. There was no preferential correlation in any one direction. Using all directions, no spatial correlation was identified in the data on the 50 by 50-ft grid spacing. The lack of correlation is illustrated in Figure 2-9, which shows the best-fit semi-variogram with a nugget of 92 and a contribution (sill) of 112. The nugget represents the inherent variance in the data at a distance of zero and the contribution is the average variance of the data. When the percentage of the nugget value is relatively high compared to the sill value, the data set has a high inherent variance and no spatial correlation. Therefore, cadmium concentrations in residual sediment samples at East Foundry Cove (using a 50 by 50-ft grid) appear to be lacking spatial correlation and may be distributed randomly.

To check the correlation at larger sample spacing, the data set was thinned so that sample results at 100 by 100-ft spacing could be statistically evaluated. Like the data on the finer 50 by 50-ft grid, these data showed no spatial correlation.

2.8.3 New Bedford Harbor Grab Samples

At the New Bedford Harbor site, 35 grab samples were collected and analyzed for total PCBs. The spatial distribution of the New Bedford samples is shown in Figures 2-10, 2-11 (grab samples), and 2-12 (core samples, discussed below). The samples were collected on an approximately 40-ft triangular grid with a clustering of additional grab samples in the northwestern corner of the site. Total PCB concentrations ranged from 0.47 to 470 mg/kg. The semi-variogram in Figure 2-11 shows that the PCB concentrations in the grab samples have no spatial correlation.

2.8.4 New Bedford Harbor Core Samples

Eighteen core samples were collected on a 40-ft triangular grid from the New Bedford Harbor site and analyzed for Total PCBs. Spatial distribution of these core samples is shown on Figure 2-12. Total PCB concentrations ranged from 0.67 to 130 mg/kg. No clustering of samples with similar concentrations was apparent. A semi-variogram was generated (Figure 2-12) and shows that there is no spatial correlation in the data.

2.8.5 Cumberland Bay

PCBs were analyzed in 55 sediment samples collected at the Cumberland Bay site in New York. Spatial distribution of the Cumberland Bay samples is shown on Figure 2-13. Samples were collected in what appears to be a random pattern throughout the site. PCB concentrations ranged from 0.09 to 61.9 mg/kg. The non-directional (all directions) semi-variogram of these data shows spatial correlation (Figure 2-13). Directional semi-variograms were generated at 15-degree intervals, but no preferential correlation was apparent in any one direction. The best-fit semi-variogram had a nugget of 0, a contribution (sill) of 130, and a range of 280 ft.

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2.8.6 Fox River Deposit N

A total of 37 sediment samples were collected and analyzed for PCBs from the Fox River Deposit N site in Wisconsin. Spatial distribution of the Fox River Deposit N samples is shown on Figure 2-14. The sampling points generally followed the bend in the river and two separate areas were represented. Spacing of samples was between 25 and 50 ft perpendicular to the river channel and 75 to 150 ft parallel to the river channel. PCB concentrations ranged from 0 to 43 mg/kg. The semi-variogram in Figure 2-14 shows that there is a non-directional spatial correlation in these data. Directional semi-variograms were generated at 15-degree intervals, but no preferential correlation was apparent in any one direction. The best-fit semi-variogram had a nugget of 0, a contribution (sill) of 120, and a range of 55 ft.

2.8.7 Fox River SMUs 56/57

At the Fox River SMUs 56/57 sites in Wisconsin, 28 core samples were collected in what appears to have been a random manner and analyzed for Total PCBs. The spatial distribution of the Fox River SMUs 56/57 samples is shown on Figure 2-15. PCB concentrations ranged from 0.0038 to 9.5 mg/kg. The higher concentrations were not clustered. The semi-variogram (Figure 2-15) shows no spatial correlation of the data.

2.8.8 GM Massena, St. Lawrence River, New York

At the GM Massena site, 111 samples were collected and analyzed for PCBs. As shown on Figure 2-16, the samples were collected in a semi-systematic grid pattern. PCB concentrations ranged from 0 to 91 mg/kg. The highest concentrations were located in an approximately 400 by 400-ft area in the western portion of the site.

The semi-variogram in Figure 2-16 was generated for all directions and shows a spatial correlation. Directional semi-variograms were generated at 15-degree intervals, but no preferential correlation was apparent in any one direction. The best-fit semi-variogram had a nugget of 55, a contribution (sill) of 250, and a range of 230 ft.

2.8.9 Summary of Semi-Variogram Analysis

Of the seven post-dredging sediment sample data sets analyzed, four data sets showed spatial correlation in PCB concentrations. Only one of these data sets, Reynolds Metals, showed a specific directional correlation, which was likely related to the limitations of dredging instead of a true correlation of PCB concentrations in the residual sediment veneer. Because of the general lack of directional correlation in the data sets, these case studies do not support the use of an asymmetrical sampling grid for the Upper Hudson River residual sediment samples.

The statistical ranges of the semi-variograms from the four sites with spatial correlation ranged from 55 ft to 280 ft. This variability among data sets indicates that a single range cannot be reasonably estimated for a residual sediment sampling grid for the Upper Hudson River dredging project. However, because existing Hudson River PCB site data have shown spatial and directional correlation, semi-variogram analyses of residual data may be useful in delineating areas where redredging is required to meet cleanup objectives. Further geostatistical evaluation will be conducted using residual sediment data obtained during Phase 1 (refer to Volume 1).

2.9 Evaluation of Available Sampling Techniques

Potentially applicable sediment sampling methods are introduced below and evaluated on the basis of representativeness, comparability to previous data sets, comparative cost, and ease of implementation. In addition, the advantages and disadvantages of discrete and composite sampling schemes are evaluated, and inferential or supplementary investigation techniques are discussed.

2.9.1 Coring

Turbulence created by core samplers descending through the water to retrieve vertical columns of sediment is minimal compared to other sampling devices.

Core samplers retrieve vertical columns of sediment via a variety of hand-driven and powered sampling methods, and preserve the depositional sequence or layering of the collected sample. Turbulence created by the descent of a coring device through the water column is minimal compared to other sampling devices (USEPA, 2001), therefore the disturbance to potential fine-grained residuals at the sediment-water interface during sample collection would be minimal.

An advantage of core sampling is that clear plastic or glass core tubes can be used for sample collection, allowing visual examination of sediment samples on collection. While they do not penetrate as deeply as other coring methods, box core rigs allow access to the retrieved bulk core sample in a manner that permits on-site subsampling with manually inserted sleeves or liners, providing greater flexibility for field characterization and sample management planning (USGS, 2001).

A disadvantage of core samplers is that particles with a relatively large diameter (*e.g.*, coarse gravel, cobbles, etc.) compared to the core tube diameter may adversely impact sample recovery and may prevent collection of a representative sample. Samplers may attempt to control this disadvantage by monitoring core recovery and making multiple sample collection attempts, where necessary.

The use of core sampling would maintain a large degree of comparability to historic core samples collected by USEPA and the SSAP (QEA, 2002) that GE is implementing to support remedial design, pursuant to an Administrative Order on Consent with USEPA.

The cost of implementing a core sampling program is dependent on whether hand-driven or powered equipment (*e.g.*, vibratory coring) is used, which is in turn dependent on the water depth and the sediment texture at the sampling location. The involved cost and the ease of implementation can be moderately higher or significantly higher compared to the collection of samples using dredges, as discussed below.

2.9.2 Sampling with Small Dredges

Peterson, Eckman, and Ponar dredges are examples of small dredges used to collect sediment grab samples. These dredges are generally clamshell-type scoops that are lowered to the sediment surface and closed remotely. Peterson dredges are reported to be the most effective dredges on rocky substrates (USEPA, 2001). Eckman dredges are considered to have limited usefulness, and are unsuitable for sampling rocky, sandy, or other hard bottoms (USACE, 1994 and USEPA, 2001). Ponar dredges are considered to be effective, broadly applicable dredges that penetrate deeper and seal better than spring-activated dredges (*e.g.*, Eckman); however, penetration depths will generally not exceed several cm (USACE, 1994).

Disadvantages of grab sample collection using dredges include the inability to collect an undisturbed sample. Shallow sediments collected from the first cm or so of sediment cannot be separated from deeper layers captured in the dredge (USACE, 1994). In addition, the shock wave created by the descent of the dredge through the water column may disturb fine surficial sediments (NJDEP, 1992). The construction of the Ponar dredge may result in reduced turbulence compared to other types of sampling dredges (USEPA, 2001). The residual sediments, which are the focus of the post-dredging sampling event, are expected to be loose materials that could be very prone to disturbances caused by the use of a small dredge.

Since the majority of the samples collected historically by USEPA and GE’s Design Support Sediment Sampling program involve the collection of sediment samples via coring, grab samples collected using dredges will have a low level of comparability to the data sets for the historic sites.

The use of small sampling dredges involves a comparatively low cost (although larger, more sophisticated units may require a winch aboard the sampling boat for dredge deployment and retrieval) and the dredges are comparatively easy to operate.

2.9.3 Underway Surficial Sediment Sampling

The University of Georgia's Center for Applied Isotope Studies has developed a method for rapid collection and analysis of surface sediments. The system is composed of a towed sled that disturbs surface sediments as it is towed along a marine bottom by a sampling vessel. The sediment plume created in the wake of the sled is sampled by a vacuum pump, which transports sediment samples to the tow vessel for management and analysis. The sled perturbs sediments to a depth of 4 to 6 cm for sampling, and at a recommended towing speed of 3 knots, a maximum collection of three samples per kilometer (km) is possible (USGS, 2001). Based on these parameters, the towed sled does not appear to meet the project sampling requirements, as the sample collection depth is too shallow for the Residuals Standard sampling; however, the technology could warrant further consideration if it is found that an extremely thin residual layer is present in the Upper Hudson and there were an emphasis on characterizing this layer separately from layers below the dredging cut line.

2.9.4 Discrete vs. Composite Sampling

A discrete sample is an aliquot of material that is representative of a specific location at a given point in time.

A discrete sample is an aliquot of material that is representative of a specific location at a given point in time (USACE, 1994). For example, the collection of a number of core samples at various locations within a dredged area and individual analyses of those samples would constitute a discrete sampling program. Decision-making based on a discrete sampling data set could involve actions based on mean (*i.e.*, arithmetic average) or median concentrations and also "single point maximum" concentrations, including remedial dredging of a specific sampling point of concern (or the grid area represented by that sample, if so arranged).

In composite sampling, several volumes of material (*e.g.*, separate discrete samples) are combined and mixed to form a single homogeneous sample. This approach is often considered when analysis costs are large relative to sample collection costs, and the mean contaminant concentration is the sole parameter of interest (USEPA, 2000b).

Composite sampling, combining several volumes of material (e.g., separate discrete samples) to form a single homogeneous sample, is not appropriate for the Residuals Standard.

Composite sampling is not appropriate for the purposes of the Residuals Standard. If discrete samples are combined into composite samples to represent larger dredged areas, and a particular composite sample result requires action to be taken (*i.e.*, redredging attempt), then the action would have to be applied to the larger area, or additional sampling would be needed. The schedule for dredging set forth in the ROD and cost concerns make this approach undesirable. In addition, composite sample results cannot be compared to PL action levels applicable to an individual sample result.

Discrete and composite sampling schemes can be combined for specific purposes, however. For example, aliquots of the discrete samples used to prepare the composite can be retained for separate analysis, where composite results are of interest or exceed action levels. However, the additional turn-around time (TAT) involved with analyzing archived discrete samples may have too great an adverse impact on project schedules to be considered.

Composite sampling over depth should not be implemented for the residual sampling program, except to the extent that each 0-to-6-in core sample is to be homogenized prior to analysis. The interval of interest is expected to be a relatively thin veneer of residual sediment. In addition, at locations where backfill is not placed (*e.g.*, in the navigation channel), the biologically active zone or layer where receptors could be exposed to contamination is expected to include (but not necessarily be limited to) the upper 6 inches of sediment. Therefore, the analysis of a discrete sample representing the residual sediment is expected to address the sampling objectives. If necessary, additional discrete samples representing deeper intervals can be collected (deeper sampling is required if the 99% UCL action level of 6 mg/kg Tri+ PCBs is exceeded). A composite sample representing a larger depth interval could “dilute” or obscure data of interest.

2.9.5 Inferential and Supplementary Techniques

Inferential and supplementary investigation techniques will provide information useful to the implementation of the residual sampling program. For example, underwater video photography and/or Sediment Profile Imaging (SPI) could be deployed to investigate the extent and thickness of residual sediments.

Underwater video photography or even visual surveys by divers could be used to explore dredged areas for swaths of sediment that were inadvertently missed by the dredge or for areas of unusually thick residual deposits. Depending on their size and potentially unique conditions, such areas might not be identified by the post-dredging bathymetric survey conducted as part of the dredging QA/QC and oversight. Information obtained from the video surveys or noted by divers would be used to select some biased or judgmental sampling points during residual sampling.

An SPI camera is capable of obtaining a cross sectional image of the sediment profile to a depth of 20 cm. Deployment of an SPI camera at multiple locations within a dredged area would allow the USEPA to evaluate the thickness of the residual sediment sampling interval required by the Phase 1 performance standard. A special study will be required during Phase 1 to evaluate the usefulness of the SPI camera or other sediment imaging technology to investigate the thickness of the residual sediment and evaluate the residual sampling interval (0 to 6 in) selected for Phase 1. The study must be conducted considering a range of conditions to include evaluations for each type of dredge planned for sediment removal on the project.

2.10 Examination of Analytical Methods and Data Validation Methods

USEPA will review and approve appropriate analytical and data validation methods for the residual samples. For the purposes of this Residuals Standard it is assumed that PCB contamination in sediments will be determined using a method appropriate for quantification of PCB homolog concentrations for comparison to the Residuals Standard action levels. A performance evaluation sample analysis program will be required as part of the residual sediment analytical program. A standard operating procedure (SOP) for data validation will be developed that is based on the selected laboratory analytical method.

3.0 Rationale for the Development of the Performance Standard

3.1 Sample Collection

The sediment samples will be collected using manual core retrieval, box cores, or vibracoring techniques, except where coring is infeasible and other technologies such as small dredges or grab sampling by divers are implemented. As discussed in Section 2.9.1, core sampling:

- Preserves the depositional sequence of the sediment sample.
- Creates a comparatively minimal disturbance at the sediment-water interface.
- Maintains comparability with historic data sets collected by USEPA and the design support sampling being conducted by GE.

The Phase 1 Residuals Standard objectives require a discrete sampling method for the collection of residual sediments so that individual results can be compared to the certification unit PL and median value action levels. Coring was selected as the most appropriate sampling method for assessing both the potential redistribution of PCB-containing sediment in each certification unit and confirming that the original cut lines were delineated appropriately for the removal of the targeted PCB-contaminated sediment "inventory" (where the term "inventory" refers to PCB mass in sediment deposits requiring removal to meet the ROD's objectives).

Because a dataset of individual residual sample results is necessary to investigate the distribution of the residual contamination at the Hudson River site, composite sampling was rejected as a method of sample management for Phase 1.

Residual sediment samples will be collected from 40 locations in each CU that is less than or equal to five acres in size. In larger dredging areas, 40 samples will be collected per five-acre area. The identification of a particular CU for application of the standard will be based on pragmatic considerations (*e.g.*, a single area enclosed by silt curtains or barriers, etc.) or by dividing a dredging area into five-acre parcels, using the following rules:

- Isolated dredging areas smaller than 5 acres in size are to be designated single certification units and 40 residual sediment cores must be collected on a grid with a proportionate spacing.

- Noncontiguous dredging areas smaller than 5 acres in size and within 0.5 miles of one another can be "corralled" into a single certification unit; the sum of the grouped dredging areas must be less than 7.5 acres. If the sum of the grouped areas is still less than 5 acres, the sampling grid is to be proportionally sized so that a minimum of 40 cores is collected from within the dredging areas. Otherwise, within areas grouped into a single certification unit with a total dredged area of 7.5 acres, up to 60 cores are to be collected by applying the 80-ft grid spacing.

- Dredging areas up to 7.5 acres in size can be considered a single CU, and the sampling grid can be extended at an 80-foot spacing to allow collection of up to 60 core samples.

- For dredging areas from 7.5 to 10 acres in size, the dredging area is to be divided into two CUs of equivalent area and 40 samples are to be collected from each, using proportionally sized grids.

- Dredging areas larger than ten acres in size are to be divided into equally sized, approximately five-acre certification units and a triangular grid with 80-ft spacing established in each certification unit.

The samples will be collected on a uniform triangular grid, designed and oriented to maximize information on the spatial distribution of potential residual contamination remaining after dredging within each five-acre or smaller sampling area. The residual sampling grid will be offset from the predesign sampling grid (the average distance between the locations of the design grid and the residual grid will be between 40% and 60% of the design grid nodal spacing with the goal being 50% of the nodal distance). The acceptable criterion for relocating grid nodes in the event an obstruction is encountered (*e.g.*, a grid node happens to fall on exposed bedrock) is to relocate the sample within a 20-ft radius of the original node location.

Observations will be made during a special study to characterize the sediment type, thickness, and stratigraphy of the disturbed sediments. This program will entail the use of SPI or coring techniques to evaluate the thickness of the residuals layer. Observations of the disturbed sediment stratigraphy will also be made during the routine residual core collection. Characteristics of the dredging residuals will be quantified using:

- Sediment imaging information (where available).
- Field assessment of penetration resistance.
- Visual classification of the material retrieved in the core tube.

The routine residual sediment core will be advanced as necessary to collect a representative 6-in core (or to refusal, whichever is first encountered). It may be desirable to collect and archive deeper sediment intervals during sampling of the 0-to-6-in layer, but it is not required by the standard. If the average concentration of the samples representing the 0-to-6-in layer exceeds the 99% UCL action level in the Residuals Standard (6 mg/kg Tri+ PCBs), additional core sampling will be required to collect and analyze deeper sediment intervals, so that the vertical extent of PCB-contaminated sediment can be recharacterized. The additional sampling and analyses must be conducted to define the elevation of the sediment stratum with non-detect PCB concentrations in part of or in the entire certification unit, as directed by the standard.

Sampling for the special study is intended to characterize the entire thickness of disturbed sediments. Cores or SPI must be advanced through the entire thickness of the disturbed sediment to the underlying undisturbed material.

As part of performance standard development, the necessity of including a waiting period (i.e., not beginning residuals sampling until at least 24 hours after dredging operations cease) was evaluated. The purpose of such a waiting period would be to allow time for contaminated material still in suspension to settle so that the residuals samples would be representative of the final surface sediment concentrations. A calculation of the likely impact of suspended material on the surface sediment concentration was conducted to determine if the waiting period is warranted, as described below.

Some conservative assumptions were made about the total suspended solids (TSS) concentrations in a certification unit and the PCB concentration in the TSS. The TSS concentration in a five-acre CU was estimated at 50 mg/L, although it is unlikely that the entire certification unit would have this concentration in the water column. At the New Bedford Harbor site, where the sediments were fine grained, the TSS concentration was less than 50 mg/L during dredging (measured 50 ft from the dredge). For the calculation specific to the Hudson, the PCB concentration on these suspended particles was estimated to be 100 mg/kg Tri+ PCBs, which is twice the average concentration of the sediments in River Section 1 of the Upper Hudson (*i.e.*, TI Pool). A "fluffy" bulk density of 1.1 g/cc was also assumed.

The calculation is presented in Table 3-1. If a 6-in sample is collected and the undisturbed portion is assumed to have a Tri+ PCBs concentration of 1 mg/kg, then the calculated increase in concentration due to the settled materials would be 0.072 mg/kg, for an adjusted total of 1.072 mg/kg Tri+ PCBs. Because suspended material is likely to account for only a minor increase in PCB concentration of the surface sediment layer in a certification unit, residuals sampling need not be delayed to allow suspended solids to settle, but can proceed immediately after it is confirmed that the design cut-lines have been achieved.

3.2 Sample Management

Following core sample collection, each 0-to-6-in sample will be adequately homogenized in preparation for laboratory analysis. The 0-to-6-in sample is intended to characterize the layer of sediment that is subject to bioturbation in a freshwater environment (6 in deep), and therefore available to biota. The selection of a 0-to-6-in residuals sampling interval does not pertain to an expected residuals thickness. Some types of dredging equipment (e.g., large hydraulic dredges) can create a disturbed bottom/residuals layer up to 1 ft thick.

The 0-to-6-in residuals sampling interval could, depending on CU-specific conditions, encounter both the dredging residuals and potential contaminated sediments that may remain below the design dredging cut lines due to inadequate design or design support characterization (also referred to as undredged PCB inventory). As discussed in Attachment A, a 6-in sampling interval is sensitive to the potential presence of a contaminated residual veneer, therefore it is not necessary to attempt to discretely sample a residuals veneer.

If the average Tri+ PCB concentration of a CU is greater than the 99% UCL, deeper core sampling must be conducted to recharacterize the vertical extent of contamination. This requirement is included because an exceedance of the 99% UCL indicates the dredge was still removing contaminated sediment when the design cut line was reached, possibly due to natural variability or to deficiencies in the design support characterization and cut line design. In this case, as a planning step for the required redredging attempt, deeper sampling (compared to the 0-to-6-in depth interval) is required to ascertain the potential presence of deeper PCB-contaminated sediment inventory.

The deeper cores will be divided (segmented) into successive 6-in depth-discrete samples, which are to be analyzed until the sediment stratum with non-detect PCB concentrations is encountered. This sampling methodology will avoid the disadvantages related to compositing schemes (refer to subsection 2.9.4) and will provide flexibility for decision-making related to further remedial dredging. The rationale for segmenting the residual sampling cores into 6-in intervals is based on likely minimum redredging depths and an evaluation of case study data from the New Bedford Harbor site indicating that segments shorter than 6 in would not provide useful data (refer to Attachment A).

3.3 Sample Analysis

Sediment samples will be extracted and analyzed via an analytical method approved by USEPA to provide PCB homolog concentrations for comparison to the action levels in the Residuals Standard, which are expressed as the sum of the Tri- and higher PCB homologs (Tri+ PCBs). A performance evaluation sample analysis program will be required during the residual sediment analysis program.

3.4 Data Evaluation and Required Actions

3.4.1 Certification Unit Evaluation

The results of the sediment sample analyses from the 0-to-6-in depth interval will be used to evaluate the certification unit by comparing the following values (rounded to whole numbers) to the action levels in the Residuals Standard:

- Average Tri+ PCB concentration in the certification unit under evaluation
- Median Tri+ PCB concentration in the certification unit under evaluation
- Individual sample concentrations in the certification unit under evaluation
- Average Tri+ PCBs concentration in a "moving" 20-acre area consisting of the certification unit under evaluation and the three to four previously dredged

certification units within 2 river miles of the unit under evaluation (measured along the centerline)

The Residuals Standard action levels are to be compared to the foregoing values as follows (refer also to Figure 3-1 and Table 3-2):

- The 1 mg/kg Tri+ PCBs residuals objective stated in the ROD (refer to subsection 2.1.1) is to be compared to the average Tri+ PCB concentrations of both the 20-acre area and the CU under evaluation.

- The 95% UCL (3 mg/kg Tri+ PCBs) and the 99% UCL (6 mg/kg Tri+ PCBs) are to be compared to the average Tri+ PCB concentration of the certification unit under evaluation.

- The 97.5% PL action level (15 mg/kg Tri+ PCBs) and the 99% PL action level (27 mg/kg Tri+ PCBs) are to be compared to each sediment sample analytical result from the certification unit under evaluation.

The values currently representing the UCLs and PLs were derived from statistical evaluation of the case study datasets, as discussed in subsection 2.1.3, and applied proportionally to the criterion in the ROD (assuming that an average residual of 1 mg/kg Tri+ PCBs is the desired central tendency of the residual sediments). The action levels (the UCL and PL values) are intended to measure the comparability of the true mean (arithmetic average) of the sediment sample population's Tri+ PCB concentrations to the 1 mg/kg Tri+ PCBs residuals concentration stated in the ROD.

3.4.2 Backfilling

The objective of the ROD will have been demonstrably achieved and no further remedial action required prior to placement of backfill (where appropriate) and demobilization of the dredge and ancillary equipment from a given certification unit with:

- An average concentration of 1 mg/kg Tri+ PCBs or less.
- Not more than one individual sample concentration equal to the 97.5% PL or greater.
- No individual sample concentrations equal to the 99% PL or greater.

The comparability to the ROD's anticipated residual of approximately 1 mg/kg Tri+ PCBs is sufficient to allow the option of placing backfill without requiring redredging attempts, provided that the 20-acre arithmetic average is 1 mg/kg Tri+ PCBs or less, for a CU with:

- A mean PCB concentration greater than 1 mg/kg Tri+ PCBs but less than or equal to the 95% UCL (3 mg/kg Tri+ PCBs).

- Not more than one individual sample concentration equal to or greater than the 97.5% PL (15 mg/kg Tri+ PCBs).

- No individual sample concentrations equal to or greater than the 99% PL (27 mg/kg Tri+ PCBs).

This option is included in the Residuals Standard to minimize redredging as much as possible while still achieving the overall residuals goal of the ROD. The 20-acre averaging basis is derived from the configuration and forecasts of the HUDTOX model used to assess the adverse impacts of PCB contamination in the sediments. Specifically, model segments were approximately 20 acres in size in the TI Pool and 40 acres or more in the remainder of the Upper Hudson River segments. Therefore, no adverse impact from local concentrations up to the 95% UCL is forecast if the 20-acre arithmetic average is controlled at 1 mg/kg Tri+ PCBs. Note that there is only a 5% probability that the true mean (arithmetic average) is 3 mg/kg or greater in an individual CU with the foregoing results.

The application of the 20-acre running mean will typically involve the current CU along with the three prior completed units. In the event that these CUs do not total to 20 acres or more, a fourth completed CU can be added to the calculation. For the startup of Phase 1, the first three CUs will not have a sufficient backlog of completed units. In this instance, a simple running mean of the completed units will be used for this evaluation, if needed.

To further control potential impacts, testing of the placed backfill is required to demonstrate that the backfill surface concentration is 0.25 mg/kg Tri+ PCBs or less (refer to Section 1.1). The backfill must be sampled using the same grid spacing as the residual sediment samples (*i.e.*, collection of 40 0-to-6-in cores for a five-acre certification unit). The backfill samples will be analyzed for PCB homologs via a method approved by USEPA. If the arithmetic average PCB concentration of the backfill is greater than 0.25 mg/kg Tri+ PCBs, the non-compliant portions of the backfill must be dredged, replaced, and resampled (or additional backfill may be added, as approved by USEPA on a case-by-case basis).

3.4.3 Redredging or Capping

If the 20-acre arithmetic average PCB concentration is greater than 1 mg/kg Tri+ PCBs, the option of placing and testing backfill is not available, and the grid nodes contributing to the elevated arithmetic average in the certification unit must be redredged or isolated with an appropriately designed subaqueous cap. These actions, along with the 20-acre joint evaluation itself, are examples of contingency actions, and are discussed further in Section 3.6. The construction manager will select either the redredging or the capping option; for the purposes of this Residuals Standard, the construction manager is defined as a resident engineer responsible for execution of all construction activities, including implementation of the Residuals Standard requirements.

The planning process for redredging or capping in a CU commences with identification of the cluster(s) of grid nodes contributing to the non-compliant arithmetic average PCB concentration, focusing on the cluster(s) with the highest detected concentrations. The horizontal extent of the non-compliant sediments must be fully characterized and an appropriate dredging area and cut elevation designed prior to any redredging attempt. If after two redredging attempts, the residual concentrations do not comply with the action levels, the construction manager may choose to place an appropriately designed subaqueous cap over the clusters. The subaqueous cap top elevation is to be equivalent with the backfill elevation in the remainder of the CU.

No 20-acre evaluation is permitted for a CU with an arithmetic average exceeding the 95% UCL and less than or equal to the 99% UCL. In this case, the grid nodes contributing to the elevated arithmetic average must be redredged or isolated with an appropriately designed subaqueous cap (an instance of an engineering contingency; refer to Section 3.6). The construction manager will select the option to be implemented.

3.4.3.1 Redredging

Redredging is required at CUs with an arithmetic average Tri+ PCBs concentration greater than the 99% UCL and/or:

- With more than one sampling location equal to the 97.5% PL or greater.
- With results equal to the 99% PL or greater at any sampling locations (even in targeted areas where the arithmetic average concentration is equal to or below 1 mg/kg Tri+ PCBs).

The goals of redredging are to:

- Further reduce the surface concentrations and sediment inventory of PCBs to contribute to achievement of the ROD's goal of removal of all PCB-contaminated sediments in a targeted area (*i.e.*, dredge to non-detect Tri+ PCBs stratum, with a residual of approximately 1 mg/kg).
- Reduce the uncertainty in the statistical evaluation
- Reduce PCB concentrations so as to facilitate the achievement of post-backfill levels of 0.25 mg/kg Tri+ PCBs or less for noncompliant areas and avoid subaqueous capping.

When the certification unit average exceeds the 99% UCL, additional core sampling must be conducted to recharacterize the vertical extent of contamination prior to redredging. The additional core sampling must consist of the collection and analysis of sufficient depth intervals below the first 6 inches to identify the elevation of the sediment stratum with a non-detect PCB concentration and design the re-dredging cut lines for the non-compliant certification unit. If the median Tri+ PCB concentration in the CU is greater than 6 mg/kg, the entire CU must be re-sampled. If the median Tri+ PCB concentration is 6 mg/kg or less, the additional core sampling may be limited to areas of elevated PCB concentrations that are contributing to the non-compliant average concentration in the certification unit.

Identification of nodes for redredging must be designed to reduce the overall mean of the CU to the Residuals Standard of 1 mg/kg Tri+ PCBs. That is, a sufficient number of elevated nodes must be selected so as to anticipate that the mean of all nodes will fall at or below 1 mg/kg Tri+ PCBs following redredging. At a minimum, the selected nodes should include all locations equal to or greater than the 97.5% PL (15 mg/kg Tri+ PCBs). Depending on the success of this approach in Phase 1, this node selection requirement may be adjusted in Phase 2.

For redredging of a sampling location that exceeds the PL action levels, or in any case where an elevated cluster is to be redredged, the redredging boundary is to be calculated in proportion to the difference in PCB concentrations detected at the non-compliant node and the nearest compliant node and the distance between the two (refer to subsection 4.5.5). In addition to the results of the calculation, the boundary is not to be set at less than half of the distance between the non-compliant node and the nearest compliant node. For the purposes of redredging, compliant nodes completely surrounded by non-compliant nodes should be treated as non-compliant.

3.4.3.2 Capping

The option to place an appropriately designed subaqueous cap to isolate residuals without attempting redredging was included based on evaluation of case study data demonstrating that continuous redredging of target areas decreased productivity without meeting the goals of the remediation. The cost of construction and maintenance of a subaqueous cap should be considered and compared to the costs and schedule impacts of redredging when selecting this option, however.

The subaqueous cap is not comparable to the capping remedial option evaluated in the FS and ROD, because it is not to be used to isolate contaminated sediment inventory. The subaqueous cap is not a stand-alone remedial action alternative but rather part of the remedial action, and is only intended to isolate recalcitrant residuals. The subaqueous cap must be constructed so that:

- The arithmetic average of the nodes in the uncapped area within the CU is 1 mg/kg Tri+ PCBs or less.
- No individual node is 15 mg/kg Tri+ PCBs or greater.

The restriction on the individual nodes is lowered to less than 15 mg/kg Tri+ PCBs, reflecting the desire to minimize locally high centers of contamination. Once the decision to cap an area has been made, it is desirable to use the cap to minimize residual PCB contamination in the uncapped area as much as possible. This is similar to the requirement for redredging, wherein all nodes greater than or equal to 15 mg/kg must be redredged, once redredging is selected for a CU.

3.5 Determining the Number of Redredging Attempts

Redredging will be limited to two attempts under the Residuals Standard, unless the construction manager determines that additional attempts are likely to provide the desired reduction in contaminant concentrations.

Residual sediment samples will be collected after obtaining the design cut elevations and after each successive redredging attempt, and within seven days after dredging is completed. In the event that the Tri+ PCB concentrations exceed the action levels in the Residuals Standard, additional dredging and resampling may be required, as shown on Figure 3-1 and Table 3-2. However, a limit must be placed on the number of redredging attempts and a contingency option must be provided after that number of attempts has taken place, due to the impact on the productivity rate and project schedule as well as the diminishing returns reported in environmental dredging case studies. For example, in the Reynolds Metals project, reduction of PCB residual concentrations was not found after the fifth attempt. At the GM Massena site, the greatest improvement was experienced through the second dredging attempt.

For the Residuals Standard, redredging is limited to two attempts following the initial residual sampling event, based on both engineering judgment and case study findings, with the understanding that case study site conditions will differ from those in the Upper Hudson River to varying degrees. The possible exception to the two-attempt limit is in a case where the construction manager determines that additional redredging attempts could provide a desired reduction in contaminant concentrations. Modification could also be made based on the experience and observations collected on the site during Phase 1 dredging.

3.6 Engineering Contingencies for the Residuals Standard

In the event that the sediment removal operations are unsuccessful in achieving a mean residual concentration of approximately 1 mg/kg Tri+ PCBs, engineering contingencies are to be implemented. To maintain flexibility and facilitate adherence to the productivity schedule, it is appropriate to allow residuals to be addressed *in situ* at concentrations greater than the ROD's requirement of 1 ppm. There are several contingency actions appropriate for control of dredging residuals that should be implemented in a tiered approach, based on the concentration of Tri+ PCBs in the residuals. In order of increasingly rigorous response, they are:

- backfilling with confirmatory testing of the surface of the backfill.
- capping with an isolation cap.
- additional sampling at depths greater than 6 inches followed by redredging.

To direct the dredging, the Residuals Standard is organized in three layers, with limits for an individual sample concentration, the average concentration of any 5-acre CU, and a moving 20-acre (comparable to the HUDTOX segment size) evaluation area weighted average concentration. Should the sediments exceed the Residuals Standard action levels after two redredging attempts, a contingency action will be implemented, consisting in this case specifically of the construction of a subaqueous cap. The use of a subaqueous cap and other technologies that were surveyed but not specifically required by the Residuals Standard (*e.g.*, *in situ* remediation and alternative dredges) are described in the following subsections and will be considered for use as engineering contingencies by the construction manager.

3.6.1 Alternative Dredges

In areas where primary dredging is performed but the ROD's objective of approximately 1 mg/kg Tri+ PCBs is not immediately achieved due to inaccessibility of the sediments (*e.g.*, areas with shallow bedrock, outcrops, boulders, cobbles, gravel, or debris), alternative dredges should be considered for use. Alternative dredges include, but are not limited to, amphibious excavators, clean-up dredges, and diver-assisted dredging. Amphibious excavators are readily transportable units that have the potential to specifically remove contaminated sediments along river shorelines and within shallow secondary channels. One of the unique characteristics of these machines is that they have hydraulically actuated arms that can be fitted with any of several heads, including a bucket, a rake, or a cutter head pump bucket.

The clean-up dredge is an auger-type system developed in Japan for removal of highly contaminated sediments. The auger is shielded with pivoting wings, which are intended to contain sediment during collection, and with shrouds for collecting gas for venting, in order to minimize resuspension. An underwater television camera is used to monitor resuspension, while sonar devices are used to monitor the depth of the cut. In diver-assisted dredging, divers hold small-diameter suction hoses or guide submersible pumps to manually remove sediments.

The production rate of alternative dredges is relatively low and the operating cost of the alternative dredges is relatively high compared to the initial dredge. The versatility brought by these dredges, such as using amphibious excavators in shallow areas and using diver-assisted dredging in rocky areas, may provide the ability to reduce PCB residual levels in these special areas. The use of alternative dredges to respond to non-compliant residual sediment concentrations should be explored during the design of the dredging project.

3.6.2 Capping

In areas where the residual level of approximately 1 mg/kg Tri+ PCBs cannot be achieved after two redredging attempts, or optionally in certification units where the arithmetic average Tri+ PCBs concentration is greater than the 95% UCL and less than or equal to the 99% UCL (refer to Figure 3-1 and Table 3-2), a subaqueous cap may be constructed over elevated clusters. Different technologies with regard to capping were evaluated and described in the FS (USEPA, 2000b) and are summarized below. In addition to these capping technologies, appropriately designed caps may be constructed from granular materials. The design of subaqueous capping systems is to consider impacts to habitat and is to be accomplished as part of the remedial design. Monitoring of cap effectiveness and long-term monitoring of capped areas are outside the scope of the Residuals Standard and are not addressed in this document.

The placement of backfill and subaqueous cap construction are undesirable in the navigation channel. Capping is also restricted in shallow water areas. However, there may be an instance where a recalcitrant, contaminated residual is present in the navigation channel, and the construction of a subaqueous cap is a desirable option to isolate the residual PCB concentrations. To accommodate the subaqueous cap in this situation, it would be necessary to conduct additional dredging to place the layers of the cap below the channel depth, and include an indicator layer of coarse material to signal the proximity of the cap during future maintenance dredging. If the cap thickness cannot be accommodated (*e.g.*, shallow bedrock is present) and all practical redredging attempts have failed, the area may need to be abandoned, subject to USEPA approval.

3.6.2.1 Capping Using Inert Materials

Inert materials include clay, silt, sand, geosynthetic clay liners (GCLs), geomembranes, and AquaBlok™. Only the use of AquaBlok™ was retained in the FS. AquaBlok™ is a capping system consisting of gravel particles to which bentonite clay is bonded. Gravel or crushed stone is obtained from a local quarry and is initially coated with a polymer. The bentonite is then added, forming a dry, hard aggregate. The composite particles, herein referred to as AquaBlok™, are spread from the surface of the water and sink quickly to the bottom of the river on top of the sediment. As the bentonite hydrates, a uniform, continuous, cohesive low permeability cap (1×10^{-8} cm/sec) is formed over the contaminated sediments.

Standard construction equipment such as front-end loaders, conveyors, and barges can be used to place AquaBlok™. The hydrated particles are cohesive and are more resistant to erosion than sand. In laboratory flume tests there was little loss of AquaBlok™ particles at a current velocity of 3 ft/sec, when compared with the amount of sand lost at the same velocity. The innovative aspects of the AquaBlok™ composite particle system are as follows:

- It overcomes the technical difficulty of subaqueous placement by using an innovative delivery system.
- It utilizes readily available materials such as bentonite and gravel or aggregate.

Based on the results of a capping project conducted in the Ottawa River (Hull & Associates, 2000), the generalized unit cost for AquaBlok™ cap construction using a barge-based conveyor, including material costs, was approximately $1.04 per square foot. This cost was developed assuming construction of a targeted 6-in hydrated AquaBlok™ cap without the geogrid or stone-layer components present.

3.6.2.2 Capping Using Active Materials

Active materials such as activated carbon can be applied to the surface of subaqueous sediment or mixed with the sediment in an attempt to limit contaminant mobility. Active materials need to be combined or covered with inert materials to provide stability, erosion resistance, and, in some cases, protection for benthic organisms. Capping using activated carbon or other active materials can be effective, but has the disadvantage of potential future release of capped (adsorbed) contaminants due to breakthrough in the active materials. Given this concern, use of this technology should be limited.

3.6.2.3 Capping Using Sealing Agents

Sealing agents such as cement, quicklime, or grout may be applied to the surface of subaqueous sediments or mixed with the uppermost layer to form a crust upon curing. This technique stabilizes the surface, preventing erosion and resuspension of the contaminated material, and reduces or eliminates leaching of contaminants into the water column. Mobile (barge-mounted) concrete pumps may be used to apply the material in order to minimize sediment disturbance. Diversion of stream flow may be required for effective application of a cap composed of sealing agents. Also, the sealing agent cap surface is not a desirable habitat for biota. Therefore, capping using sealing agents should only be implemented on a limited basis.

3.6.3 *In Situ* Treatment

In areas not feasible to cap, such as shallow or navigational areas, other *in situ* treatments may be considered during design of the dredging project. Not all of these technologies have been proven effective in the remediation of PCBs, however. Also, the mobilization and fixed costs associated with implementing these technologies on small, widely spread areas could be prohibitive. The main limitation of *in situ* treatment is the lack of process control during treatment, which can lead to incomplete or ineffective treatment and release of treatment by-products to the water column. *In situ* treatment technologies are most effective in low-flow streams or embayments where flow can be diverted during treatment. In-situ treatment technologies include physical/chemical methods.

In situ immobilization methods, for example, involve mixing solidification/stabilization agents such as cement, quicklime, grout, and pozzolanic materials, as well as reagents, with sediments in place to solidify/stabilize contaminants in the matrix. The solidification/stabilization agents are mixed throughout the zone of contamination using conventional excavation equipment or specially designed injection apparatus such as mixing blades attached to vertical-drive augers. The effectiveness of stabilization/solidification technologies is variable depending on the characteristics of the contaminated soil and the particular additives used. In general, this technique is more effective for inorganic constituents (metals) than for organic constituents. Since PCBs tend to strongly adsorb to sediments, stabilization/solidification can potentially be effective in reducing the mobility of PCBs. Solidification/stabilization may not be appropriate for shallow areas of the river, where volume expansion of the treated sediments may interfere with small craft navigation in these areas. In addition, a solidified mass may present problems as habitat for biota in the river. Consequently, implementation of this option should be limited on that basis.

3.6.4 Engineering Contingencies Used at Other Sites

Engineering contingencies have been designed and implemented at other dredging sites. The following subsections contain discussions of some examples. As noted previously, Volume 5 contains details pertaining to these sites.

3.6.4.1 Reynolds Metals

At the Reynolds Metals site, a cable arm environmental bucket was employed to dredge the PCB-contaminated sediments. When sampling results indicated that the cable arm environmental bucket was not effectively removing the contaminated sediments, the conventional rock bucket and hydraulic clamshell of the Caterpillar Model 350 (Cat 350) were used as an alternative dredge for redredging, based on persistent contamination in certain cells and the fact that the previous dredging attempt had not been successful in reducing contamination levels. The conventional rock bucket consisted of a 2.5 cubic yard (cy) clamshell bucket that could be used with the lattice boom cranes on the derrick barge, capable of digging into the more resistant hard bottom materials and also more effective in removing rocks and gravel. The disadvantages of the conventional bucket were that it did not have a venting system to allow water to pass through the opened bucket during descent, which minimizes downward water pressure and sediment disturbance, nor did it have a regulated closing system or overlapping side seals that minimize both the disturbance of sediment on the bottom and the sediment loss on closure. The Cat 350 had a hydraulically operated clamshell bucket with a 2.5 cy capacity. The hydraulics on this bucket provided for better closure, and also allowed it to dig into stiff sediment and rocky material. Its primary disadvantage was that the operator had to be extremely careful not to overfill.

Cells with residual concentrations greater than 10 mg/kg were designated for capping. The cap consisted of a 6-in separation layer, a 12-in containment layer, and a greater than 9-in armor and bioturbation layer. At the end of first year construction, an average of 2.2 ft of gravel was placed as the interim cap.

3.6.4.2 Cumberland Bay

Hydraulic dredging was used to dredge the contaminated sediments in the Cumberland Bay project. Divers dredged some areas using hand-held hydraulic dredge lines to remove pockets of sludge. The hand-held dredging proved effective in areas that had been identified as difficult to dredge using the hydraulic auger.

3.6.4.3 Manistique River

Diver assisted dredging was utilized with a suction pump to aid in the removal of residual sediment areas and furrows that remained after removal operations to the required dredge depth. It was indicated that a single diver would guide the suction hose over the mounded material to ensure accurate removal of residuals.

4.0 Implementation of the Performance Standard for Dredging Residuals

The Residuals Standard covers the collection and analysis of sediment samples representing dredging residuals in all Phase 1 target areas and describes the procedures by which the sediment sampling data will be used to characterize residuals, evaluate the effectiveness of the dredging remedy, and plan post-dredging construction actions. The Residuals Standard is comprised of the following tasks:

- Sampling Grid Establishment
- Sample Collection
- Sample Management
- Sample Analysis
- Data Evaluation and Required Actions
- Engineering Contingencies

4.1 Sampling Grid Establishment

Cores of the residual sediment will be collected at 40 locations in each five-acre certification unit. The cores will be collected on a regular triangular grid developed to maximize the spatial distribution of samples within each dredged area. This grid should be offset from the design support sampling grid so that the average distance between the design grid nodes and the residuals grid nodes is between 40% and 60% of the design grid nodal distance, with the goal being 50% of the nodal distance. In the event an obstruction is encountered (*e.g.*, a grid node “falls” on exposed bedrock), the sample is to be relocated within a 20-ft radius of the original location. For backfill testing (refer to subsection 4.5.2), core samples will be collected using the same grid established for the residuals.

The following guidelines are to be used for implementation of a sampling grid on certification units other than five acres in size:

- Isolated dredging areas smaller than five acres in size are to be designated single certification units and 40 residual sediment cores must be collected on a triangular grid with a proportionate spacing.

- Noncontiguous dredging areas smaller than 5 acres in size and within 0.5 miles of one another can be “corralled” into a single certification unit; the sum of the grouped dredging areas must be less than 7.5 acres. If the sum of the grouped areas is still less than 5 acres, the sampling grid is to be proportionally sized so that a minimum of 40 cores is collected from within the dredging areas. Otherwise, within areas grouped into a single certification unit with a total dredged area of 7.5 acres, up to 60 cores are to be collected by applying the 80-ft grid spacing.

- If a number of noncontiguous dredging areas smaller than 5 acres in size are contained within a common silt barrier during dredging, the construction manager must submit a proposal to USEPA that explains how the dredging project will be managed to prevent the spread of contamination to the interstitial, non-targeted areas, or propose additional sampling to investigate those areas during the residuals sampling in the certification units.

- Dredging areas up to 7.5 acres in size can be considered a single certification unit and the sampling grid can be extended at an 80-ft spacing to allow collection of up to 60 core samples.

- For dredging areas between 7.5 and 10 acres in size, the dredging area is to be divided into two CUs of equivalent area and 40 samples collected from each using proportionally sized grids.

- Dredging areas larger than 10 acres in size are to be divided equally into - approximately 5-acre certification units and a triangular grid with 80-ft spacing established in each certification unit. (For example, a 32-acre dredging area would be divided into six certification units, each 5.33 acres in size.)

4.2 Sample Collection

Residual sediment sample collection will take place once inventory removal (as designed) has been confirmed and within seven days after dredging is completed in a particular targeted area.

The sediment samples will be collected via coring, using vibracoring or manual coring techniques (including box coring, as appropriate). Core samples will be retrieved in clear Lexan® (or other appropriate semi-transparent) sleeves or liners. Where vibracoring techniques are used, the vibracoring rig will be activated at the sediment water interface and used throughout the depth of the core. Where difficult conditions, for example shallow bedrock, preclude collection of core samples, sediment samples will be collected using small dredges or via grab sampling by divers. The core sampling locations are to be located using GPS and referenced to an appropriate horizontal coordinate system and vertical datum. The core sampling location data is to be recorded with the other information collected in the field.

Prior to core collection, sediment probing will be conducted in an area adjacent to the target location (so as not to disturb the sediments in the target area) to identify the approximate depth and the texture of the sediments. The information will be used to determine whether or not a core can be obtained and if a grab sampler should be deployed instead.

Sediment cores will be advanced as necessary for the collection of a representative 0-to-6-in core or to refusal, whichever occurs first. The target coring depth will be determined using design information and field assessment of penetration resistance (probing). Backfill samples (refer to subsection 4.5.2) and samples from redredged nodes will also be collected as 0-to-6-in core samples; and in all respects sample collection, management, and analysis will be identical to residual sediment samples. Based on the comparison of the sediment sample results to the Residuals Standard's action levels (refer to subsection 4.5.3), additional core sampling may be required to recharacterize the depth of contamination in all or part of a certification unit. In this case, sediment cores will be advanced to the depth necessary to define the vertical extent of non-compliant sediments.

Core recovery in Lexan® tubes will be measured directly though visual inspection of the sample. The actual sample recovery will be calculated by dividing the length of the sediment recovered by the total penetration depth of the core. The sampler will then document the sediment recovery and visually classify the sediment sample, including the thickness of the residual veneer. If sediment probing indicates a sediment depth of less than 6 in over a hard material, at least one attempt will be made to collect a core. If a sediment sample cannot be retrieved via coring, a Ponar grab sample will be collected. For all locations, sampling is to continue, either by coring, a grab sampler or diver assisted sampling until successful, unless exposed bedrock can be demonstrated within the entire 20-foot radius circle around the sampling node. Sample locations may be moved within 20 ft of the original location if necessary, as noted previously. If a Ponar grab sampler is deployed, it must be of sufficient size to penetrate at least 6 inches or the thickness of sediment believed present on the river bottom, whichever is less.

Once a core has been collected, the core will be capped, sealed, and labeled. Labeling will be done by writing directly on the core tube using a permanent marker, and will include the following: core identification information, date, and time. In addition, an arrow will also be drawn on the core to indicate which end is the top. All other field data will be recorded in a field logbook. The cores will be stored on ice in a storage rack in a vertical position and kept in the dark until they are submitted for processing and analysis. Ponar grab samples will be homogenized in a dedicated, laboratory-decontaminated, stainless steel bowl, transferred to an appropriately selected and labeled sample jar, and stored on ice in a cooler until they are submitted for laboratory analysis.

4.3 Sample Management

The retrieved core samples are to be photographed and prepared for laboratory analysis (if recharacterization of the vertical extent of contamination is required, the core samples must be divided into successive 6-in depth-discrete samples). The sampling methodology is intended to provide flexibility for decision-making if remedial dredging or contingency actions are required.

A field processing facility similar to that used by GE for the design support sediment sampling program (QEA, 2002) will be required for management of the sediment cores collected for characterization of the residuals. When a sediment core arrives at the field processing facility, the field notes prepared by the sampling personnel will accompany it. A sample custodian will enter the information contained in the field notes into a database.

The initial step in the processing of each core will be to remove the cap and siphon off excess water contained in the core tube, as the cores will be transported with river water in the headspace to minimize disturbance of the top core layer. The weight of the core tube will then be measured and will be used as an initial estimate of the sediment bulk density. Any additional standing water above the sediment will be siphoned off once the fines have settled. Any observed sediment "fluff" layer must be retained and homogenized as part of the 0-to-6-in sample. The length of the recovered core will then be measured, and the outside of the core tube will be marked to identify where the core tube will be cut into segments (may not be necessary where only 0-to-6-in core samples are required). The marking procedure will include the placement of arrows on each segment to indicate the upper end.

Prior to extrusion of the sediment core from the core tube, the tube will be cut into segments. Since the core sections will be separated prior to the extrusion process, the sediment will only be extruded from the section of core tubing that corresponds to the sample to be mixed and analyzed, in most cases, the 0-to-6 in interval. While the core tube is being cut, support will be given to the areas above and below the cut. Once the core tube has been cut through, the core segment will be separated from the rest of the core.

The sediment will then be extruded from the core tubing using a decontaminated stainless steel tool. The extruded sample will subsequently be rigorously homogenized, because there will be a potential for very high heterogeneity in the 0-to-6-in interval. All reusable equipment will be constructed of stainless steel or glass (*e.g.*, blenders for homogenization, if used) and decontaminated prior to reuse.

A description of the physical characteristics of each core segment will be recorded in the field database, including observations on the general soil type (sand, silt, clay, and organic/other matter such as wood chips, as determined using the Unified Soil Classification System (USCS)), approximate grain size (fine, medium, coarse), presence of observable biota, odor, and color. During the extrusion process, each core segment will be examined visually to identify changes in sediment characteristics.

If stratigraphy changes are observed within a core segment, then the nature and approximate length of the layers will also be noted in the field database. If any objects of cultural significance are observed during the processing of the core, they will be noted in the field database, separated from the sediment, and stored at the field processing facility for inspection by a qualified geomorphologist or archeologist. Wood chips will not be separated from the sample due to size but will be manually pulverized or chopped, as necessary, to allow their homogenization with and inclusion in the sediment samples submitted for laboratory analysis.

Sample aliquots designated for analysis will be chilled to 4^{o}C and kept in a dark location until they are sent to the analytical laboratory.

4.4 Sample Analysis

Each sample will be extracted and analyzed for PCB via an analytical method approved by USEPA and that provides at least equivalent sensitivity and accuracy to the analytical method used during the design support sediment sampling. Grain size and moisture content analyses will also be required for selected core sample analyses. A performance evaluation sample analysis program will be required as part of the residual sediment sample analytical program.

4.5 Evaluation of Sample Data and Required Actions

The results of the sediment sample analyses will be used to evaluate the certification unit by converting the validated results to Tri+ PCB equivalents and comparing the following values (rounded to whole numbers) to the action levels in the standard:

- Arithmetic average Tri+ PCB concentration in the certification unit or portion of a certification unit under evaluation
- Individual sample concentrations in the certification unit under evaluation
- The median Tri+ PCB concentration in the certification unit under evaluation
- Area-weighted average Tri+ PCB concentration in a moving 20-acre area consisting of the certification unit under evaluation and the three or four previously dredged CUs within two river miles of the current unit (measured along the centerline)

The equations provided below are to be used for calculating the certification unit arithmetic average and 20-acre area weighted average concentrations.

4.5.1 Certification Unit Arithmetic Average

$$m_{t,\text{int}} = \frac{\sum_{i=i}^{n} c_{i,\text{int}}}{n}$$

where:

n = the number of sample locations in the certification unit

$c_{i,\text{int}}$ = the Tri+ PCB concentration associated with the *i*th sample location in a single depth interval

The following guidelines address handling of special cases in the calculation of mean (*i.e.*, arithmetic average) concentrations:

- Non-detect sample results are to be included in the mean calculation at a value of one-half the detection limit.

- If no sample is available from a grid node due to field difficulties that cannot be resolved, the mean should be calculated based on the reduced total of data points (*e.g.*, 39 data points instead of 40).

- If backfill is placed in a CU with an arithmetic average greater than 1 mg/kg Tri+ PCBs but less than or equal to 3 mg/kg Tri+ PCBs (*i.e.*, where the 20-acre evaluation was compliant with the requirements of the standard), the pre-backfill arithmetic average for that particular CU must be used in subsequent 20-acre evaluations. No substitution of the tested surface concentrations in the backfill is permitted for subsequent 20-acre evaluations involving that CU.

- Following redredging of all or part of a certification unit, residuals samples must be collected from the redredged nodes and analyzed. The arithmetic average is to be subsequently recalculated by substituting the new results from the redredged nodes.

If a subaqueous cap is constructed, the Residuals Standard's action levels must be applied to the arithmetic average of the sample results from the nodes in the uncapped area alone (*i.e.,* the uncapped area must be in compliance with the Residuals Standard), with the additional restriction that no single node exceed the 97.5% PL of 15 mg/kg Tri+ PCBs. Following placement of the subaqueous cap, the CU's arithmetic average will be recalculated for subsequent use in the 20-acre area-weighted average based on the uncapped area and associated nodes only. Capped areas are eliminated from the 20-acre running average calculation.

4.5.2 20-Acre Area-Weighted Average

$$m_{20,\text{int}} = \frac{\sum_{i=i}^{n} a_{t,i}\, m_{t,\text{int},i}}{\sum_{i=i}^{n} a_{t,i}}$$

where:

n	=	the number of certification units included in the 20-acre average
$a_{t,i}$	=	the area associated with the *i*th certification unit
$m_{t,\text{int},i}$	=	the Tri+ PCB average concentration associated with the *i*th certification unit in a single depth interval (int)

4.5.3 Required Actions

The following actions are required by the standard, based on the sediment sample analytical results obtained (refer to Figure 3-1 and Table 3-2):

Response 1: Backfill (where appropriate) and demobilize at certification units with

- An arithmetic average residual concentration less than or equal to 1 mg/kg Tri+ PCBs.
- No sediment sample result greater than or equal to 27 mg/kg Tri+ PCBs, and
- Not more than one sediment sample result greater than or equal to 15 mg/kg Tri+ PCBs.

Response 2: Jointly evaluate a 20-acre area at a certification unit

- With an arithmetic average residuals concentration greater than 1 mg/kg Tri+ PCBs and less than or equal to 3 mg/kg Tri+ PCBs.
- No sediment sample result greater than or equal to 27 mg/kg Tri+ PCBs.
- Not more than one sediment sample result greater than or equal to 15 mg/kg Tri+ PCBs.

For the 20-acre evaluation, if the area-weighted arithmetic average of the individual means from the certification unit under evaluation and the three previously dredged certification units (within two miles of the current unit) is less than or equal to 1 mg/kg Tri+ PCBs, backfill may be placed. In this case, subsequent testing of the backfill is required to confirm that its surface concentration is less than or equal to 0.25 mg/kg Tri+ PCBs. If the surface concentration does not meet this criterion, the backfill must be dredged, replaced, and retested, or otherwise remedied with input from USEPA.

If the 20-acre evaluation does not yield a combined average of 1 mg/kg Tri+ PCBs or less, the certification unit must be redredged (see #4 below for actions required during and following redredging) or a subaqueous cap constructed. Redredging or capping is to be conducted at the specific areas within the certification unit that are causing the non-compliant mean concentration. If the certification unit does not comply with #1 or #2, above, after two redredging attempts, capping may be implemented in lieu of further redredging attempts, as described in #5, below.

Note that for the startup of Phase 1, the first three CUs will not have a sufficient backlog of completed units of the 20-acre average. In this instance, a simple running mean of the completed units will be used for this evaluation, if needed.

Response 3: Redredge or construct subaqueous cap at a certification unit

- With an arithmetic average residuals concentration greater than 3 mg/kg Tri+ PCBs but less than or equal to 6 mg/kg Tri+ PCBs.
- No single sediment sample result is greater than or equal to 27 mg/kg Tri+ PCBs.
- Not more than one sediment sample result is greater than or equal to 15 mg/kg Tri+ PCBs.

The choice of two options is provided to maintain flexibility and productivity (*e.g.*, some areas may not be conducive to dredging). If redredging is chosen, the surface sediment of the redredged area must be sampled and the certification unit reevaluated. Redredging should be designed so as to attain the Residuals Standard goal of 1 mg/kg Tri+ PCBs. As a result, redredging should include, at a minimum, all of the nodal locations greater than or equal to the 97.5 % PL (15 mg/kg). If the certification unit does not meet the objectives of #1 or #2, above, following two redredging attempts, capping may be implemented in lieu of further redredging attempts, as described in #5, below.

In the event a subaqueous cap is selected, the area selected must be such that the following criteria are met:

- The arithmetic average of the nodes in the uncapped area within the CU is 1 mg/kg Tri+ PCBs or less.
- No individual node is 15 mg/kg Tri+ PCBs or greater.

Response 4: Redredging is required

- For areas of elevated Tri+ PCB concentrations within a certification unit with an arithmetic average residuals concentration greater than 6 mg/kg Tri+ PCBs.
- To address individual sampling point(s) with concentrations greater than or equal to 27 mg/kg Tri+ PCBs.
- For instances of more than one sampling point with concentrations greater than or equal to 15 mg/kg Tri+ PCBs.

Sampling at depths greater than 6 inches will be triggered by an arithmetic average residual concentration of greater than 6 mg/kg Tri+ PCBs. The spatial extent of this sampling at greater depth will be determined by the median Tri+ PCB concentration. If the median concentration in the certification unit is greater than 6 mg/kg Tri+ PCBs, collection and analysis of additional sediment samples is required from deeper intervals over the entire certification unit (*e.g.*, 6-to-12-

inch, 12-to-18-inch, etc.) as necessary to recharacterize the vertical extent of PCB contamination. If the median concentration is 6 mg/kg Tri+ PCBs or less, characterization of the vertical extent of contamination is required only in the areas within the certification unit that are contributing to the non-compliant mean concentration. Additional sampling to characterize the vertical extent of contamination is required only once.

The Residuals Standard provides a mechanism for calculating the horizontal extent of redredging. All redredging attempts are to be designed to reduce the mean Tri+ PCB concentration of the entire certification unit to 1 mg/kg Tri+ PCBs or less. As a result, redredging should include, at a minimum, all of the nodal locations greater than or equal to the 97.5 % PL (15 mg/kg Tri+ PCBs). If after two redredging attempts, the arithmetic average Tri+ PCB concentration in the surface sediment still is greater than 1 mg/kg, then capping is to be implemented as stated in #5, below.

Response 5: Capping. At areas where two redredging attempts do not achieve compliance with the residuals criteria, as verified by USEPA, construct an appropriately designed subaqueous cap, where conditions allow. As with #3, the following criteria are met for the area left uncapped:

- The arithmetic average of the nodes in the uncapped area within the CU is 1 mg/kg Tri+ PCBs or less.
- No individual node is 15 mg/kg Tri+ PCBs or greater.

Portions of a contiguous five-acre CU may be backfilled after the cut lines are met if:

- The area will not be recontaminated.
- Dredging proceeds downstream in the certification unit.
- The Tri+ PCB arithmetic average concentration of the samples collected from the portion of the certification unit is 1 mg/kg or less.
- All such nodes sampled are less than both PL action levels.

This may be helpful in managing the operation and a benefit to productivity. If this option is chosen, a proposal to implement closing out sections of a certification unit must be presented with schedules of the operation for USEPA review and approval.

4.5.4 Redredging and Required Number of Redredging Attempts

Redredging must be conducted when more than one sediment sample result is greater than or equal to the 97.5% PL (*i.e.,* 15 mg/kg, in which case all such locations must be redredged), any sediment sample results are greater than or equal to the 99% PL (27 mg/kg), and in part (elevated clusters) or all of the

> *Redredging must be conducted when more than one sediment sample result is greater than or equal to the 97.5% PL (i.e., 15 mg/kg).*

certification unit as necessary to address residual sediments with an arithmetic average concentration greater than the 99% UCL (6 mg/kg). Redredging is an option to reduce PCB concentrations in certification units with average concentrations greater than 1 mg/kg Tri+ PCBs and less than or equal to the 99% UCL (6 mg/kg), depending on the 20-acre joint evaluation area average (refer to Figure 3-1 and Table 3-2).

Prior to conducting a redredging attempt, the horizontal extent (and vertical extent, if the certification unit average concentration exceeds the 99% UCL) of the contaminated sediments requiring removal must be appropriately characterized through sediment sampling and analysis, and appropriate dredge areas and cut elevations designed. If PCB contamination exceeding the 99% UCL (6 mg/kg) is determined for the 0-6 inch sediment interval via calculation of the CU mean, this is considered indicative of the presence of undredged contaminated sediment inventory, which should have been removed during implementation of the initial remedial dredging design. Additional sampling at depths greater than 0 to 6 inches is required in this instance to establish the true depth of the sediment PCB inventory. Redredging attempts to remove such inventory will not be counted towards the required two redredging attempts in a certification unit.

Sediment coring will be conducted after each completed redredging attempt. Following redredging, the redredged locations will be resampled (10-foot offset from the original locations) using the same coring and sample management procedures required in Sections 4.2 and 4.3. The analytical results will be substituted into the original data set and compliance with the action levels reevaluated through calculations of the appropriate arithmetic average concentration(s) and review of single sampling locations.

Up to two redredging attempts are required under this standard. If the Residuals Standard action levels are not met after three dredging attempts (including the initial dredging event), capping may be implemented as described in Section 4.6. If, in the construction manager's judgment, additional dredging attempts are reasonably expected to realize the desired reduction in residual sediment concentrations, additional redredging may be conducted before resorting to the implementation of a contingency such as a subaqueous cap. As stated above, dredging attempts required to remove contaminated sediment inventory (where the certification unit arithmetic average concentration is greater than the 99% UCL after the initial dredging attempt and re-characterization of the vertical extent of contamination reveals more than 6 inches of contaminated residuals are present) are not counted towards the requirement for two re-dredging attempts in non-compliant certification units.

4.5.5 Determining the Extent of the Non-Compliant Area

Use of geostatistics to define the non-compliant area that will require re-dredging or capping was not considered viable for the remediation. Multiple interpretations of the data are possible, potentially leading to conflicts and delays. Analysis of residuals data from other sites has not shown a strong spatial correlation. The lack of spatial correlation could reasonably be interpreted as a need to redredge the entire area in any certification unit that does not comply with the standard. Instead, it is assumed that there will be some degree of spatial correlation, even if it is not well defined, and a conservative routine approach for defining the non-compliant areas can be implemented as a part of the standard.

The extent of the non-compliant area about any single point will be determined by the following equation (repeated for each surrounding node) as long as the result is at least half the distance between the evenly spaced grid nodes:

$$d_r = \frac{d\ * (C_1 - C_3)}{(C_1 - C_2)}$$

where:

d_r	=	the distance to redredge from the C_1 to C_2
d	=	the distance between nodes
C_1	=	the concentration at the elevated node under consideration
C_2	=	the concentration at a compliant node surrounding C_1
C_3	=	the desired concentration for the area (1 mg/kg)

If d_r is less than half of the distance between nodes, the distance to define the non-compliant area is, at a minimum, half of the distance between nodes. C_3 will always be set to 1 mg/kg Tri+ PCBs, which is the desired average concentration for the area. The estimate of distance is conservative, making the assumption that a linear relationship exists between concentration and distance. The non-compliant area will be contained within a boundary that has sides perpendicular to the axes between the sampled nodes. This area will not extend beyond the hexagon created by connecting the surrounding nodes. An example is shown on Figure 4-1. If the node is next to the boundary of the certification unit, the non-compliant area should follow the boundary because there is no information to reduce the area.

4.6 Subaqueous Capping

The Residuals Standard contains the option to place an appropriately designed subaqueous cap if a CU's arithmetic average concentration following dredging exceeds 1 mg/kg Tri+ PCBs but is less than the 99% UCL (6 mg/kg), or where redredging attempts to reduce more elevated concentrations are unsuccessful after two attempts (refer to Figure 3-1 and Table 3-2 for further detail). Depending on the concentration and thickness of the residual sediment requiring capping, an appropriately designed subaqueous cap can be constructed. Note that if the Tri+ PCB concentration exceeds 1 mg/kg, but is less than the 95% UCL (3 mg/kg), and the Joint Evaluation area is 1 mg/kg

Tri+ PCBs or less, then only backfill is required with post-backfill testing for the Tri+ PCB concentration of the backfill surface.

An appropriately designed subaqueous cap differs from the placement of backfill material. The type of backfill and capping material will vary to account for the river conditions and ecological setting. This will be an important consideration for the remedial design with regard to habitat issues, and may require the design of multi-layer caps that address both residuals isolation and habitat preservation needs.

Development of capping specifications during the remediation for areas of the river will be required. In order to avoid delays to the remediation, prototype capping specifications for typical river conditions and ecological settings will need to be developed during the remedial design phase. These prototypes can then be readily customized for the situations encountered during remediation. Guidance documents that should be considered during the design phase include, but are not limited to, the following:

- Palermo, M., Maynard, S., Miller, J., and D. Reible. September 1998. Guidance for In-Situ Subaqueous Capping of Contaminated Sediments. USEPA 905-B96-004, Great Lakes National Program Office, Chicago, Illinois.

- USACE. June 1998. Guidance for Subaqueous Dredged Material Capping. Technical Report DOER-1, Washington, D.C.

As described in these guidance documents, the cap must be designed to perform the following functions:

- Physically isolate residual sediments from indigenous benthos and minimize bioturbation of the residual sediments
- Resist erosion due to currents, waves, propeller wash, ice rafting, etc. and stabilize the contaminated sediments (*i.e.,* prevent resuspension and migration of the contaminated sediments)
- Minimize or eliminate the flux of contaminants into the water column
- Maintain integrity among the individual cap layers/components (*e.g.,* address consolidation of compressible materials)
- Include consideration of additional protective measures and institutional controls that are needed (*e.g.,* additional controls for caps constructed in any area where future navigation dredging may be necessary, notifications to boaters not to drop anchors in capped areas, etc.)

The cap design must also address the following elements:

- Selection and characterization of materials for cap construction
- Equipment and placement techniques to be used for cap construction
- Appropriate monitoring and management program, including construction monitoring during cap placement, followed by long-term monitoring. Both a routine maintenance program and a set of actions that may be required based on

monitoring results must be developed. The program must identify regular intervals for the long-term monitoring activities (*e.g.,* annual or other duration) and event-based intervals (*e.g.,* following significant erosion events such as storms, floods, etc.).
- Ability to isolate the contaminated sediments chemically such that the concentration of Tri+ PCBs in the upper 6 in of the cap is 0.25 mg/kg or less.

The specific design details of the capping contingency are to be addressed in the design phase of the Hudson River PCBs site remediation. USEPA will review the submitted design for conformance with the requirements of the ROD and the engineering performance standards.

For purposes of these standards, backfill and isolation cap are defined as follows:

Backfill will consist of a 1-ft thickness of material. It is to be placed, where appropriate, over a dredged surface that meets the Residuals Standard of 1 mg/kg Tri+ PCBs or less. Backfill may also be placed where a CU's arithmetic average PCB concentration is greater than 1 mg/kg Tri+ PCBs and less than or equal to the 95% UCL (3 mg/kg), and the 20-acre joint evaluation area weighted average is less than or equal to 1 mg/kg Tri+ PCBs, with testing to certify that the upper 6 inches of placed backfill contains 0.25 mg/kg or less Tri+ PCBs.

An **isolation cap** is defined as the placement of an engineered subaqueous cover, or cap, of clean isolating material over the contaminated sediment. Such an isolation cap would be designed and constructed such that the cap will remain physically stable and that concentration of Tri+ PCBs in the upper 6 inches will remain at concentrations less than or equal to 0.25 mg/kg. An isolation cap would be appropriate for a situation in which a portion of the contaminated sediment inventory cannot be effectively dredged due to rocky or other conditions, and Tri+ PCB concentrations are elevated over the action levels. The elevation of the isolation cap's surface must be equivalent to the elevation of the surrounding backfill.

The subaqueous cap must be constructed so that:

- The arithmetic average concentration in the uncapped area within the certification unit is 1 mg/kg Tri+ PCBs or less.
- No uncapped nodes are greater than or equal to the 97.5% PL (15 mg/kg).

The placement of backfill and subaqueous cap construction are undesirable in the navigation channel. Cap construction will also be restricted in areas of shallow water. However, there may be instances where a recalcitrant, contaminated residual is present in the navigation channel, and the construction of a subaqueous cap is a desirable option to isolate the residual PCB concentrations. To accommodate the subaqueous cap in this situation, it would be necessary to conduct additional dredging to place the layers of the cap below the channel depth, and include an indicator layer of coarse material to signal the proximity of the cap during future maintenance dredging. Cap construction will not be permitted where shallow bedrock is present in the navigation channel.

4.7 Special Study for Characterization of Residuals Strata and Thickness

A **special study** will be conducted during Phase 1 to characterize the physical structure of the disturbed sediment layer created during dredging. The goal of the study will be to determine whether separate layers of redeposited sediment, disturbed sediment and undisturbed underlying sediment can be readily examined and characterized through the use of sediment profile imagery or other exploration techniques (*e.g.*, coring). The results of the study are intended to aid in the assessment of residual contamination, and may prove most useful for areas that do not conform to the standard after multiple dredging passes. The intention of the study in Phase 1 is to examine a limited number of CUs and assess the usefulness of the technologies. Based on this analysis, additional application of the methods may be required in Phase 2. The data quality objectives for the study are outlined in Attachment B. The final details of the program will be developed during the remedial design.

4.8 Minimum Reporting Requirements

Weekly progress reports will be prepared by the construction manager and submitted to the USEPA site manager, according to a schedule to be defined by the USEPA, for the USEPA's use in evaluating compliance with the Residuals Standard. The reports will need to summarize, at a minimum, the results of residual sediment sampling, exceedances of the Residuals Standard criteria by CU and joint evaluation area, the course of actions taken, and rationale. Laboratory data will need to be made available to USEPA upon receipt from the laboratory.

Following the completion of remedial activities in each certification unit, the construction manager will prepare individual certification unit reports and submit them to the USEPA site manager, according to a schedule to be defined by the USEPA, for the USEPA's use in evaluating compliance with the Residuals Standard. Each certification unit report will need to include, at a minimum, the following information:

- Certification unit identification
- Description of type(s) of dredging equipment used
- Description of sediment type(s) encountered
- Residual sediment sampling results
- Sediment imaging results (if available)
- An attestation that the sampling data was validated, including a discussion of any data qualifiers applied
- The results of the required comparisons to action levels for each dredging pass

- Discussion of any contingency actions taken
- Number of dredging passes for residual concentration reduction
- For each attempt, a map of the CU showing the concentration at each node and the non-compliant area to be redredged or capped

A signed attestation that the CU was closed in accordance with the requirements of the Residuals Standard and the approved remedial design.

4.9 Adjustments to the Standard during Phase 1

Data gathered during Phase 1 will characterize the implementation and efficiency of the remedial design by such activities as:

- Quantifying residual Tri+ PCB concentrations after various dredging and redredging attempts.
- Tracking actual dredging productivity.
- Quantifying water column Tri+ PCB concentrations during dredging and other activities.

It is possible that "lessons learned" during Phase 1 will generate requests for modifications to the remedial design (corrective actions) and selected aspects of the Performance Standards to capitalize on the information gathered as Phase 1 is occurring. It is envisioned that requested corrective actions would be reviewed and acted upon via the following process:

1. The construction manager will prepare and submit correspondence to USEPA describing the requested modification and including supporting data to facilitate agency decision-making.

2. USEPA will review the request and supporting data and respond in writing with an approval, request for further information, or rejection of the requested modification.

3. During the USEPA review period, the construction manager will continue work under the existing remedial design and performance standard framework. The requested modification may not be implemented in the field until approval is received from USEPA.

5.0 References

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Tables

Table 1-1
Case Study Information

Site	Dredge	Subbottom	Number of Passes	No. of Samples	Sample Grid Size	Sampling Method	Sample Depth	Analytical Method	Post-dredge Avg. Conc. (ppm)	Target Conc. (ppm)
Reynolds Metals	Cable Arm, Rock Bucket, and Hydraulic Clamshell	Mud, clay, sand, gravel and cobbles underlain by till	Maximum of 10	263	50x50' & 70x70'	Core	0-8 in.	Aroclors (EPA 8082) and Immunoassay	2 (Excluding the one quadrant with conc. 5,941 ppm)	1
GM Massena	Horizontal Auger	Clay, silt, and fine-grained sand containing gravel, cobbles, and large boulders underlain by till	Typically 2 to 6 15 to 18 passes in some areas.	111	50x50' & 70x70'	Core	0-6 in.	Aroclors (EPA 8082)	3	1
New Bedford Predredge Test	Hydraulic Excavator with a Clamshell Bucket	Soft Clay	1	18	~40x40'	Cores and Grabs	0-1 ft. 0-2 cm.	NOAA 18 Congener	29 (0-1 ft.)	None
Cumberland Bay	Hydraulic Cutterhead	Sand	Multiple	69	50x50'	Cores and Grabs	0-2 ft. 0-2 cm.	Aroclor (EPA 8082)	6-7	10
Fox River SMU 56/57	Hydraulic Cutterhead	Silty-Sand overlying Clay	4 subunits were redredged	28	Random within 100x100' grids	Core	0-4 in. and 4-12 in.	Aroclors (EPA 8082)	2 (0-4 in.)	10
Fox River Deposit N	Hydraulic Cutterhead with a Swinging Ladder	Silty-Sand overlying Clay	Not Available	36	Random within 50x50' grids	Cores and Grabs	0-6 in.	Aroclors	8	None
Grasse River Inventory Removal	Horizontal Auger	Rocky with a Boulder field	Multiple	12	Random	Cores	0-6 in. to 0-8 in.	Aroclors	80	None

Notes:
1. The Marathon Battery site is omitted from this table because a report was not available .
2. PCB contamination was present at each site listed.

Table 2-1
Summary Statistics for Case Studies

Reynolds Metals

Normal Distribution		Lognormal Distribution			
Number of Samples	263	Number of Samples	263	Minimum	-3.218876
Minimum	0.04	Minimum	0.04	Maximum	4.7912928
Maximum	120.457	Maximum	120.457	Mean	-0.317828
Mean	2.37546768	Mean	2.3754677	Standard Deviation	1.1903279
Median	0.5	Median	0.5	Variance	1.4168806
Standard Deviation	9.58444658	Standard Deviation	9.5844466		
Variance	91.8616162	Variance	91.861616	Lilliefors Test Statisitic	0.2165685
Coefficient of Variation	4.03476194	Coefficient of Variation	4.0347619	Lilliefors 5% Critical Value	0.0546331
Skewness	9.39213246	Skewness	9.3921325	Data Not Lognormal at 5% Significance Level	
				Try Normal or Non-parametric UCL	
Lilliefors Test Statisitic	0.40374222	95 % UCL (Normal Data)			
Lilliefors 5% Critical Value	0.0546331	Student's t	3.3510293	Estimates Assuming Lognormal Distribution	
Data Not Normal at 0.05 Significance Level				MLE Mean	1.4778851
Try Lognormal or Non-parametric UCL		95 % UCL (Adjusted for Skewness)		MLE Standard Deviation	2.6122367
		Adjusted CLT	3.713306	MLE Coefficient of Variation	1.7675506
95 % UCL (Normal Data)		Modified t	3.4080751	MLE Skewness	10.824896
Student's t	3.35102925			MLE Median	0.7277278
		95 % Non-parametric UCL		MLE 80% Quantile	1.9897298
95 % UCL (Adjusted for Skewness)		CLT	3.3475799	MLE 90% Quantile	3.3593354
Adjusted CLT	3.71330602	Jackknife	3.3510293	MLE 95% Quantile	5.1565163
Modified t	3.40807513	Standard Bootstrap	3.3277375	MLE 99% Quantile	11.598486
		Bootstrap t	4.4723665		
95 % Non-parametric UCL		Chebyshev (Mean, Std)	4.951587	MVU Estimate of Median	0.7257701
CLT	3.34757995			MVU Estimate of Mean	1.4711508
Jackknife	3.35102925	97.5 % Non-parametric UCL		MVU Estimate of Std. Dev.	2.5512107
Standard Bootstrap	3.35265422	Chebyshev (Mean, Std)	6.0662758	MVU Estimate of SE of Mean	0.139453
Bootstrap t	4.39854247				
Chebyshev (Mean, Std)	4.95158696	99 % Non-parametric UCL		UCL Assuming Lognormal Distribution	
		Chebyshev (Mean, Std)	8.2558663	95% H-UCL	1.7485376
				95% Chebyshev (MVUE) UCL	2.0790125
				99% Chebyshev (MVUE) UCL	2.858691
				Recommended UCL to use:	H-UCL

NOTE: Units are in mg/kg

Table 2-1
Summary Statistics for Case Studies

East Foundry Cove Marathon Battery

Normal Distribution		Lognormal Distribution			
Number of Samples	85	Number of Samples	85	Minimum	-2.30258509
Minimum	0.1	Minimum	0.1	Maximum	4.477336814
Maximum	88	Maximum	88	Mean	2.232355205
Mean	13.265294	Mean	13.265294	Standard Deviation	0.946246934
Median	9.2	Median	9.2	Variance	0.895383259
Standard Deviation	12.53175	Standard Deviation	12.53175		
Variance	157.04476	Variance	157.04476	Lilliefors Test Statisitic	0.104529935
Coefficient of Variation	0.944702	Coefficient of Variation	0.944702	Lilliefors 5% Critical Value	0.096100193
Skewness	3.2110989	Skewness	3.2110989	Data Not Lognormal at 5% Significance Level	
				Try Normal or Non-parametric UCL	
Lilliefors Test Statisitic	0.1752375	95 % UCL (Normal Data)			
Lilliefors 5% Critical Value	0.0961002	Student's t	15.526009	Estimates Assuming Lognormal Distribution	
Data Not Normal at 0.05 Significance Level				MLE Mean	14.5857764
Try Lognormal or Non-parametric UCL		95 % UCL (Adjusted for Skewness)		MLE Standard Deviation	17.55314371
		Adjusted CLT	16.006932	MLE Coefficient of Variation	1.203442534
95 % UCL (Normal Data)		Modified t	15.604912	MLE Skewness	5.353242056
Student's t	15.526009			MLE Median	9.321794982
		95 % Non-parametric UCL		MLE 80% Quantile	20.73729694
95 % UCL (Adjusted for Skewness)		CLT	15.501076	MLE 90% Quantile	31.44633727
Adjusted CLT	16.006932	Jackknife	15.526009	MLE 95% Quantile	44.20913361
Modified t	15.604912	Standard Bootstrap	15.456639	MLE 99% Quantile	84.21100154
		Bootstrap t	16.225874		
95 % Non-parametric UCL		Chebyshev (Mean, Std)	19.190167	MVU Estimate of Median	9.272823537
CLT	15.501076			MVU Estimate of Mean	14.47660349
Jackknife	15.526009	97.5 % Non-parametric UCL		MVU Estimate of Std. Dev.	16.91577065
Standard Bootstrap	15.42967	Chebyshev (Mean, Std)	21.753865	MVU Estimate of SE of Mean	1.748954098
Bootstrap t	16.182128				
Chebyshev (Mean, Std)	19.190167	99 % Non-parametric UCL		UCL Assuming Lognormal Distribution	
		Chebyshev (Mean, Std)	26.789752	95% H-UCL	18.26224888
				95% Chebyshev (MVUE) UCL	22.10011766
				99% Chebyshev (MVUE) UCL	31.87847705
				Recommended UCL to use:	H-UCL

NOTE: Units are in mg/kg

Table 2-1
Summary Statistics for Case Studies

New Bedford Harbor (0-1 ft.)

Normal Distribution		Lognormal Distribution			
Number of Samples	18	Number of Samples	18	Minimum	-0.400478
Minimum	0.67	Minimum	0.67	Maximum	4.8675345
Maximum	130	Maximum	130	Mean	2.7656102
Mean	29.065	Mean	29.065	Standard Deviation	1.2326933
Median	15	Median	15	Variance	1.5195329
Standard Deviation	33.8794253	Standard Deviation	33.879425		
Variance	1147.81546	Variance	1147.8155	Shapiro-Wilk Test Statisitic	0.9501964
Coefficient of Variation	1.1656434	Coefficient of Variation	1.1656434	Shapiro-Wilk 5% Critical Value	0.897
Skewness	1.95343137	Skewness	1.9534314	Data Are Lognormal at 5% Significance Level	
Shapiro-Wilk Test Statisitic	0.74634222	95 % UCL (Normal Data)		Estimates Assuming Lognormal Distribution	
Shapiro-Wilk 5% Critical Value	0.897	Student's t	42.956553	MLE Mean	33.966565
Data Not Normal at 0.05 Significance Level				MLE Standard Deviation	64.178741
Try Lognormal or Non-parametric UCL		95 % UCL (Adjusted for Skewness)		MLE Coefficient of Variation	1.8894681
		Adjusted CLT	46.128547	MLE Skewness	12.413975
95 % UCL (Normal Data)		Modified t	43.569341	MLE Median	15.888733
Student's t	42.956553			MLE 80% Quantile	45.025819
		95 % Non-parametric UCL		MLE 90% Quantile	77.449116
95 % UCL (Adjusted for Skewness)		Chebyshev (Mean, Std)	63.872801	MLE 95% Quantile	120.70997
Adjusted CLT	46.1285469			MLE 99% Quantile	279.45881
Modified t	43.5693412	97.5 % Non-parametric UCL			
		CLT	46.584386	MVU Estimate of Median	15.230602
95 % Non-parametric UCL		Jackknife	47.929724	MVU Estimate of Mean	31.76221
CLT	42.1999081	Standard Bootstrap	46.02077	MVU Estimate of Std. Dev.	48.170573
Jackknife	42.956553	Bootstrap t	60.975621	MVU Estimate of SE of Mean	10.560521
Standard Bootstrap	42.0065579	Chebyshev (Mean, Std)	82.627761		
Bootstrap t	50.8459146			UCL Assuming Lognormal Distribution	
Chebyshev (Mean, Std)	63.8728007	99 % Non-parametric UCL		95% H-UCL	83.653334
		Chebyshev (Mean, Std)	108.5193	**95% Chebyshev (MVUE) UCL**	**77.794451**
				99% Chebyshev (MVUE) UCL	136.83806
				Recommended UCL to use:	
				95 % Chebyshev (MVUE) UCL	

NOTE: Units are in mg/kg

Table 2-1
Summary Statistics for Case Studies

New Bedford Harbor (0-2 cm)

Normal Distribution		Lognormal Distribution			
Number of Samples	35	Number of Samples	35	Minimum	-0.755023
Minimum	0.47	Minimum	0.47	Maximum	6.1527327
Maximum	470	Maximum	470	Mean	4.6412476
Mean	173.922	Mean	173.922	Standard Deviation	1.38356
Median	140	Median	140	Variance	1.9142383
Standard Deviation	136.498253	Standard Deviation	136.49825		
Variance	18631.7732	Variance	18631.773	Shapiro-Wilk Test Statisitic	0.8313256
Coefficient of Variation	0.78482454	Coefficient of Variation	0.7848245	Shapiro-Wilk 5% Critical Value	0.934
Skewness	0.76596072	Skewness	0.7659607	Data Not Lognormal at 5% Significance Level	
				Try Normal or Non-parametric UCL	
Shapiro-Wilk Test Statisitic	0.90555522	95 % UCL (Normal Data)			
Shapiro-Wilk 5% Critical Value	0.934	Student's t	212.9357	Estimates Assuming Lognormal Distribution	
Data Not Normal at 0.05 Significance Level				MLE Mean	269.98509
Try Lognormal or Non-parametric UCL		95 % UCL (Adjusted for Skewness)		MLE Standard Deviation	649.18764
		Adjusted CLT	215.06462	MLE Coefficient of Variation	2.4045314
95 % UCL (Normal Data)		Modified t	213.43357	MLE Skewness	21.116045
Student's t	212.935702			MLE Median	103.67361
		95 % Non-parametric UCL		MLE 80% Quantile	333.73785
95 % UCL (Adjusted for Skewness)		CLT	211.87275	MLE 90% Quantile	613.46439
Adjusted CLT	215.064623	Jackknife	212.9357	MLE 95% Quantile	1009.4933
Modified t	213.43357	Standard Bootstrap	210.91456	MLE 99% Quantile	2589.9871
		Bootstrap t	216.07113		
95 % Non-parametric UCL		Chebyshev (Mean, Std)	274.49233	MVU Estimate of Median	100.87484
CLT	211.872747			MVU Estimate of Mean	256.83879
Jackknife	212.935702	97.5 % Non-parametric UCL		MVU Estimate of Std. Dev.	514.7549
Standard Bootstrap	211.209841	Chebyshev (Mean, Std)	318.00919	MVU Estimate of SE of Mean	75.435962
Bootstrap t	217.189058				
Chebyshev (Mean, Std)	274.492329	99 % Non-parametric UCL		UCL Assuming Lognormal Distribution	
		Chebyshev (Mean, Std)	403.48964	**95% H-UCL**	**534.68894**
				95% Chebyshev (MVUE) UCL	585.65652
				99% Chebyshev (MVUE) UCL	1007.4171
				Recommended UCL to use:	H-UCL

NOTE: Units are in mg/kg

Table 2-1
Summary Statistics for Case Studies

Fox River Deposit N

Normal Distribution		Lognormal Distribution			
Number of Samples	36	Number of Samples	36	Minimum	-2.302585
Minimum	0.1	Minimum	0.1	Maximum	3.7612001
Maximum	43	Maximum	43	Mean	0.9788068
Mean	7.56388889	Mean	7.5638889	Standard Deviation	1.5784163
Median	2.2	Median	2.2	Variance	2.4913981
Standard Deviation	11.0019778	Standard Deviation	11.001978		
Variance	121.043516	Variance	121.04352	Shapiro-Wilk Test Statisitic	0.9585836
Coefficient of Variation	1.45453985	Coefficient of Variation	1.4545399	Shapiro-Wilk 5% Critical Value	0.935
Skewness	1.90171296	Skewness	1.901713	Data Are Lognormal at 5% Significance Level	
Shapiro-Wilk Test Statisitic	0.68743355	95 % UCL (Normal Data)		Estimates Assuming Lognormal Distribution	
Shapiro-Wilk 5% Critical Value	0.935	Student's t	10.661995	MLE Mean	9.2489112
Data Not Normal at 0.05 Significance Level				MLE Standard Deviation	30.783944
Try Lognormal or Non-parametric UCL		95 % UCL (Adjusted for Skewness)		MLE Coefficient of Variation	3.3283857
		Adjusted CLT	11.200999	MLE Skewness	46.857517
95 % UCL (Normal Data)		Modified t	10.758859	MLE Median	2.6612788
Student's t	10.6619947			MLE 80% Quantile	10.100335
		95 % Non-parametric UCL		MLE 90% Quantile	20.228081
95 % UCL (Adjusted for Skewness)		Chebyshev (Mean, Std)	15.55664	MLE 95% Quantile	35.70539
Adjusted CLT	11.200999			MLE 99% Quantile	104.60624
Modified t	10.7588586	99 % Non-parametric UCL			
		Chebyshev (Mean, Std)	25.808605	MVU Estimate of Median	2.5706829
95 % Non-parametric UCL				MVU Estimate of Mean	8.6125296
CLT	10.5799961			MVU Estimate of Std. Dev.	22.078824
Jackknife	10.6619947	97.5 % Non-parametric UCL		MVU Estimate of SE of Mean	2.9588652
Standard Bootstrap	10.5022151	CLT	11.157802		
Bootstrap t	11.5704128	Jackknife	11.286422	UCL Assuming Lognormal Distribution	
Chebyshev (Mean, Std)	15.5566405	Standard Bootstrap	11.147567	95% H-UCL	21.350789
		Bootstrap t	12.993791	**95% Chebyshev (MVUE) UCL**	**21.509924**
		Chebyshev (Mean, Std)	19.01511	99% Chebyshev (MVUE) UCL	38.052866
				Recommended UCL to use:	
				95 % Chebyshev (MVUE) UCL	

NOTE: Units are in mg/kg

Table 2-1
Summary Statistics for Case Studies

Fox River SMU 56/57

Normal Distribution		Lognormal Distribution			
Number of Samples	28	Number of Samples	28	Minimum	-3.963316
Minimum	0.019	Minimum	0.019	Maximum	2.2512918
Maximum	9.5	Maximum	9.5	Mean	0.0418062
Mean	2.15235714	Mean	2.1523571	Standard Deviation	1.4477639
Median	1.5	Median	1.5	Variance	2.0960202
Standard Deviation	2.46622094	Standard Deviation	2.4662209		
Variance	6.08224572	Variance	6.0822457	Shapiro-Wilk Test Statisitic	0.9473799
Coefficient of Variation	1.14582329	Coefficient of Variation	1.1458233	Shapiro-Wilk 5% Critical Value	0.924
Skewness	1.87173306	Skewness	1.8717331	Data Are Lognormal at 5% Significance Level	
Shapiro-Wilk Test Statisitic	0.7627895	95 % UCL (Normal Data)		Estimates Assuming Lognormal Distribution	
Shapiro-Wilk 5% Critical Value	0.924	Student's t	2.946212	MLE Mean	2.9737279
Data Not Normal at 0.05 Significance Level				MLE Standard Deviation	7.9425453
Try Lognormal or Non-parametric UCL		95 % UCL (Adjusted for Skewness)		MLE Coefficient of Variation	2.6709053
		Adjusted CLT	3.0951336	MLE Skewness	27.066246
95 % UCL (Normal Data)		Modified t	2.9736888	MLE Median	1.0426924
Student's t	2.94621196			MLE 80% Quantile	3.5436834
		95 % Non-parametric UCL		MLE 90% Quantile	6.7005043
95 % UCL (Adjusted for Skewness)		CLT	2.9189773	MLE 95% Quantile	11.28391
Adjusted CLT	3.09513362	Jackknife	2.946212	MLE 99% Quantile	30.244217
Modified t	2.97368879	Standard Bootstrap	2.916509		
		Bootstrap t	3.2880817	MVU Estimate of Median	1.0043382
95 % Non-parametric UCL		Chebyshev (Mean, Std)	4.1839177	MVU Estimate of Mean	2.7729667
CLT	2.91897728			MVU Estimate of Std. Dev.	5.7946196
Jackknife	2.94621196	97.5 % Non-parametric UCL		MVU Estimate of SE of Mean	0.94187
Standard Bootstrap	2.89246037	Chebyshev (Mean, Std)	5.0629755		
Bootstrap t	3.23818912			UCL Assuming Lognormal Distribution	
Chebyshev (Mean, Std)	4.18391767	99 % Non-parametric UCL		**95% H-UCL**	**6.9967449**
		Chebyshev (Mean, Std)	6.7897145	95% Chebyshev (MVUE) UCL	6.878483
				99% Chebyshev (MVUE) UCL	12.144455
				Recommended UCL to use:	H-UCL

NOTE: Units are in mg/kg

Table 2-1
Summary Statistics for Case Studies

Cumberland Bay

Normal Distribution		Lognormal Distribution			
Number of Samples	69	Number of Samples	69	Minimum	-2.407946
Minimum	0.09	Minimum	0.09	Maximum	4.8675345
Maximum	130	Maximum	130	Mean	1.9421117
Mean	13.4402899	Mean	13.44029	Standard Deviation	1.3535453
Median	8.7	Median	8.7	Variance	1.832085
Standard Deviation	18.4796242	Standard Deviation	18.479624		
Variance	341.496512	Variance	341.49651	Lilliefors Test Statisitic	0.1704982
Coefficient of Variation	1.37494239	Coefficient of Variation	1.3749424	Lilliefors 5% Critical Value	0.1066619
Skewness	4.27803012	Skewness	4.2780301	Data Not Lognormal at 5% Significance Level	
				Try Normal or Non-parametric UCL	
Lilliefors Test Statisitic	0.24897719	95 % UCL (Normal Data)			
Lilliefors 5% Critical Value	0.10666187	Student's t	17.150113	Estimates Assuming Lognormal Distribution	
Data Not Normal at 0.05 Significance Level				MLE Mean	17.429325
Try Lognormal or Non-parametric UCL		95 % UCL (Adjusted for Skewness)		MLE Standard Deviation	39.9238
		Adjusted CLT	18.323816	MLE Coefficient of Variation	2.2906107
95 % UCL (Normal Data)		Modified t	17.34107	MLE Skewness	18.890432
Student's t	17.1501128			MLE Median	6.9734611
		95 % Non-parametric UCL		MLE 80% Quantile	21.886226
95 % UCL (Adjusted for Skewness)		CLT	17.099572	MLE 90% Quantile	39.702629
Adjusted CLT	18.3238165	Jackknife	17.150113	MLE 95% Quantile	64.630972
Modified t	17.3410703	Standard Bootstrap	17.00876	MLE 99% Quantile	162.46427
		Bootstrap t	19.747748		
95 % Non-parametric UCL		Chebyshev (Mean, Std)	23.137468	MVU Estimate of Median	6.8814761
CLT	17.0995716			MVU Estimate of Mean	17.006707
Jackknife	17.1501128	97.5 % Non-parametric UCL		MVU Estimate of Std. Dev.	35.348288
Standard Bootstrap	16.9797274	Chebyshev (Mean, Std)	27.333445	MVU Estimate of SE of Mean	3.624611
Bootstrap t	19.4844389				
Chebyshev (Mean, Std)	23.1374684	99 % Non-parametric UCL		UCL Assuming Lognormal Distribution	
		Chebyshev (Mean, Std)	35.575629	**95% H-UCL**	**26.827136**
				95% Chebyshev (MVUE) UCL	32.80602
				99% Chebyshev (MVUE) UCL	53.071131
				Recommended UCL to use:	H-UCL

NOTE: Units are in mg/kg

Table 2-1
Summary Statistics for Case Studies

GM Massena Uncapped Areas

Normal Distribution		Lognormal Distribution			
Number of Samples	83	Number of Samples	83	Minimum	-2.302585
Minimum	0.1	Minimum	0.1	Maximum	2.1282317
Maximum	8.4	Maximum	8.4	Mean	0.6180034
Mean	3.24337349	Mean	3.2433735	Standard Deviation	1.3229122
Median	3.1	Median	3.1	Variance	1.7500967
Standard Deviation	2.51610388	Standard Deviation	2.5161039		
Variance	6.33077873	Variance	6.3307787	Lilliefors Test Statisitic	0.1763712
Coefficient of Variation	0.77576754	Coefficient of Variation	0.7757675	Lilliefors 5% Critical Value	0.0972511
Skewness	0.38505553	Skewness	0.3850555	Data Not Lognormal at 5% Significance Level	
				Try Normal or Non-parametric UCL	
Lilliefors Test Statisitic	0.12870992	95 % UCL (Normal Data)			
Lilliefors 5% Critical Value	0.09725113	Student's t	3.7028372	Estimates Assuming Lognormal Distribution	
Data Not Normal at 0.05 Significance Level				MLE Mean	4.4506571
Try Lognormal or Non-parametric UCL		95 % UCL (Adjusted for Skewness)		MLE Standard Deviation	9.7052486
		Adjusted CLT	3.7101189	MLE Coefficient of Variation	2.1806327
95 % UCL (Normal Data)		Modified t	3.7047826	MLE Skewness	16.911154
Student's t	3.70283719			MLE Median	1.8552202
		95 % Non-parametric UCL		MLE 80% Quantile	5.6738291
95 % UCL (Adjusted for Skewness)		CLT	3.6976463	MLE 90% Quantile	10.154791
Adjusted CLT	3.71011886	Jackknife	3.7028372	MLE 95% Quantile	16.349445
Modified t	3.70478265	Standard Bootstrap	3.6817777	MLE 99% Quantile	40.249484
		Bootstrap t	3.7199999		
95 % Non-parametric UCL		Chebyshev (Mean, Std)	4.4472067	MVU Estimate of Median	1.8357614
CLT	3.69764634			MVU Estimate of Mean	4.3659761
Jackknife	3.70283719	99 % Non-parametric UCL		MVU Estimate of Std. Dev.	8.8141736
Standard Bootstrap	3.69274581	CLT	3.8858603	MVU Estimate of SE of Mean	0.8294745
Bootstrap t	3.71693112	Jackknife	3.8986581		
Chebyshev (Mean, Std)	4.44720671	Standard Bootstrap	3.8847076	UCL Assuming Lognormal Distribution	
Chebyshev (Mean, Std)	4.44720671	Bootstrap t	3.9534834	**95% H-UCL**	**6.4661883**
		Chebyshev (Mean, Std)	5.9913127	95% Chebyshev (MVUE) UCL	7.9815715
				99% Chebyshev (MVUE) UCL	12.619143
				Recommended UCL to use:	H-UCL

NOTE: Units are in mg/kg

Table 2-1
Summary Statistics for Case Studies

GM Massena Pass 1

Normal Distribution		Lognormal Distribution			
Number of Samples	83	Number of Samples	83	Minimum	-2.617296
Minimum	0.073	Minimum	0.073	Maximum	8.9834398
Maximum	7970	Maximum	7970	Mean	1.883984
Mean	192.840265	Mean	192.84027	Standard Deviation	2.3538202
Median	5.68	Median	5.68	Variance	5.5404693
Standard Deviation	940.857471	Standard Deviation	940.85747		
Variance	885212.78	Variance	885212.78	Lilliefors Test Statisitic	0.1341868
Coefficient of Variation	4.8789472	Coefficient of Variation	4.8789472	Lilliefors 5% Critical Value	0.0972511
Skewness	7.34681485	Skewness	7.3468148	Data Not Lognormal at 5% Significance Level	
				Try Normal or Non-parametric UCL	
Lilliefors Test Statisitic	0.41883114	95 % UCL (Normal Data)			
Lilliefors 5% Critical Value	0.09725113	Student's t	364.64949	Estimates Assuming Lognormal Distribution	
Data Not Normal at 0.05 Significance Level				MLE Mean	105.02712
Try Lognormal or Non-parametric UCL		95 % UCL (Adjusted for Skewness)		MLE Standard Deviation	1673.1897
		Adjusted CLT	451.69518	MLE Coefficient of Variation	15.931025
95 % UCL (Normal Data)		Modified t	378.52962	MLE Skewness	4091.0481
Student's t	364.649486			MLE Median	6.5796658
		95 % Non-parametric UCL		MLE 80% Quantile	48.084601
95 % UCL (Adjusted for Skewness)		CLT	362.70845	MLE 90% Quantile	135.45546
Adjusted CLT	451.695182	Jackknife	364.64949	MLE 95% Quantile	316.08719
Modified t	378.529618	Standard Bootstrap	353.66584	MLE 99% Quantile	1570.2178
		Bootstrap t	769.82837		
95 % Non-parametric UCL		Chebyshev (Mean, Std)	642.99476	MVU Estimate of Median	6.3636006
CLT	362.708451			MVU Estimate of Mean	93.546427
Jackknife	364.649486	99 % Non-parametric UCL		MVU Estimate of Std. Dev.	905.03614
Standard Bootstrap	359.140366	Chebyshev (Mean, Std)	1220.3889	MVU Estimate of SE of Mean	40.037661
Bootstrap t	744.579574				
Chebyshev (Mean, Std)	642.994761			UCL Assuming Lognormal Distribution	
				95% H-UCL	**282.22836**
				95% Chebyshev (MVUE) UCL	268.06654
				99% Chebyshev (MVUE) UCL	491.91612
				Recommended UCL to use:	H-UCL

NOTE: Units are in mg/kg

Table 2-1
Summary Statistics for Case Studies

GM Massena Pass 2

Normal Distribution		Lognormal Distribution			
Number of Samples	101	Number of Samples	101	Minimum	-2.617296
Minimum	0.073	Minimum	0.073	Maximum	7.927685
Maximum	2773	Maximum	2773	Mean	1.4946466
Mean	51.3407723	Mean	51.340772	Standard Deviation	2.0537772
Median	4.66	Median	4.66	Variance	4.2180006
Standard Deviation	279.519802	Standard Deviation	279.5198		
Variance	78131.3195	Variance	78131.32	Lilliefors Test Statisitic	0.0915029
Coefficient of Variation	5.44440197	Coefficient of Variation	5.444402	Lilliefors 5% Critical Value	0.0881603
Skewness	9.43741581	Skewness	9.4374158	Data Not Lognormal at 5% Significance Level	
				Try Normal or Non-parametric UCL	
Lilliefors Test Statisitic	0.42723671	95 % UCL (Normal Data)			
Lilliefors 5% Critical Value	0.0881603	Student's t	97.517293	Estimates Assuming Lognormal Distribution	
Data Not Normal at 0.05 Significance Level				MLE Mean	36.731951
Try Lognormal or Non-parametric UCL		95 % UCL (Adjusted for Skewness)		MLE Standard Deviation	300.43412
		Adjusted CLT	124.99726	MLE Coefficient of Variation	8.1790951
95 % UCL (Normal Data)		Modified t	101.87034	MLE Skewness	571.6991
Student's t	97.517293			MLE Median	4.4577611
		95 % Non-parametric UCL		MLE 80% Quantile	25.281891
95 % UCL (Adjusted for Skewness)		CLT	97.089514	MLE 90% Quantile	62.411547
Adjusted CLT	124.997256	Jackknife	97.517293	MLE 95% Quantile	130.72686
Modified t	101.870337	Standard Bootstrap	97.094767	MLE 99% Quantile	529.39367
		Bootstrap t	269.39029		
95 % Non-parametric UCL		Chebyshev (Mean, Std)	172.57596	MVU Estimate of Median	4.3656242
CLT	97.0895136			MVU Estimate of Mean	34.541133
Jackknife	97.517293	99 % Non-parametric UCL		MVU Estimate of Std. Dev.	215.85848
Standard Bootstrap	96.3415467	Chebyshev (Mean, Std)	328.07921	MVU Estimate of SE of Mean	11.271008
Bootstrap t	276.540047				
Chebyshev (Mean, Std)	172.575961			UCL Assuming Lognormal Distribution	
				95% H-UCL	**73.243625**
				95% Chebyshev (MVUE) UCL	83.670317
				99% Chebyshev (MVUE) UCL	146.68624
				Recommended UCL to use:	H-UCL

NOTE: Units are in mg/kg

Table 2-1
Summary Statistics for Case Studies

GM Massena Pass 3

Normal Distribution		Lognormal Distribution			
Number of Samples	108	Number of Samples	108	Minimum	-2.617296
Minimum	0.073	Minimum	0.073	Maximum	7.1308988
Maximum	1250	Maximum	1250	Mean	1.4193864
Mean	40.9644537	Mean	40.964454	Standard Deviation	2.0443003
Median	3.995	Median	3.995	Variance	4.1791635
Standard Deviation	145.395453	Standard Deviation	145.39545		
Variance	21139.8377	Variance	21139.838	Lilliefors Test Statisitic	0.109575
Coefficient of Variation	3.54930774	Coefficient of Variation	3.5493077	Lilliefors 5% Critical Value	0.0852554
Skewness	6.30064135	Skewness	6.3006414	Data Not Lognormal at 5% Significance Level	
				Try Normal or Non-parametric UCL	
Lilliefors Test Statisitic	0.40580308	95 % UCL (Normal Data)			
Lilliefors 5% Critical Value	0.08525539	Student's t	64.178062	Estimates Assuming Lognormal Distribution	
Data Not Normal at 0.05 Significance Level				MLE Mean	33.413773
Try Lognormal or Non-parametric UCL		95 % UCL (Adjusted for Skewness)		MLE Standard Deviation	267.95929
		Adjusted CLT	73.040504	MLE Coefficient of Variation	8.0194263
95 % UCL (Normal Data)		Modified t	65.591772	MLE Skewness	539.7972
Student's t	64.1780616			MLE Median	4.1345828
		95 % Non-parametric UCL		MLE 80% Quantile	23.261977
95 % UCL (Adjusted for Skewness)		CLT	63.977081	MLE 90% Quantile	57.186179
Adjusted CLT	73.0405038	Jackknife	64.178062	MLE 95% Quantile	119.37387
Modified t	65.5917724	Standard Bootstrap	63.40722	MLE 99% Quantile	480.3086
		Bootstrap t	87.332635		
95 % Non-parametric UCL		Chebyshev (Mean, Std)	101.94843	MVU Estimate of Median	4.055342
CLT	63.977081			MVU Estimate of Mean	31.567596
Jackknife	64.1780616	99 % Non-parametric UCL		MVU Estimate of Std. Dev.	197.0267
Standard Bootstrap	63.3977181	Chebyshev (Mean, Std)	180.17	MVU Estimate of SE of Mean	9.9507611
Bootstrap t	88.1537284				
Chebyshev (Mean, Std)	101.948431			UCL Assuming Lognormal Distribution	
				95% H-UCL	**64.560527**
				95% Chebyshev (MVUE) UCL	74.941957
				99% Chebyshev (MVUE) UCL	130.57642
				Recommended UCL to use:	H-UCL

NOTE: Units are in mg/kg

Table 2-1
Summary Statistics for Case Studies

GM Massena Pass 4

Normal Distribution		Lognormal Distribution			
Number of Samples	111	Number of Samples	111	Minimum	-2.617296
Minimum	0.073	Minimum	0.073	Maximum	6.9382845
Maximum	1031	Maximum	1031	Mean	1.3653794
Mean	34.7532162	Mean	34.753216	Standard Deviation	2.012762
Median	3.81	Median	3.81	Variance	4.051211
Standard Deviation	118.195981	Standard Deviation	118.19598		
Variance	13970.2899	Variance	13970.29	Lilliefors Test Statisitic	0.1178874
Coefficient of Variation	3.40100842	Coefficient of Variation	3.4010084	Lilliefors 5% Critical Value	0.0840954
Skewness	6.36035657	Skewness	6.3603566	Data Not Lognormal at 5% Significance Level	
				Try Normal or Non-parametric UCL	
Lilliefors Test Statisitic	0.39445567	95 % UCL (Normal Data)			
Lilliefors 5% Critical Value	0.0840954	Student's t	53.363008	Estimates Assuming Lognormal Distribution	
Data Not Normal at 0.05 Significance Level				MLE Mean	29.695184
Try Lognormal or Non-parametric UCL		95 % UCL (Adjusted for Skewness)		MLE Standard Deviation	223.14307
		Adjusted CLT	60.442997	MLE Coefficient of Variation	7.5144532
95 % UCL (Normal Data)		Modified t	54.491789	MLE Skewness	446.86205
Student's t	53.3630076			MLE Median	3.9172089
		95 % Non-parametric UCL		MLE 80% Quantile	21.459411
95 % UCL (Adjusted for Skewness)		CLT	53.20628	MLE 90% Quantile	52.027821
Adjusted CLT	60.4429971	Jackknife	53.363008	MLE 95% Quantile	107.37989
Modified t	54.4917892	Standard Bootstrap	53.206037	MLE 99% Quantile	422.86961
		Bootstrap t	74.226061		
95 % Non-parametric UCL		Chebyshev (Mean, Std)	83.654248	MVU Estimate of Median	3.8463618
CLT	53.2062797			MVU Estimate of Mean	28.172485
Jackknife	53.3630076	99 % Non-parametric UCL		MVU Estimate of Std. Dev.	167.81704
Standard Bootstrap	53.1596447	Chebyshev (Mean, Std)	146.37753	MVU Estimate of SE of Mean	8.5803464
Bootstrap t	73.0054821				
Chebyshev (Mean, Std)	83.6542477			UCL Assuming Lognormal Distribution	
				95% H-UCL	**55.809618**
				95% Chebyshev (MVUE) UCL	65.573348
				99% Chebyshev (MVUE) UCL	113.54585
				Recommended UCL to use:	H-UCL

NOTE: Units are in mg/kg

Table 2-1
Summary Statistics for Case Studies

GM Massena Pass 5

Normal Distribution		Lognormal Distribution			
Number of Samples	111	Number of Samples	111	Minimum	-2.617296
Minimum	0.073	Minimum	0.073	Maximum	6.4457198
Maximum	630	Maximum	630	Mean	1.3107931
Mean	31.3812342	Mean	31.381234	Standard Deviation	1.9320256
Median	3.9	Median	3.9	Variance	3.7327229
Standard Deviation	98.1246579	Standard Deviation	98.124658		
Variance	9628.44849	Variance	9628.4485	Lilliefors Test Statisitic	0.1346319
Coefficient of Variation	3.12685783	Coefficient of Variation	3.1268578	Lilliefors 5% Critical Value	0.0840954
Skewness	4.26605032	Skewness	4.2660503	Data Not Lognormal at 5% Significance Level	
				Try Normal or Non-parametric UCL	
Lilliefors Test Statisitic	0.44087919	95 % UCL (Normal Data)			
Lilliefors 5% Critical Value	0.0840954	Student's t	46.830824	Estimates Assuming Lognormal Distribution	
Data Not Normal at 0.05 Significance Level				MLE Mean	23.978426
Try Lognormal or Non-parametric UCL		95 % UCL (Adjusted for Skewness)		MLE Standard Deviation	153.14829
		Adjusted CLT	50.730307	MLE Coefficient of Variation	6.3869202
95 % UCL (Normal Data)		Modified t	47.45936	MLE Skewness	279.7008
Student's t	46.830824			MLE Median	3.7091141
		95 % Non-parametric UCL		MLE 80% Quantile	18.97941
95 % UCL (Adjusted for Skewness)		CLT	46.700711	MLE 90% Quantile	44.409169
Adjusted CLT	50.7303072	Jackknife	46.830824	MLE 95% Quantile	89.030158
Modified t	47.4593596	Standard Bootstrap	46.425293	MLE 99% Quantile	331.85051
		Bootstrap t	52.604719		
95 % Non-parametric UCL		Chebyshev (Mean, Std)	71.97819	MVU Estimate of Median	3.647261
CLT	46.7007107			MVU Estimate of Mean	22.897888
Jackknife	46.830824	97.5 % Non-parametric UCL		MVU Estimate of Std. Dev.	119.49894
Standard Bootstrap	47.069511	Chebyshev (Mean, Std)	89.544525	MVU Estimate of SE of Mean	6.5653365
Bootstrap t	55.4274201				
Chebyshev (Mean, Std)	71.9781898	99 % Non-parametric UCL		UCL Assuming Lognormal Distribution	
		Chebyshev (Mean, Std)	124.05019	**95% H-UCL**	**43.161392**
				95% Chebyshev (MVUE) UCL	51.515527
				99% Chebyshev (MVUE) UCL	88.222161
				Recommended UCL to use:	H-UCL

NOTE: Units are in mg/kg

Table 2-1
Summary Statistics for Case Studies

GM Massena Pass 6

Normal Distribution		Lognormal Distribution			
Number of Samples	111	Number of Samples	111	Minimum	-2.617296
Minimum	0.073	Minimum	0.073	Maximum	9.7526647
Maximum	17200	Maximum	17200	Mean	1.3846902
Mean	192.104207	Mean	192.10421	Standard Deviation	2.0984493
Median	4.09	Median	4.09	Variance	4.4034896
Standard Deviation	1635.6954	Standard Deviation	1635.6954		
Variance	2675499.45	Variance	2675499.4	Lilliefors Test Statisitic	0.1689156
Coefficient of Variation	8.51462561	Coefficient of Variation	8.5146256	Lilliefors 5% Critical Value	0.0840954
Skewness	10.409404	Skewness	10.409404	Data Not Lognormal at 5% Significance Level	
				Try Normal or Non-parametric UCL	
Lilliefors Test Statisitic	0.45673265	95 % UCL (Normal Data)			
Lilliefors 5% Critical Value	0.0840954	Student's t	449.64215	Estimates Assuming Lognormal Distribution	
Data Not Normal at 0.05 Significance Level				MLE Mean	36.105131
Try Lognormal or Non-parametric UCL		95 % UCL (Adjusted for Skewness)		MLE Standard Deviation	324.4154
		Adjusted CLT	611.37578	MLE Coefficient of Variation	8.9852991
95 % UCL (Normal Data)		Modified t	475.20764	MLE Skewness	752.3894
Student's t	449.642153			MLE Median	3.9935883
		95 % Non-parametric UCL		MLE 80% Quantile	23.520676
95 % UCL (Adjusted for Skewness)		CLT	447.47322	MLE 90% Quantile	59.216343
Adjusted CLT	611.37578	Jackknife	449.64215	MLE 95% Quantile	126.04504
Modified t	475.20764	Standard Bootstrap	445.98904	MLE 99% Quantile	526.20103
		Bootstrap t	4021.0674		
95 % Non-parametric UCL		Chebyshev (Mean, Std)	868.83781	MVU Estimate of Median	3.9151401
CLT	447.473222			MVU Estimate of Mean	33.991844
Jackknife	449.642153	99 % Non-parametric UCL		MVU Estimate of Std. Dev.	233.61177
Standard Bootstrap	445.240568	Chebyshev (Mean, Std)	1736.8554	MVU Estimate of SE of Mean	11.009002
Bootstrap t	4059.15934				
Chebyshev (Mean, Std)	868.837814			UCL Assuming Lognormal Distribution	
				95% H-UCL	**71.161377**
				95% Chebyshev (MVUE) UCL	81.978971
				99% Chebyshev (MVUE) UCL	143.53003
				Recommended UCL to use:	H-UCL

NOTE: Units are in mg/kg

Table 2-1
Summary Statistics for Case Studies

GM Massena Pass 7

Normal Distribution		Lognormal Distribution			
Number of Samples	111	Number of Samples	111	Minimum	-2.617296
Minimum	0.073	Minimum	0.073	Maximum	7.4079243
Maximum	1649	Maximum	1649	Mean	1.2276367
Mean	26.9147477	Mean	26.914748	Standard Deviation	1.7823737
Median	4.09	Median	4.09	Variance	3.1768559
Standard Deviation	158.20013	Standard Deviation	158.20013		
Variance	25027.2812	Variance	25027.281	Lilliefors Test Statisitic	0.1202548
Coefficient of Variation	5.87782325	Coefficient of Variation	5.8778233	Lilliefors 5% Critical Value	0.0840954
Skewness	10.0042568	Skewness	10.004257	Data Not Lognormal at 5% Significance Level	
				Try Normal or Non-parametric UCL	
Lilliefors Test Statisitic	0.432635	95 % UCL (Normal Data)			
Lilliefors 5% Critical Value	0.0840954	Student's t	51.823136	Estimates Assuming Lognormal Distribution	
Data Not Normal at 0.05 Significance Level				MLE Mean	16.710958
Try Lognormal or Non-parametric UCL		95 % UCL (Adjusted for Skewness)		MLE Standard Deviation	80.092865
		Adjusted CLT	66.848596	MLE Coefficient of Variation	4.7928351
95 % UCL (Normal Data)		Modified t	54.199525	MLE Skewness	124.476
Student's t	51.8231363			MLE Median	3.4131537
		95 % Non-parametric UCL		MLE 80% Quantile	15.390377
95 % UCL (Adjusted for Skewness)		CLT	51.613363	MLE 90% Quantile	33.716484
Adjusted CLT	66.848596	Jackknife	51.823136	MLE 95% Quantile	64.04855
Modified t	54.1995248	Standard Bootstrap	51.791586	MLE 99% Quantile	215.60281
		Bootstrap t	182.64378		
95 % Non-parametric UCL		Chebyshev (Mean, Std)	92.366631	MVU Estimate of Median	3.3646525
CLT	51.613363			MVU Estimate of Mean	16.12557
Jackknife	51.8231363	97.5 % Non-parametric UCL		MVU Estimate of Std. Dev.	66.267232
Standard Bootstrap	52.7797377	Chebyshev (Mean, Std)	120.68771	MVU Estimate of SE of Mean	4.1065247
Bootstrap t	184.358978				
Chebyshev (Mean, Std)	92.3666311	99 % Non-parametric UCL		UCL Assuming Lognormal Distribution	
		Chebyshev (Mean, Std)	176.319	**95% H-UCL**	**27.89429**
				95% Chebyshev (MVUE) UCL	34.025497
				99% Chebyshev (MVUE) UCL	56.984976
				Recommended UCL to use:	H-UCL

NOTE: Units are in mg/kg

Table 2-1
Summary Statistics for Case Studies

GM Massena Pass 8

Normal Distribution		Lognormal Distribution			
Number of Samples	111	Number of Samples	111	Minimum	-2.617296
Minimum	0.073	Minimum	0.073	Maximum	4.5108595
Maximum	91	Maximum	91	Mean	1.149203
Mean	9.34051351	Mean	9.3405135	Standard Deviation	1.6232285
Median	4.09	Median	4.09	Variance	2.6348707
Standard Deviation	16.6216972	Standard Deviation	16.621697		
Variance	276.280818	Variance	276.28082	Lilliefors Test Statisitic	0.1148705
Coefficient of Variation	1.77952713	Coefficient of Variation	1.7795271	Lilliefors 5% Critical Value	0.0840954
Skewness	3.0985833	Skewness	3.0985833	Data Not Lognormal at 5% Significance Level	
				Try Normal or Non-parametric UCL	
Lilliefors Test Statisitic	0.34289033	95 % UCL (Normal Data)			
Lilliefors 5% Critical Value	0.0840954	Student's t	11.957576	Estimates Assuming Lognormal Distribution	
Data Not Normal at 0.05 Significance Level				MLE Mean	11.78277
Try Lognormal or Non-parametric UCL		95 % UCL (Adjusted for Skewness)		MLE Standard Deviation	42.387702
		Adjusted CLT	12.431324	MLE Coefficient of Variation	3.5974309
95 % UCL (Normal Data)		Modified t	12.034909	MLE Skewness	57.348478
Student's t	11.9575764			MLE Median	3.1556768
		95 % Non-parametric UCL		MLE 80% Quantile	12.43893
95 % UCL (Adjusted for Skewness)		CLT	11.935536	MLE 90% Quantile	25.407682
Adjusted CLT	12.431324	Jackknife	11.957576	MLE 95% Quantile	45.577484
Modified t	12.0349093	Standard Bootstrap	11.933457	MLE 99% Quantile	137.66627
		Bootstrap t	12.815109		
95 % Non-parametric UCL		Chebyshev (Mean, Std)	16.217381	MVU Estimate of Median	3.1184402
CLT	11.9355361			MVU Estimate of Mean	11.473004
Jackknife	11.9575764	97.5 % Non-parametric UCL		MVU Estimate of Std. Dev.	36.867029
Standard Bootstrap	11.9830084	Chebyshev (Mean, Std)	19.193008	MVU Estimate of SE of Mean	2.5490774
Bootstrap t	12.9503849				
Chebyshev (Mean, Std)	16.2173813	99 % Non-parametric UCL		UCL Assuming Lognormal Distribution	
		Chebyshev (Mean, Std)	25.038049	**95% H-UCL**	**18.267251**
				95% Chebyshev (MVUE) UCL	22.584175
				99% Chebyshev (MVUE) UCL	36.836004
				Recommended UCL to use:	H-UCL

NOTE: Units are in mg/kg

Table 2-1
Summary Statistics for Case Studies

Grasse River Non-Time-Critical Removal Action

Normal Distribution		Lognormal Distribution			
Number of Samples	12	Number of Samples	12	Minimum	0.0953102
Minimum	1.1	Minimum	1.1	Maximum	5.5606816
Maximum	260	Maximum	260	Mean	3.8216843
Mean	80.3166667	Mean	80.316667	Standard Deviation	1.4394868
Median	63	Median	63	Variance	2.0721223
Standard Deviation	72.4489141	Standard Deviation	72.448914		
Variance	5248.84515	Variance	5248.8452	Shapiro-Wilk Test Statisitic	0.8657577
Coefficient of Variation	0.90204085	Coefficient of Variation	0.9020408	Shapiro-Wilk 5% Critical Value	0.859
Skewness	1.46808782	Skewness	1.4680878	Data Are Lognormal at 5% Significance Level	
Shapiro-Wilk Test Statisitic	0.88071442	95 % UCL (Normal Data)		Estimates Assuming Lognormal Distribution	
Shapiro-Wilk 5% Critical Value	0.859	Student's t	117.87616	MLE Mean	128.73365
Data Are Normal at 0.05 Significance Level				MLE Standard Deviation	339.17493
Recommended UCL to use	Student's t	95 % UCL (Adjusted for Skewness)		MLE Coefficient of Variation	2.6347031
		Adjusted CLT	124.18819	MLE Skewness	26.193323
95 % UCL (Normal Data)		Modified t	119.3534	MLE Median	45.681086
Student's t	117.876158			MLE 80% Quantile	154.1692
		95 % Non-parametric UCL		MLE 90% Quantile	290.4481
95 % UCL (Adjusted for Skewness)		CLT	114.71746	MLE 95% Quantile	487.6706
Adjusted CLT	124.188186	Jackknife	117.87616	MLE 99% Quantile	1299.7545
Modified t	119.353399	Standard Bootstrap	113.35923		
		Bootstrap t	134.71237	MVU Estimate of Median	41.878121
95 % Non-parametric UCL		Chebyshev (Mean, Std)	171.47955	MVU Estimate of Mean	111.24064
CLT	114.717465			MVU Estimate of Std. Dev.	191.42658
Jackknife	117.876158			MVU Estimate of SE of Mean	50.57418
Standard Bootstrap	113.142199				
Bootstrap t	140.660245			UCL Assuming Lognormal Distribution	
Chebyshev (Mean, Std)	171.479551			95% H-UCL	661.23971
				95% Chebyshev (MVUE) UCL	**331.68838**
99 % UCL (Normal Data)				99% Chebyshev (MVUE) UCL	614.44738
Student's t	137.163116			Recommended UCL to use:	
				95 % Chebyshev (MVUE) UCL	

NOTE: Units are in mg/kg

Table 2-2
Summary Statistics for All Sites and Estimates of the UCL and PL

	Result of Normality Test	Arith. Mean	MVUE	Coef. of Variance	Sy	Sx	Central Tendency (1)	95% UCL			99% UCL			97.5% PL			99% PL			
								Site	Hudson River (Proportional)	Hudson River (Using Eqn.) (2)	Site	Hudson River (Proportional)	Hudson River (Using Eqn.) (2)	Site	Hudson River (Proportional)	Hudson River (Using Eqn.) (3)	Site	Hudson River (Proportional)	Hudson River (Using Eqn.) (3)	(4)
Reynolds Metals	Not Normal or Lognormal	2.4	1.5	4.0	1.2	10	1.5	5	3	8	8	6	16	17	11	11	34	23	19	*
Marathon Battery East Foundry Cove	Not Normal or Lognormal	13	14	0.94	0.95	13	13	19	1	10	27	2	21	44	3	7	57	4	10	*
New Bedford Harbor Cores	Lognormal	29	32	1.2	1.2	34	29	78	3	24	137	5	54	230	8	12	410	14	21	*
New Bedford Harbor Grabs	Not Normal or Lognormal	174	257	0.78	1.4	136	174													
Cumberland Bay	Not Normal or Lognormal	13	17	1.4	1.4	18	17	23	1	14	36	2	30	55	3	16	83	5	28	*
Fox River SMU 56/57	Lognormal	2.2	2.8	1.1	1.4	2	2.2	7	3	3	12	6	5	21	10	19	40	19	35	*
Fox River Deposit N	Lognormal	7.6	8.6	1.5	1.6	11	8.6	22	2	9	38	4	18	132	15	25	132	15	48	*
GM Massena Uncapped Areas	Not Normal or Lognormal	3	2	0.8	1.3	3	2	4	2	3	6	3	5	8	4	15	8	4	26	*
GM Massena Pass 1	Not Normal or Lognormal	193	94	4.9	2.4	941	94													
GM Massena Pass 2	Not Normal or Lognormal	51	35	5.4	2.1	280	35													
GM Massena Pass 3	Not Normal or Lognormal	41	32	3.5	2.0	145	32													
GM Massena Pass 4	Not Normal or Lognormal	35	28	3.4	2.0	118	28													
GM Massena Pass 5	Not Normal or Lognormal	31	23	3.1	1.9	98	23													
GM Massena Pass 6	Not Normal or Lognormal	192	34	8.5	2.1	1636	34													
GM Massena Pass 7	Not Normal or Lognormal	27	16	5.9	1.8	158	16													
GM Massena Pass 8	Not Normal or Lognormal	9.3	11	1.8	1.6	17	11													
Grasse River Inventory Removal	Normal	80.3	111	0.9	1.4	72	80													
													Average:			15			27	

Notes:

1. The central tendency is either the arithmetic mean or the minimum variance unbiased estimator of the mean (MVUE), depending on the coefficent of variance. If the coefficent of variance is less than or equal to 1.2, the arithmetic mean is selected, otherwise the MVUE is selected.

2. The upper confidence limits are calculated using the following equation:

$$UCL = \bar{x} + \frac{S_x \sqrt{((1/\alpha) - 1)}}{\sqrt{n}}$$

substituting 40 for n, 1 for , and the case study standard deviation for . S_x

3. The prediction limit is calculated using the following equation:

$$PL = e^{\left(\bar{y} + t(\alpha, n-1) \sqrt{S_y^2 + \frac{S_y^2}{n}} \right)}$$

substituting 40 for n, 0 for , and the case study variance for s_y^2

α	df	t
5%	39	1.685
2.5%	39	2.023
1%	39	2.426

4. These sites were selected because the average concentrations are in the same range as the target concentration for the Hudson River CUs. The New Bedford Harbor Grab and GM Massena (passes 1, 2 and 3) were determined to be outliers.

5. The statistics presented for the GM Massena Passes 1 though 8 include the capped area.

Table 2-3
Summary of UCL and PL Values for the Hudson River Based on Estimates of the Variability from the Case Studies

Linear Regression Mean vs. Sx [2]	
Sx at 1 ppm	3
Equation	Nonparametric Chebyshev UCL (Eqn. 2)
95% UCL	3
99% UCL	6
Average of PL Values Calculated Using the Sx from Each Case Study Parametric Assymetric PL (Table 2-2) [1]	
Equation	Parametric Assymetric PL (Eqn. 4)
97.5% PL	15
99% PL	27
Average Sy of the Case Studies	
Sy [3]	1.31
Equation	H-UCL (Eqn. 3)
95% UCL	4
99% UCL	6
Equation	Parametric Assymetric PL (Eqn. 4)
97.5% PL	15
99% PL	25
Range of UCL and PL Values Using the Variance from Each Individual Case Study (shown in Table 2-2)	
Equation	Proportion (Eqn. 1)
95% UCL	1-3
99% UCL	2-6
97.5% PL	3-15
99% PL	4-23
Equation	Nonparametric Chebyshev UCL (Eqn. 2)
95% UCL	3-24
99% UCL	5-54
Equation	Parametric Assymetric PL (Eqn. 4)
97.5% PL	7-25
99% PL	10-48

NOTES:

1. Units are in ppm.

2. Excludes the Grasse River Site because both the mean and standard deviation of the untransformed data are outliers.

3. Includes the Grasse River Site because the standard deviation of the transformed data is not an outlier.

Table 2-4
Area Within the Action Levels for a Percentage of Inventory Remaining in the Residuals

Tri+ PCBs (mg/kg)		Percentage				Acreage			
Inventory Remaining	Residual Thickness	0-1 (ppm)	1-3 (ppm)	3-6 (ppm)	>6 (ppm)	0-1 (ppm)	1-3 (ppm)	3-6 (ppm)	>6 (ppm)
1%	6"	91%	6%	2%	1%	385	26	8	5
5%	6"	58%	25%	5%	11%	247	107	23	47
10%	6"	52%	9%	22%	17%	221	39	94	71

Table 2-5
Non-Compliant Area Resulting From the PL Criteria if the Average Concentration is 1 mg/kg Tri+ PCBs

No. of Failures per CU	Probability that the No. of Failures will Occur		No. of CUs with Exceedances of PL Assuming 100 CUs (Approximate)	No. of Nodes to Address per CU	Area to be Redredged (Acres)
	97.5%	99%			
0	36.3%	66.9%	0	0	0
1	37.3%	27.0%	27	1	10.3
2	18.6%	5.3%	19	2	14.4
3	6.0%	0.7%	6	3	6.8
4	1.4%	0.1%	1	4	1.5
5-40	0.4%	0.0%	--	--	--
		Total:	52		33

Table 2-6
Estimate of the Number of Samples/Target Area

Site	Std. Dev. of Log. Sy	No. of Samples (1)
Reynolds Metals *	1.19	23
Marathon Battery East Cove *	0.95	15
New Bedford Harbor Cores *	1.23	25
New Bedford Harbor Grabs	1.38	32
Cumberland Bay *	1.35	30
Fox River SMU 56/57 *	1.45	35
Fox River Deposit N *	1.58	41
GM Massena Uncapped Areas *	1.32	29
GM Massena Pass 1	2.35	92
GM Massena Pass 2	2.05	70
GM Massena Pass 3	2.04	69
GM Massena Pass 4	2.01	67
GM Massena Pass 5	1.93	62
GM Massena Pass 6	2.10	73
GM Massena Pass 7	1.78	53
GM Massena Pass 8	1.62	44
Grasse River Inventory Removal *	1.44	34
	Minimum	15
	Mean	29
	Maximum	41

Notes:
1. From Gilbert (1987) n=(Z^2*Sy^2)/((ln(d+1))^2+Z^2*Sy^2/N)
Sy=the standard deviation of the data
Z=the Z-score based on z (1.65)
a=Defined such that 100*(1-a) is the confidence limit required (0.05)
N= the total population (very large)
d=the error in the median which can be tolerated (0.5)

2. Sites marked with an asterisk (*) are included in the summary statistics.

Table 3-1
Impact of the Settled Material on Surface Sediment Concentrations

TSS Conc.	**50 mg/L**	(TSS in suspension just following dredging in the entire 5 acre area)	
Area	5 acres	4.05E+03 sq.m/acre	20234 sq.m
Depth	8 ft	3.05E-01 m/ft	2.44 m
Volume	49339 cu.m	1000 L/cu.m	49339317 L
TSS Mass	2466965856 mg	1.00E-06 kg/mg	2466.9659 kg
Sediment Bulk			
Density	1.1 g/cc	0.001 kg/g	0.0011 kg/cc
Thickness of the Settled Material			
Volume	2242696 cc	1.00E-06 cu.m/cc	2.24 cu.m
Thickness	0.000111 m	1000 mm/m	0.111 mm
		1.00E+06 microns/m	111 microns
		39.4 in./m	0.0044 inches
Residual Sample Concentration			
Residual sediment thickness		6 inches	
Concentration of the settled material:		100 mg/kg	
Concentration in the remaning 5.996 inches:		1 mg/kg	

LWA Concentration (full 6 inches): 1.0720606 mg/kg

Table 3-2
Summary of the Performance Standard for Dredging Residuals

Case	Certification Unit Arithmetic Average (mg/kg Tri+ PCBs)	No. of Sample Results $\geq$15 mg/kg Tri+ PCBs AND < 27 mg/kg Tri+ PCBs	No. of Sample Results $\geq$ 27 mg/kg Tri+ PCBs	No. of Re-Dredging Attempts Conducted	Required Action (when all conditions are met)*
A	avg. ≤ 1	≤ 1	0	N/A	Backfill certification unit (where appropriate); no testing of backfill required.
B	N/A	≥ 2	N/A	< 2	Redredge sampling nodes and re-sample.
C	N/A	N/A	1 or more	< 2	Redredge sampling node(s) and re-sample.
D	1 < avg. ≤ 3	≤ 1	0	N/A	Evaluate 20-acre area-weighted average concentration. If 20-acre area-weighted average concentration ≤ 1 mg/kg Tri+ PCBs, place and sample backfill. **If 20-acre area-weighted average concentration > 1 mg/kg, follow actions for Case E below.
E	3 < avg. ≤ 6	≤ 1	0	< 2	Construct sub-aqueous cap immediately OR redredge. Construct cap so that arithmetic avg. of uncapped nodes is ≤ 1 mg/kg Tri+ PCBs, no nodes > 27 mg/kg Tri+ PCBs, and not more than one node > 15 mg/kg Tri+ PCBs.
F	avg. > 6	N/A	N/A	0	Collect additional sediment samples to re-characterize vertical extent of contamination and redredge. If certification unit median > 6 mg/kg Tri+ PCBs, entire certification unit must be sampled for vertical extent. If certification unit median ≤ 6 mg/kg Tri+ PCBs, additional sampling required only in portions of certification unit contributing to elevated mean concentration.
G	avg. > 6	N/A	N/A	1	Re-dredge.
H	avg. > 1 (20-acre avg. > 1)	≥ 2	≥ 1	2	Construct sub-aqueous cap (if any of these arithmetic average/sample result conditions are true) as described in Case E and two re-dredging attempts have been conducted OR choose to continue to re-dredge.

* Except for Case H, where any of the listed conditions will require cap construction.

** Following placement of backfill, sampling of 0 to 6 inch backfill surface must demonstrate average concentration ≤ 0.25 mg/kg Tri+ PCBs. If backfill surface average concentration is > 0.25 mg/kg, backfill must be dredged and replaced or otherwise remediated with input from the USEPA.