Hudson River

PCBs SUPERFUND SITE

Draft Engineering Performance Standards
Peer Review Copy

Part 2: Performance Standard for Dredging Residuals

October 2003

Prepared for:

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On Behalf of: U.S. Environmental Protection Agency, Region 2

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Volume 2 of 4

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To All Interested Parties:

The U.S. Environmental Protection Agency (EPA) is pleased to release the *Draft Engineering Performance Standards - Peer Review Copy* for the Hudson River PCBs Superfund Site (Site).

EPA's February 2002 Record of Decision for the Site calls for the independent peer review of the engineering performance standards for dredging-related resuspension, dredging residuals, and dredging productivity. Eastern Research Group, Inc. (ERG), an EPA contractor, has established a peer review panel to independently review and ensure that the engineering performance standards for the Site cleanup are technically adequate, properly documented, and satisfy quality requirements. ERG is responsible for administering the peer review and selecting the independent experts for the peer review panel.

EPA released the *Draft Engineering Performance Standards – Public Review Copy*, for public review on May 14, 2003 and accepted public comments on this document from May 14, 2003 through July 14, 2003. EPA is separately responding to comments received on the *Draft Engineering Performance Standards – Public Review Copy.* Copies of all comments received by EPA, as well as EPA's responses, will be provided to the peer reviewers and will be placed in the information repositories established for the site. Copies also will be available online at EPA's web site for the Hudson River PCBs Site (www.epa.gov/hudson).

A briefing meeting for the peer reviewers has been scheduled for October 15-16, 2003 in Saratoga Springs, NY. At the meeting, the peer reviewers will listen to presentations by EPA, other interested agencies, and the public on the engineering performance standards, take a tour of the Upper Hudson, and hear the charge questions that are the focus of their review. Electronic versions of the Draft Engineering Performance Standards and other documents related to the peer review are available on EPA's project Web site.

For questions about the *Draft Engineering Performance Standards*, please contact Alison A. Hess, EPA, at (212) 637-3959.

Sincerely yours,

George Pavlou, Director
Emergency and Remedial Response Division

Draft Engineering Performance Standards – Peer Review Copy
Hudson River PCBs Superfund Site
Executive Summary
October 2003

In February 2002, the United States Environmental Protection Agency (USEPA) issued a Record of Decision (ROD) for the Hudson River PCBs Superfund Site (Site). The ROD calls for targeted environmental dredging of approximately 2.65 million cubic yards of PCB-contaminated sediment from the Upper Hudson River (approximately 40 river miles) in two phases over a six-year period, and monitored natural attenuation of the PCB contamination that remains in the river after dredging.

In the ROD, USEPA identified five remedial action objectives, which are as follows:

- Reduce the cancer risks and non-cancer health hazards for people eating fish from the Hudson River by reducing the concentration of PCBs in fish;
- Reduce the risks to ecological receptors by reducing the concentration of PCBs in fish;
- Reduce PCB levels in sediments in order to reduce PCB concentrations in river (surface) water that are above applicable or relevant and appropriate requirements for surface water;
- Reduce the inventory (mass) of PCBs in sediments that are or may be bioavailable; and
- Minimize the long-term downstream transport of PCBs in the river.

In selecting its cleanup remedy, USEPA required that performance standards for resuspension during dredging, production rates during dredging, and residuals after dredging (together called the "Engineering Performance Standards") be established. This decision was made to address comments received from members of the public who expressed a wide spectrum of views on the project. Some suggested that the environmental dredging could "do more harm than good" and take much longer than stated, while others were concerned that the ROD was not sufficiently comprehensive in its requirements for the environmental cleanup. USEPA required these performance standards in its final cleanup decision to promote accountability and ensure that the cleanup meets the human health and environmental protection objectives set forth in the ROD.[1]

This document presents the draft Engineering Performance Standards for public review and comment. For each performance standard, it discusses the major ways performance is measured, the techniques used to assess performance, the supporting analyses for the

[1] Other performance standards will address public concerns related to potential impacts of the cleanup on the surrounding community, such as air emissions, navigation, and noise. These are being developed separately.

recommendations (including case studies), and some of the major interactions among the performance standards.

Consistent with the ROD, the Engineering Performance Standards were developed in consultation with New York State, the National Oceanic and Atmospheric Administration and the U.S. Fish and Wildlife Service. (New York State is developing substantive water quality certification requirements for the environmental dredging pursuant to the federal Clean Water Act; USEPA will review the requirements when they become available for any implications with respect to the Engineering Performance Standards). USEPA's consultants included a team of senior scientists and engineers who developed the standards, which then were reviewed by a separate team of recognized technical experts. General Electric Company reviewed a near-final version of the draft standards. Comments from these organizations were considered in preparing this Public Review Copy of the Draft Engineering Performance Standards.

Following the close of the public comment period, the Draft Engineering Performance Standards were revised as appropriate and are now released to the public as this Draft Engineering Performance Standards – Peer Review Copy. The standards will be peer reviewed by a panel of independent experts, modified as appropriate to address the peer reviewers' recommendations, and then implemented during the Phase 1 dredging. The results from the first season of dredging (Phase 1) will be used to evaluate the project's progress compared to the assumptions in the ROD in order to determine whether there are any necessary adjustments to the dredging operations in the succeeding phase (Phase 2) or to the standards. The report evaluating the dredging with respect to the Phase 1 standards also will be peer reviewed. USEPA will use the peer reviewers' recommendations to help determine whether the dredging plan is feasible in achieving the human health and environmental protection objectives of the ROD. The Engineering Performance Standards will be refined or adjusted, if necessary, for the remaining dredging seasons (Phase 2).

Based on the analyses performed to develop the standards, USEPA believes that the standards are consistent with the human health and environmental protection objectives of the ROD. USEPA has determined:

- Compliance with the Resuspension Standard will limit the concentration of Total PCBs in river water one mile or more downstream of the dredging area to levels that are acceptable for potable water under the requirements of the Safe Drinking Water Act;

- Resuspension of PCBs in compliance with the Resuspension Standard will have a negligible adverse effect on Tri+ PCB concentrations in Hudson River fish, as compared to a scenario assuming no dredging-related PCB releases;[2]

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[2] A negligible effect is defined, in this case, as a predicted Tri+ PCB concentration in Upper Hudson fish of 0.5 mg/kg or less, and in Lower Hudson River fish of 0.05 mg/kg or less, within 5 years after the completion of dredging in the Upper Hudson.

- Compliance with the Control Level of the Resuspension Standard is expected to result in a Total PCB load (mass) transported downstream during remedial dredging that is similar to the range of Total PCB loads detected during recent baseline (*i.e.*, pre-dredging) conditions, as documented by weekly measurements from 1996 to 2001;

- The Residuals Standard specified in the ROD (approximately 1 mg/kg Tri+ PCBs prior to backfilling) is achievable based on case studies of other environmental dredging projects and can be applied in the Upper Hudson on an area-wide average basis;

- The Productivity Standard will result in completion of the dredging within the six dredging seasons called for in the ROD, based on an example conceptual schedule for project implementation; and

- The three Draft Engineering Performance Standards, including their respective monitoring programs, are achievable individually and in combination. The standards appropriately balance their points of interaction, allowing flexibility during design and implementation while ensuring protection of human health and the environment. For example, the requirements concerning additional dredging attempts in the Residuals Standard must consider the requirements for dredging production in the Productivity Standard.

A summary of each of the three Draft Engineering Performance Standards is presented below, followed by discussion of some of the major interactions among the Standards.

Performance Standard for Dredging Resuspension

Objectives

The Performance Standard for Dredging Resuspension (*i.e.*, Resuspension Standard) is designed to limit the concentration of PCBs in river water such that water supply intakes downstream of the dredging operations are protected, and to limit the downstream transport of PCB-contaminated dredged material. The attendant water quality monitoring program will be implemented to verify that the objectives of the Resuspension Standard have been met during dredging. The analytical results obtained from the water quality monitoring will be compared to the Resuspension Standard and associated lower action levels to monitor and control resuspension through appropriate actions. Such actions could include, as appropriate, expanding the monitoring program, notifying public water suppliers, implementing operational or engineering improvements, and, if necessary, temporarily halting the dredging.

The ROD requires the development of a Resuspension Standard but does not set forth any framework or numerical value for the Standard. The Resuspension Standard and a series of tiered action levels were developed based on extensive modeling, review of environmental dredging case study data, and evaluation of applicable or relevant and appropriate requirements (ARARs) identified in the ROD for PCBs in river water.

Statement of the Resuspension Standard

Resuspension Standard

Under the Resuspension Standard, the maximum allowable Total PCB concentration in the water column is 500 nanograms per liter (ng/L) (*i.e.*, 500 parts per trillion) at any far-field monitoring station, regardless of the source of the PCBs. This concentration is the USEPA Safe Drinking Water Act Maximum Contaminant Level (MCL) for PCBs in drinking water supplies.[3] Potential sources include dredging, tender and tugboat movements, materials handling, and PCBs from upstream and non-dredging sources. Dredging is only allowed to proceed when concentration of Total PCBs in the river water at any Upper River far-field station is 500 ng/L or less.

Action Levels

Action levels were developed to help identify potential problems and to guide appropriate responses, such as preventive actions or engineering improvements, as necessary, as a means of avoiding an exceedance of the Resuspension Standard. As shown in Table ES-1 below, there are three action levels leading up to the Resuspension Standard, which are designated “Evaluation Level,” “Concern Level,” and “Control Level.” The monitoring requirements become more stringent at each level to increase the types and quantity of data available to interpret the river’s response to the dredging. If the monitoring shows an exceedance at the Evaluation or Concern Level, engineering solutions are suggested. If the monitoring shows an exceedance at the Control Level, implementation of an engineering solution is required.

[3] The New York State MCL is also 500 ng/L.

Table ES-1: Resuspension Standard and Action Levels

Action Level	Parameter	Required Action
Evaluation Level	• 300 g/day Total PCB load or 100 g/day Tri+ PCB load as a 7-day running average (far-field) • 100 mg/L 6-hour running average net suspended solids increase or average net increase in the daily dredging period if the dredging period is less than 6 hours (near-field, 300 m, River Sections 1 & 3) • 60 mg/L 6-hour running average net suspended solids increase or average net increase in the daily dredging period if the dredging period is less than 6 hours (near-field, 300 m, River Section 2) • 700 mg/L net suspended solids average 3-hour continuous (near field, 100 m and channel-side) • 12 mg/L 6-hour running average net suspended solids increase or average net increase in the daily dredging period if the dredging period is less than 6 hours (far-field)	Monitoring Contingencies Engineering Evaluations (recommended) Engineering Solutions (recommended)
Concern Level	• 350 ng/L Total PCBs as a 7-day running average (far-field) • 600 g/day Total PCB load or 200 g/day Tri+ PCB load as a 7-day running average (far-field) • 100 mg/L net suspended solids daily average for the dredging period (greater than 6 hours) or 24 hours (near-field, 300 m, River Sections 1 & 3) • 60 mg/L net suspended solids daily average for the dredging period (greater than 6 hours) or 24 hours (near-field, 300 m, River Section 2) • 24 mg/L net suspended solids daily average for the dredging period (greater than 6 hours) or 24 hours (far-field)	Monitoring Contingencies Engineering Evaluations Engineering Solutions (recommended)
Control Level	• 350 ng/L Total PCBs as a 4-week running average (far-field) • 65 kg/year Total PCB or 22 kg/year Tri+ PCB load during the Phase 1 dredging season (far-field) • 600 g/day Total PCB load or 200 g/day Tri+ PCB load as a 4-week running average (far-field)	Monitoring Contingencies Engineering Evaluations Engineering Solutions
Resuspension Standard	500 ng/L Total PCBs (confirmed far-field occurrence)	Temporarily Halt Dredging Monitoring Contingencies Engineering Evaluations Engineering Solutions

The Evaluation Level is based on PCB load (net mass loss) criteria and suspended solids concentrations. The PCB load criteria are 300 g/day Total PCBs (and 100 g/day Tri+ PCBs), which approximates the amount that could reasonably be distinguished from baseline conditions. These amounts are approximately three times the best engineering estimate of mass loss from the dredging operation at full production as reported in the ROD. The near-field suspended solids concentration criteria were derived for each River Section of the Upper Hudson to correspond to a far-field PCB concentration of 350 ng/L Total PCBs. There is a corresponding far-field suspended solids criterion derived for a far-field concentration of 500 ng/L Total PCBs, the Resuspension Standard. Consistent with the ROD, the Evaluation Level, Control Level and Concern Level each require the collection of site-specific data in Phase 1 that will be used to determine whether adjustment to the dredging operations or to the standards are needed in Phase 2. Once these data have been evaluated, it may be appropriate to eliminate the Evaluation Level in the Resuspension Standard for Phase 2.

The Concern Level includes both a PCB concentration and load-based criteria. The concentration criterion is a seven-day running average exceedance of 350 ng/L Total PCBs (*i.e.*, 70% of the 500 ng/L Resuspension Standard, which is a reasonable warning threshold). The load criteria are structured similarly, with a one-week exceedance of 600 g/day Total PCBs (and 200 g/day Tri+ PCBs). This daily load rate is based on a total project load of up to 650 kg Total PCBs over the duration of the dredging as estimated from various engineering and modeling analyses.[4] The near-field suspended solids concentration criteria were derived for each River Section of the Upper Hudson to correspond to a far-field PCB concentration of 350 ng/L Total PCBs, but the threshold duration of the concentration criteria is longer. There is an associated far-field suspended solids criterion derived to correspond to a far-field PCB concentration at twice the Resuspension Standard (*i.e.*, 1000 ng/L).[5]

The Control Level criteria for PCB concentration and load are similar in form to those for the Concern Level, but the threshold duration of the concentration criteria is increased. In this case, the concentration criterion is a four-week running average concentration of 350 ng/L Total PCBs. The load criteria, likewise, consist of a four-week exceedance of 600 g/day Total PCBs (and 200 g/day Tri+ PCBs). There are no increased suspended solids criteria associated with the Control Level (*i.e.*, the Control Level is not triggered by suspended solids concentrations alone).

Near-field and Far-field Monitoring Stations

The Resuspension Standard requires water quality monitoring at both "near-field" stations (located within a few hundred meters of the dredging operation) and "far-field" stations (to be established at fixed locations in the Upper and Lower Hudson River, primarily dams and bridges). Monitoring is required at all far-field stations during Phase 1 (two stations upstream of the project area, four stations in the Upper River, two stations in the Lower River and one station in the Mohawk River at Cohoes). The Resuspension Standard of 500 ng/L Total PCBs is applied to the PCB concentration data collected at any far-field station that is at least 1 mile downstream of the dredging area. The data collected at both near-field and far-field stations are compared to the action level criteria.

Water quality impacts that are detected only in the immediate dredging area, including within containment barriers that the Contractor may employ around the dredging area, are not covered by the Resuspension Standard. Some resuspension within the dredging areas is likely unavoidable regardless of the type of dredging equipment used, and is of concern only to the extent it transports PCBs downstream.

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[4] The daily rate is based on attainment of the recommended target cumulative volume as specified in the Productivity Standard, and should be prorated according to the production rate planned in the Production Schedule to be submitted annually to USEPA.

[5] This higher level recognizes the high degree of uncertainty in the suspended solids measurement. Additional PCB sampling prompted by this level will be used to confirm compliance with the Resuspension Standard.

Routine Monitoring Program[6]

The routine water quality monitoring program consists of PCB sampling and analysis at the far-field stations and the collection of suspended solids data at the near-field and far-field stations every three hours. The routine monitoring program is specific with respect to the details and frequency of the sample collection, potential development of continuous field monitoring techniques for suspended solids, requirements for representative discrete and composite sampling schemes at the far-field stations (Upper and Lower Hudson), and the number and configuration of near-field suspended solids sampling stations. Monitoring results will be made available to USEPA upon receipt from the laboratories. Corrective actions and analytical results will be summarized in weekly reports to USEPA.

Contingencies

Monitoring Contingencies

If an action level is exceeded, monitoring contingencies are required at both near-field and far-field stations. The monitoring contingencies consist of increased sampling frequency and more rapid laboratory turn-around of analytical data at the sampling locations, compared to the routine monitoring program. The monitoring contingency is intended to provide additional data to better characterize the developing changes and trends in water quality. The Resuspension Standard allows the monitoring program to revert to routine frequencies and normal turnaround times when conditions have decreased below the action levels for specific durations.

Engineering Contingencies

If the Evaluation Level is exceeded, the Resuspension Standard suggests that an engineering evaluation be undertaken and that a range of engineering contingencies be considered.

If the Concern Level is exceeded, the Resuspension Standard requires that an engineering evaluation be undertaken and suggests a range of engineering contingencies. However, at the Concern Level, implementation of an engineering solution is discretionary.

If the Control Level is exceeded, the Resuspension Standard requires implementation of an engineering solution, with the exact engineering solution to depend on the specific circumstances encountered in the field and an interpretation of the monitoring data collected in connection with the action level exceedance.

If the Resuspension Standard is exceeded, all dredging operations must be temporarily halted pending the results of an engineering evaluation and selection of an engineering solution in consultation with USEPA.

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[6] The term "routine" refers to a level of monitoring appropriate to this project to be conducted while the dredging operation is in compliance with the Resuspension Standard and all action level criteria.

The suggested engineering evaluations and solutions include examination of boat traffic patterns, additional evaluation of sediment pipelines for leaks, implementation or modification of silt barriers and may include, for the Control Level, temporarily halting the dredging operations.

Public Water Supply Monitoring and Contingencies

The Resuspension Standard provides for notification to downstream public water suppliers when the Total PCB concentration at the Waterford far-field station is predicted to be 350 ng/L or greater. The monitoring and notification required by the Resuspension Standard is in addition to monitoring and notification requirements that will be developed separately for the Community Health and Safety Plan for the remedial work activities.[7]

Supporting Analyses and Assumptions

A large number of analyses were conducted in developing the Resuspension Standard, including the action levels. Some of the most important analyses are summarized below.

Dissolved-Phase PCB Releases

Case studies regarding environmental dredging projects provide different conclusions regarding the importance of dissolved-phase PCBs in the absence of a release of suspended solids. Some data from the Fox River in Wisconsin suggest that relatively large dissolved-phase releases of PCBs are possible during dredging without an associated release of contaminated sediments (suspended solids). In contrast, field measurements of dissolved and particle-associated PCBs collected during environmental dredging at the New Bedford Harbor site in Massachusetts suggest that dissolved phase PCB releases are not significant.

In developing the Resuspension Standard, analyses were conducted to evaluate possible mechanisms for dissolved-phase PCB releases during dredging of the Upper Hudson. These analyses sought to consider the likelihood and magnitude of potential dissolved-phase effects. Potential releases of dissolved-phase PCBs, via 1) release of contaminated porewater from the dredged sediment surface and 2) a release of contaminated solids into the water column, were quantitatively modeled to estimate a range of potential PCB contaminant loads that could be experienced. The modeling indicated that the amount of dissolved-phase PCBs likely to be introduced into the system is relatively small compared to baseline concentrations (*i.e.*, without dredging).

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[7] The ROD requires development of a Community Health and Safety Plan to protect the community, including persons in residences and businesses, from potential exposures as a direct result of remedial work activities. The Community Health and Safety Plan will provide for community notification of ongoing health and safety issues, monitoring of contaminants and protection of the community from physical and other hazards. The plan will include a section that outlines the actions to be followed should monitoring of contaminants show contaminant levels above certain levels to be identified in the plan.

Modeling

USEPA's peer-reviewed fate and transport models and bioaccumulation models (HUDTOX and FISHRAND) were used to simulate concentrations of PCBs in the water column, sediment, and fish in the Upper Hudson that could result from resuspension during the remedial dredging. The Farley model, along with FISHRAND, was used to simulate conditions in the Lower Hudson. The modeling efforts examined the impact of allowing the dredging to proceed at the action levels (both PCB concentrations in the water column and PCB mass loads). The model results indicate that the PCB water column concentrations and the PCB mass loads would have a negligible impact on PCB concentrations in Hudson River fish as compared to a scenario with no dredging-related releases (see footnote 2). Using the model results, the impact to human health and ecological receptors were calculated consistent with USEPA's site-specific risk assessments.

Analyses of Baseline Water Quality Data

In developing the Resuspension Standard, analyses were conducted using historical Hudson River water quality data to distinguish between the pre-dredging baseline concentrations of PCBs and suspended solids in the water column and PCB concentrations expected due to resuspension during dredging. Data collected since 1996 as part of GE's ongoing weekly sampling program were statistically evaluated to derive the monthly mean concentration of PCBs and the variance for the months of the dredging season (*i.e.*, May through November). The findings indicate maximum PCB concentrations during May and June of each year. Subsequent sensitivity analyses also indicate that the Total PCB loads specified in the Concern and Control Levels are similar to the range of existing baseline loads experienced by the river system. The baseline data to be collected prior to Phase 1 dredging will be used to refine these statistical analyses.

Performance Standard for Dredging Residuals

Objectives

The Performance Standard for Dredging Residuals (*i.e.*, Residuals Standard) is designed to detect and manage contaminated sediments that may remain after initial remedial dredging in the Upper Hudson River. The ROD calls for removal of all PCB-contaminated sediments in areas targeted for dredging, and anticipates a residual of approximately 1 mg/kg Tri+ PCBs (prior to backfilling). The "residual sediments" may consist of contaminated sediments that were disturbed but escaped capture by the dredge, resuspended sediments that were redeposited/settled, or contaminated sediments remaining below the initial dredging cut elevations (*e.g.*, due to uncertainties associated with interpolation between core nodes of the design sediment sampling program or insufficient core recovery).

The Residuals Standard requires the implementation of a post-dredging sampling and analysis program to detect and characterize PCB concentrations in the residual sediments.

The post-dredging sediment data are compared to the anticipated residual of approximately 1 mg/kg Tri+ PCBs stated in the ROD and a group of statistical action levels developed for the Residuals Standard. The approach to be taken to manage the residual sediments (including re-dredging) is then selected depending on the statistical analyses of the post-dredging data. The use of statistical analyses to evaluate environmental datasets is a scientifically accepted practice.

Statement of the Residuals Standard

Sampling and Analysis

The Residuals Standard requires the collection of surface sediment samples following dredging and after USEPA has confirmed that the design cut-lines have been achieved. Based on engineering judgment, the dredging is assumed to proceed within work areas that are similar to the median size of the targeted areas identified in the ROD. Therefore, a 5-acre "certification unit" was considered for the post-dredging sampling program and the subsequent statistical evaluation of the post-dredging surface sediment data. The Residuals Standard specifies that each certification unit be sampled for compliance directly after it is dredged, so that appropriate actions can be taken as the project progresses. In each 5-acre certification unit, sediment samples representing the 0-6 inch depth interval below the dredged sediment surface are to be obtained from 40 grid nodes and analyzed for Tri+ PCBs. The analytical results from those samples will be compared to the action levels in the Residuals Standard, and the required actions taken.[8]

Action Levels and Required Responses

The Residuals Standard requires the review of: 1) the Tri+ PCB concentrations in all 40 individual sediment samples within each 5-acre certification unit, 2) the mean Tri+ PCB concentration of the certification unit, 3) the median Tri+ PCB concentration of the certification unit, and 4) the average of the mean Tri+ PCB concentrations of a 20-acre joint evaluation area (certification unit under review and the three units within 2 mile stretch of river). The following responses are required for Phase 1 of the dredging project. Adjustments may be made before finalizing the Residuals Standard for Phase 2 based on analyses of the post-dredging sediment data collected during Phase 1. For example, if justified, the joint evaluation area may be increased to 40 acres for Phase 2.

1. <u>Backfill (where appropriate) and Demobilize</u>: 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, backfill (where appropriate) and demobilize from the certification unit.

[8] The Residuals Standard does not preclude collection of samples from deeper intervals, which may be cost-effective.

2. Jointly Evaluate 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, and not more than one sediment sample result greater than or equal to 15 mg/kg Tri+ PCBs, jointly evaluate a 20-acre area.

   For 20-acre evaluation, if the area-weighted arithmetic average of the individual means from the certification unit under evaluation and the 3 previously dredged certification units (within 2 miles of the current unit) is less than or equal to 1 mg/kg Tri+ PCBs, backfill may be placed (with subsequent testing required). Otherwise, the certification unit must be re-dredged (see #4 below for actions required during and following re-dredging) or a sub-aqueous cap constructed. Re-dredging 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 re-dredging attempts, contingency actions may be implemented in lieu of further re-dredging attempts, as described in #5, below.

3. Re-dredge or Construct Sub-aqueous 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, and not more than one sediment sample result is greater than or equal to 15 mg/kg Tri+ PCBs, re-dredge or construct a sub-aqueous cap. The choice of two options is provided to maintain flexibility and productivity (*e.g.*, some areas may not be conducive to dredging). If re-dredging is chosen, the surface sediment of the re-dredged area must be sampled and the certification unit re-evaluated. If the certification unit does not meet the objectives of #1 or #2, above, following two re-dredging attempts, contingency actions may be implemented in lieu of further re-dredging attempts, as described in #5, below.

4. Re-dredging 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 or to address individual sampling point(s) with concentrations greater than or equal to 27 mg/kg Tri+ PCBs or more than one sampling point with concentrations greater than or equal to 15 mg/kg Tri+ PCBs, re-dredging is required.

   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.*, 6-12 inch, 12-18 inch, etc.) as necessary to re-characterize 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 contemplated only once.

The Residuals Standard provides a mechanism for calculating the horizontal extent of re-dredging. All re-dredging attempts are to be designed to reduce the mean Tri+ PCB concentration of the certification unit to 1 mg/kg Tri+ PCBs or less. If after two re-dredging attempts, the arithmetic average Tri+ PCB concentration in the surface sediment still is greater than 1 mg/kg, then contingency actions are to be implemented as stated in #5, below.

5. Contingency Actions: At areas where two re-dredging attempts do not achieve compliance with the residuals criteria, as verified by USEPA, construct an appropriately designed sub-aqueous cap, where conditions allow.

A flow chart illustrating implementation of the *Performance Standard for Dredging Residuals* is shown in Figure ES-1. The flow chart options are summarized in Table ES-2.

TABLE ES-2
SUMMARY OF DRAFT RESIDUALS STANDARD

Case	Certification Unit Mean (mg/kg Tri+ PCBs)	No. of Sample Results where 27 > *result* ≥15 mg/kg Tri+ PCBs	No. of Sample Results ≥ 27 mg/kg Tri+ PCBs	No. of Re-Dredging Attempts Conducted	Required Action (when all conditions are met)*
A	$x_i \leq 1$	≤ 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	$1 < x_i \leq 3$	≤ 1	0	N/A	Evaluate 20-acre average concentration. If 20-acre average concentration ≤ 1 mg/kg Tri+ PCBs, place and sample backfill. If 20-acre average concentration > 1 mg/kg, follow actions for Case E below.
E	$3 < x_i \leq 6$	≤ 1	0	< 2	Construct sub-aqueous cap immediately OR re-dredge.
F	$x_i > 6$	N/A	N/A	0	Collect additional sediment samples to re-characterize vertical extent of contamination and re-dredge. If certification unit median > 6, entire certification unit must be sampled for vertical extent. If certification unit median ≤ 6, additional sampling required only in portions of certification unit contributing to elevated mean concentration.
G	$x_i > 6$	N/A	N/A	1	Re-dredge.
H	$x_i > 1$ (and 20-acre average > 1)	≥ 2	≥ 1	2	Construct sub-aqueous cap (if any of these mean/sample result conditions are true) 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.

Preference for Dredging

The selected remedy includes dredging of contaminated sediment, using PCB inventory as the primary means to target removal areas. The Residuals Standard of approximately 1 mg/kg Tri+ PCBs (prior to backfilling) is achievable based on case studies of other environmental dredging projects and can be applied on an area-wide average basis. However, review of case studies also indicates that, for some isolated areas, residual concentrations subsequent to the initial dredging attempt may exceed the 1 mg/kg Tri + PCB standard. The non-compliant residuals will likely be associated with difficult-to-dredge bottom conditions such as bedrock outcrops and boulder fields. As a result, in limited areas of the Upper Hudson River, it may be difficult to achieve the Residuals Standard. The capping contingency was added as an option to address this scenario.

Capping of the existing PCB inventory was assessed as a remedial action alternative in the 2000 Feasibility Study, but was not selected as the most appropriate remedy, largely because it does not provide the same degree of reliability as dredging. This finding was due to the potential for defects or damage to the cap, thereby reducing its effectiveness relative to dredging while still requiring the sediment handling, processing, and disposal activities needed for dredging. The option for capping allowed in the Residuals Standard differs significantly from the remedial action alternative that was evaluated in the Feasibility Study in that the design dredging cut lines must be met and the targeted PCB inventory removed before this option can be considered (*i.e.*, the capping contingency in the Residuals Standard is not a stand-alone remedial action alternative). Capping performed under the Residuals Standard would not be used to sequester significant PCB inventory and, because the mass of PCBs to be isolated is greatly reduced, the reliability of a cap placed for the purpose of isolating residual contamination is less critical. Were the cap breached in this situation, the potential spread of contamination would be much less because of the much lower contaminant mass and potential for mixing (dilution) with the surrounding capping material.

Although application of a sub-aqueous cap has been added as an option in the Residuals Standard, there is a decided preference for dredging alone. Capping is less reliable for long-term control than dredging, and there are long-term operation and maintenance requirements associated with capping. Factors for deciding if an area should be capped and preparation of the site-specific cap design must include the river conditions (sediment texture, water depth, location in the channel, compatibility with habitat, etc.) as well as cost and impact on productivity. The option for capping is not meant to compensate for any deficiency in the dredging design or operations. USEPA will be fully apprised of the decision-making for areas to be capped in accordance with the requirements of the Standard as represented in Figure ES-1. Through the required submittal of Certification Unit-specific closure reports, USEPA will review the residual sampling data collected for the areas, confirm that the dredging cut lines have been met, review field notes, and review and approve each site-specific cap design. A limit on the amount of area that can be capped without obtaining approval from USEPA may be added to the standard for Phase 2, based on information gathered during Phase 1.

Supporting Analyses and Assumptions

Certification Unit Sample Size and Sampling Grid

USEPA's 2002 "Guidance for Choosing a Sampling Design for Environmental Data Collection" provides methods to determine the number of samples required to estimate the mean contaminant concentration of a given area. Evaluation of the 1984 Upper Hudson River sediment data (which is the most comprehensive to date), case study residuals data from other environmental dredging projects, and USEPA statistical guidance supported the use of 40 samples to characterize each 5-acre certification unit.

The 40 samples are to be collected from a regular triangular grid, which equates to a sample spacing of approximately 80 feet. The residuals sampling grid is to be offset from the design support sediment sampling grid by 40-60 percent of the grid spacing. Criteria for relocating sampling points, when necessary, are provided in the Residuals Standard. The Residuals Standard accommodates the application of the sampling grid to certification units that differ in size from the conceptual 5-acre unit. This flexibility is provided to address circumstances in which the remedial dredging may result in certification units of varying sizes (*e.g.*, due to the installation of silt barriers, if used).

Action Level Development

The action levels originated with the statement in the ROD that anticipates a residual in dredged areas of approximately 1 mg/kg Tri+ PCBs (before backfilling). Statistical thresholds were developed to evaluate residuals sampling data and trigger responses, a common scientifically accepted practice for interpreting environmental data. The thresholds consist of action levels for the area-weighted mean concentration (upper confidence limits, or UCLs) and action levels for individual sample results (prediction limits, or PLs). Both UCLs and PLs are measures of the probability that a sample result belongs to a sample population that has a specific mean; consistent with the ROD, the desired mean for Upper Hudson River residuals is 1 mg/kg Tri+ PCBs or less).

Since no residual sediment data exist for the Upper Hudson River (and will not exist until after remedial dredging is initiated), UCLs and PLs were calculated based on residual sediment data from other environmental dredging projects. The values derived for the Residuals Standard are: 3 mg/kg Tri+ PCBs (95% UCL), 6 mg/kg Tri+ PCBs (99% UCL), 15 mg/kg Tri+ PCBs (97.5% PL), and 27 mg/kg Tri+ PCBs (99% PL). These criteria are used to evaluate the degree to which the residual of approximately 1 mg/kg Tri+ PCBs specified in the ROD is attained in a particular certification unit, and to trigger appropriate actions for managing residual sediments.

Requirement for Collection of Additional Core Samples

The Residuals Standard requires the collection of additional sediment samples where the initial mean Tri+ PCB concentration (0-6 inch interval) for the certification unit is greater than 6 mg/kg. Residual sediments with a Tri+ PCB concentration above the 99% UCL indicates the dredge was still removing material from a contaminated stratum. In this case, it is possible that additional contaminated sediment "inventory" remains to be removed. The median concentration is used as a criterion to determine whether deeper sediment samples (*e.g.*, 6-12 inch, 12-18 inch, etc. as necessary to define the vertical extent of contamination) must be collected from all 40 sampling points in the certification unit or, as appropriate, from smaller sub-areas where isolated or clustered elevated nodes are causing the mean concentration to exceed the requirements of the standard. Following the collection and evaluation of the deeper sediment samples, new cut-lines must be established and re-dredging conducted to reduce the residual concentrations.

Required Number of Re-dredging Attempts

To maintain dredging productivity, and noting that case studies of other environmental dredging projects report diminishing returns for successive re-dredging in an attempt to obtain the remedial objectives, the number of required re-dredging attempts was set at two attempts. Re-dredging attempts are dredging efforts conducted to reduce residual concentrations, and by definition occur subsequent to the USEPA's confirmation of attainment of the initial design cut elevations to remove inventory. The Construction Manager may also choose to conduct additional re-dredging attempts, based on cost considerations or knowledge of the dredging area, with the intent of reducing the mean Tri+ PCB concentration in the certification unit to 1 mg/kg or less Tri+ PCBs.[9]

Based on the Phase 1 results and the second peer review, USEPA may modify the required number of redredging attempts (or the triggers for engineering contingencies and capping, described below).

Engineering Contingencies and Capping

In the event that the dredging operations after two or more dredging attempts cannot achieve the Residuals Standard of a mean concentration of 1 mg/kg Tri+ PCBs or less, engineering contingencies must be implemented, including the construction of a sub-aqueous cap, where conditions permit, over the recalcitrant area to address the residual PCB contamination.

Where further dredging is not practicable, the sub-aqueous cap is intended to support recovery of the Hudson River ecosystem following removal of inventory, similar to the function of the backfill. 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 recovery.

The installation of a sub-aqueous cap is likely to further reduce residual concentrations of PCBs and may require additional dredging to accommodate the cap thickness. While not expected, should conditions encountered in the navigation channel require the installation

[9] This option is limited to circumstances where no project delays affecting the ability to meet the Productivity Standard will be incurred.

of a sub-aqueous cap, sufficient dredging may be required to install the cap and an upper, armored layer below the navigation depth. The armored layer would act as an indicator during future navigational dredging in the channel to prevent damage to the cap.

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. General cap design criteria and relevant USEPA and USACE guidance documents for cap design are identified in the Residuals Standard. 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.

The cost of cap construction and maintenance should be balanced by the Construction Manager, in consultation with USEPA, against the cost of additional re-dredging attempts and their respective impacts on the schedule. Following the completion of Phase 1, the areas capped (if any) during Phase 1 will be evaluated to review the decisions that were made given river conditions in the capped areas and impacts on productivity. Using the information gathered during Phase 1 and the data gathered during the design sampling (*e.g.*, subbottom profiling results), a limit on the amount of area that can be capped without prior approval from USEPA may be added to the standard for Phase 2, if warranted.

Joint Evaluations and Backfill Testing

The concept of a 20-acre joint evaluation was developed to maintain flexibility where the mean residual concentrations in selected 5-acre certification units are only slightly higher than 1 mg/kg Tri+ PCBs. The size of the joint evaluation area was chosen based on USEPA's peer-reviewed fate, transport and bioaccumulation models for the Upper Hudson River (HUDTOX and FISHRAND), which were used to evaluate recovery of the Upper Hudson following remediation. The models used river segments in the Thompson Island Pool that are similar in size to the 20-acre joint-evaluation areas. The benefits of targeted remedial dredging projected by the USEPA models hold if the mean residuals concentration is 1 mg/kg Tri+ PCBs or less on average, over 20-acre areas.

If a certification unit has a mean residuals concentration of greater than 1 mg/kg Tri+ PCBs but less than or equal to 3 mg/kg Tri+ PCBs, and the average concentration in the 20-acre joint evaluation area that contains the certification unit is 1 mg/kg Tri+ PCBs or less, backfill may be placed without a re-dredging attempt. In this case, testing of the backfill after placement is required.

The backfill testing is to be accomplished by collecting surface sediment samples (0-6 inches) of the backfill after it is placed, using the same grid spacing used for the residual sediment sampling. Each 0-6 inch backfill sample is to be analyzed for PCBs. The mean concentration of PCBs in the backfill samples must be 0.25 mg/kg Tri+ PCBs or less. If this criterion is not met, the non-compliant areas of the backfill layer must be removed via dredging, replaced, and retested until the criterion is achieved. Alternately, in some areas it may be possible to place additional backfill material. However USEPA approval is required for this option.

Performance Standard for Dredging Productivity

Objective

The Performance Standard for Dredging Productivity (*i.e.*, Productivity Standard) is designed to monitor and maintain the progress of the dredging to meet the schedule stated in the ROD. The project schedule stated in the ROD has a six-year duration and consists of the first dredging season designated “Phase 1” (initial dredging at a reduced scale) followed by five dredging seasons collectively designated “Phase 2” (each with dredging at full production to remove the remainder of the contaminated sediments identified for removal). The Productivity Standard specifies the cumulative volume of sediment to be dredged during each dredging season, based on the current estimate of 2.65 million cubic yards of sediment to be removed.

Statement of the Productivity Standard

Required and Recommended Cumulative Annual Dredging Volumes

The Productivity Standard requires compliance with minimum cumulative volumes of sediment for each dredging season and targets larger volumes for the first five dredging seasons, as provided in Table ES-3 below. The minimum cumulative volume of sediment to be removed, processed and shipped off-site by the end of each dredging season is the quantity shown in the “Required Cumulative Volume” column. The targeted cumulative volumes allow for the work to be designed for completion at a somewhat faster rate, so that a reduced volume remains in the sixth and final dredging season. This recommended approach provides additional time to address any unexpected difficulties within the schedule called for in the ROD. The targeted cumulative dredging volumes are shown in the “Target Cumulative Volume” column.

Table ES-3: Productivity Requirements and Targets

Dredging Season[1]	Required Cumulative Volume (cubic yards)	Target Cumulative Volume (cubic yards)
Phase 1 (Year 1)	Approx. 240,000	265,000
Phase 2 (Year 2)	720,000	795,000
Phase 2 (Year 3)	1,200,000	1,325,000
Phase 2 (Year 4)	1,680,000	1,855,000
Phase 2 (Year 5)	2,160,000	2,385,000
Phase 2 (Year 6)	2,650,000[2]	2,650,000[2]

(1) The overall completion schedule, if appropriate, should be adjusted to be consistent with the total volume of sediment to be dredged as determined by USEPA during remedial design (for example, based on the findings of the design support sediment characterization program).
(2) Represents total estimated in-situ volume to be removed as per the ROD, exclusive of any amounts generated by re-dredging to meet the Residuals Performance Standard.

Monitoring and Recordkeeping

The Productivity Standard requires the Contractor managing the dredging project to track and report progress to the USEPA. The recordkeeping, in addition to and as verified by USEPA or its representatives in the field, will become the basis for measuring compliance with the Productivity Standard By March 1 of each year, the Contractor shall provide USEPA with a schedule showing cumulative volumes planned to be removed each month during the upcoming dredging season (*i.e.*, Production Schedule). The production schedule should consider the targeted cumulative volumes and must meet or exceed the requirements of the Productivity Standard (or as revised in accordance with USEPA-approved design documents).

Monthly and annual productivity progress reports shall be submitted to USEPA. Monthly productivity progress reports will be compared to the production schedule submitted by the Contractor and will be the primary tool for assessing whether the project is on schedule. Annual production progress reports, prepared at the conclusion of each dredging season, will be used to evaluate compliance with the Productivity Standard.

The monthly and annual reports will summarize daily records of the dredging locations, approximate production and number of operating hours of operation for each dredge, estimates of in-situ sediment volumes removed, and the weight of dewatered sediments and estimated mass of PCBs shipped off-site.

Action Levels and Required Responses

The Productivity Standard's action levels and responses are summarized in Table ES-4 below.

Table ES-4: Action Levels and Required Responses

Action Level	**Description**	**Response**
Concern Level	Monthly production rate falls 10% below scheduled rate.	Notify USEPA and take immediate steps to erase shortfall in production over next two months.
Control Level	Production falls below scheduled production by 10% or more for two or more consecutive months.	Submit an action plan explaining the reasons for the production shortfall and describing the engineering and management actions taken or underway to increase production and erase shortfall by end of the dredging season.
Standard	Annual cumulative volume fails to meet required production requirements.	Action to be determined by USEPA.

In any dredging season, if the planned monthly cumulative production falls below the scheduled amount by 10 percent or more, the Contractor shall identify the cause of the shortfall to USEPA and take immediate steps (adding equipment and crews, working extended hours, modifying the plant and equipment or approach to the work, or other) to erase the cumulative shortfall over the following two months or by the end of the dredging season, whichever occurs sooner. Any steps taken to increase production shall conform to all other Performance Standards established for the project. Significant changes to operating procedures or equipment, such as use of an entirely different dredging technology or means of processing the dredged sediments prior to shipment, will require USEPA approval.

If the monthly productivity falls below the scheduled productivity by 10 percent or more for two or more consecutive months, the Contractor shall provide a written action plan to the USEPA explaining the reasons for the production shortfall and describing the engineering and management steps taken or underway to erase the shortfall in production during that dredging season.

If an annual production shortfall occurs, USEPA will determine the appropriate action to address non-compliance with the Productivity Standard. USEPA will also evaluate the circumstances that led to the annual shortfall, if encountered, when assessing compliance.

Supporting Analyses and Assumptions

Conceptual Project Schedule

To evaluate the feasibility of the required and target cumulative annual volumes specified in the Productivity Standard (refer to Table ES-3), a detailed conceptual critical path schedule was developed using Primavera Systems, Inc. software. A number of conservative assumptions were made regarding means and methods that could be used during the dredging project in order to demonstrate that the Productivity Standard is achievable. The Productivity Standard, however, does not require that the remedial design adhere to the assumptions and work sequence used to develop the Productivity Standard conceptual schedule. The schedule output indicates that both the required and the target cumulative volumes developed for the Productivity Standard are reasonable and achievable. Selected examples of the supporting analyses and assumptions used to develop the schedule are summarized below.

Removal Volume

The Productivity Standard is based on the removal of approximately 2.65 million cubic yards of sediment, as stated in the ROD. This volume may be revised upward or downward based on the results of the design support sediment characterization program. The Productivity Standard requires adjustment if the final targeted dredging volume differs by more than 10% from the current estimate.

Construction Schedule and Dredging Season

The Productivity Standard is based on a construction period for the project of six (6) years (including Phases 1 and 2, as stated in the ROD) and assumes that there will be a minimum of 30 weeks available each year to conduct dredging operations, unconstrained by any work hours limitations. To implement this schedule, coordination would be required with the New York State Canal Corporation to extend their routine hours and season of operation.

Dredging Equipment

Both mechanical and hydraulic dredges were considered during the development of the conceptual schedule. Smaller specialty equipment was also considered for use near shorelines, in shallow water, and in difficult locations (such as shallow bedrock areas). Estimated dredging volumes were developed by river section and dredge type for the schedule. The conceptual schedule included only the use of a mechanical dredge as a conservative approach, since mechanical dredging is typically a slower process. The schedule assumes that dredging can take place in multiple river sections simultaneously, with the dredging generally progressing from upstream to downstream within each river section.

Work Elements and Sequence

The conceptual schedule assumptions address the potential elements and sequence of the dredging work. The assumptions include, but are not limited to, the following:

- Silt barriers, while not required by the Productivity Standard, were assumed to be installed for all dredging work outside the navigation channel. The assumed silt barriers consist of segments of steel sheet piling installed at the upstream and downstream limits of the work area, connected by high density polyethylene (HDPE) curtains with floatation booms and weighted at the bottom. This assumption is conservative with respect to the schedule, which accounts for the time necessary to install and remove the silt barriers.

- Silt barriers are removed only after backfill and shoreline stabilization where appropriate, has been completed.

- Backfilling and shoreline stabilization at each area dredged in a particular season is completed prior to demobilization at the end of each dredging season.

- Work is conducted in a generally upstream to downstream sequence within a given river section.

Sediment Processing/Transfer Facility

The conceptual schedule of the Productivity Standard assumed the establishment of one land-based sediment processing/transfer facility, located at the northern extreme of the 40-mile long project area. Conceptual design calculations were prepared regarding railroad sidings, transportation of scows loaded with dredged sediments via the canal system, and other transportation issues to evaluate whether the dredged sediment volumes to be removed could be transferred, processed (*e.g.*, dewatered), and shipped off-site at an appropriate rate (compared to the required and target production rates). The assumption of one facility was made to be conservative with respect to the schedule, in that it requires sufficient time for sediments removed from any location within the Upper Hudson to be transported to one location. A less conservative assumption would entail two facilities, as was assumed for purposes of evaluating engineering feasibility of the remedy. Note, however, that the assumption does not reflect a worst case based on available information, which would be one facility at or below the southern extreme of the project area.

Interactions Among Performance Standards

The development of the Performance Standards included consideration of the degree to which they are interrelated. Some of the major points of interaction between the Standards, and issues identified as being significant to the compliance with all the standards, are summarized below. The design of the project should be optimized in consideration of these interactions.

- The Resuspension Standard controls PCB mass loss during dredging. It is important to note that PCB mass loss is intrinsically linked to dredging productivity, in that ongoing project activities (dredging, vessel traffic, installation and removal of barriers, if used, and debris removal) will contribute to PCB mass loss. The Resuspension Standard Concern Level and Control Level are triggered if the average daily Total PCB mass loss exceeds 600 g/day for more than a one-week, or four-week stretch, respectively.[10] Non-compliance with the Productivity Standard beyond the six (6) year schedule will increase the total project PCB mass loss. If unforeseen difficulties require extensions to the schedule, the daily allocation of PCB mass loss will have to be commensurately lowered during the remainder of the dredging project to maintain the PCB mass loss of 650 kg upon which the Resuspension Standard action levels are based. Achievement of the target cumulative annual volumes in the Productivity Standard is strongly encouraged to minimize the total project-related downstream transport of PCBs.

- Balancing the limits on PCB concentrations in the water column in the Resuspension Standard and the cumulative annual volumes in the Productivity Standard requires careful planning during equipment deployment considering, for example, the impacts of the number and types of equipment selected, location of dredging areas, and the monthly baseline variation in PCB water column concentrations. This is an area where Phase 1 monitoring is expected to contribute significantly to the understanding of how to efficiently proceed with dredging and maintain compliance with the Performance Standards.

- The Residuals Standard requires characterization of residual sediments, which may include redeposited/settled sediments. To avoid recontamination of a satisfactorily completed certification unit, the Productivity Standard assumes that dredging generally will proceed from upstream to downstream within each River Section. The Resuspension Standard modeling also indicates that the dredge may create a deposit of resuspended sediments slightly downstream of each dredging area, providing further incentive for work to proceed generally from upstream to downstream.

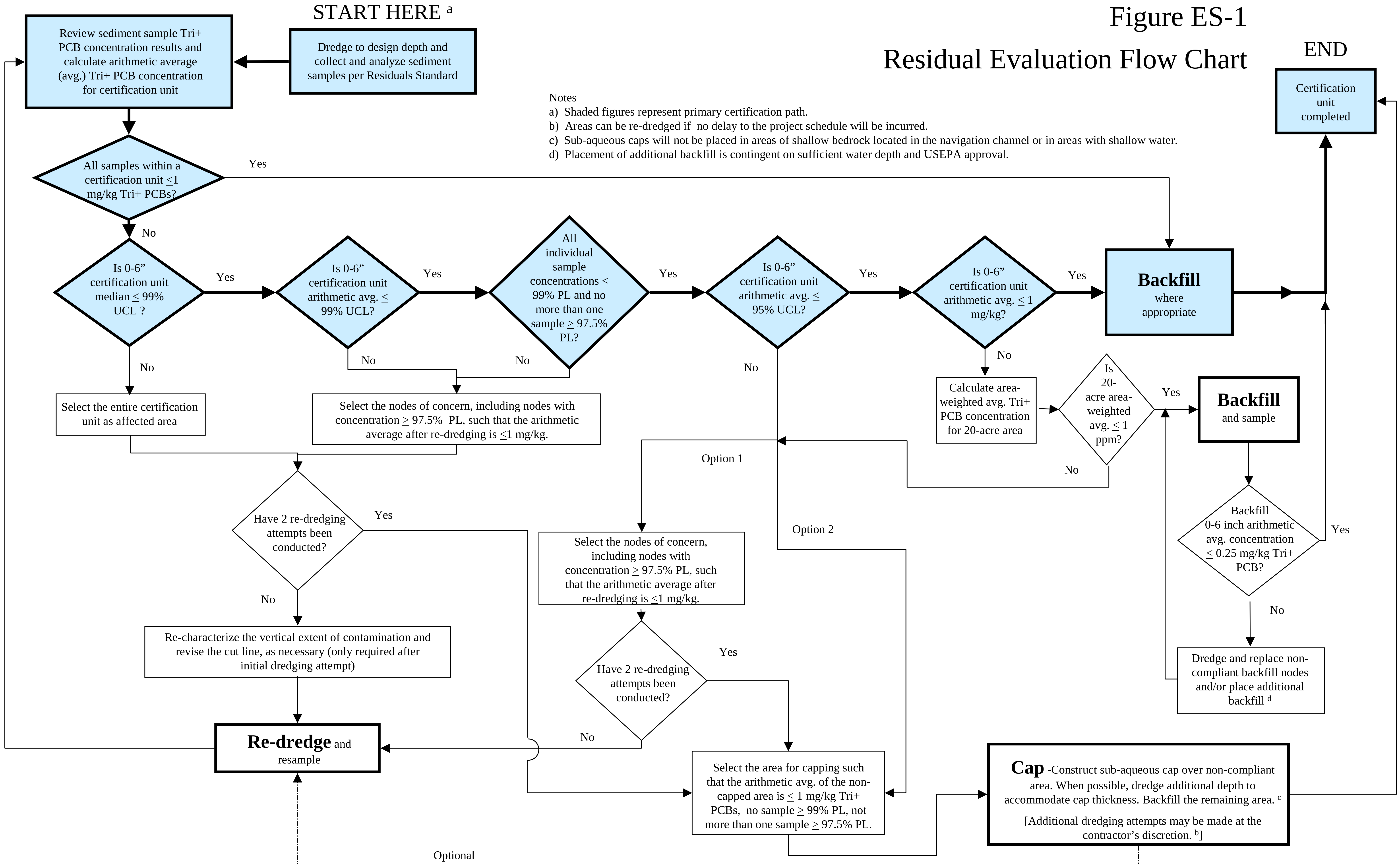
- The Productivity Standard includes a conceptual sequence of work and schedule for the dredging work to validate the feasibility of the required and target cumulative annual dredging volumes. The conceptual sequence of work and schedule necessarily included, among other elements, the time needed to comply with the requirements of the Residual Standard for sampling and analysis of each certification unit, possibly two re-dredging attempts and/or sub-aqueous cap

[10] The daily rate is based on attainment of the recommended target cumulative volume as specified in the Productivity Standard, and should be prorated according to the production rate planned in the Production Schedule to be submitted annually to USEPA.

construction, and placement of backfill (where appropriate) prior to demobilization. For instance, USEPA conservatively assumed that re-dredging could require half of the total time spent on the initial dredging. However, if significantly more time is needed for re-dredging than was estimated in the conceptual schedule, it may affect the ability to meet the overall productivity standard. Understanding that these work elements contribute to the project duration, flexibility was designed in the Residuals Standard (*e.g.*, provisions for 20-acre joint evaluations during Phase 1, options for immediate capping where the certification unit mean is only slightly greater than the objective of 1 mg/kg Tri+ PCBs, and provisions for successively closing portions of a certification unit as dredging progresses) to maintain productivity. The experience and information gained during Phase 1 of dredging will be the subject of the second peer review. This peer review will evaluate the project performance in Phase 1, so that any necessary refinements and adjustments can be made to the dredging operations or standards, including the Productivity Standard, prior to the second phase of dredging.

Figure ES-1

Residual Evaluation Flow Chart



Introduction
Draft Engineering Performance Standards – Peer Review Copy
Hudson River PCBs Superfund Site

Overview

In February 2002, the United States Environmental Protection Agency (USEPA) issued a Record of Decision (ROD) for the Hudson River PCBs Superfund Site (Site). The ROD calls for targeted environmental dredging of approximately 2.65 million cubic yards of PCB-contaminated sediment from the Upper Hudson River (approximately 40 river miles) in two phases over a six-year period, and monitored natural attenuation of the PCB contamination that remains in the river after dredging.

In the ROD, USEPA identified five remedial action objectives, which are as follows:

- Reduce the cancer risks and non-cancer health hazards for people eating fish from the Hudson River by reducing the concentration of PCBs in fish;
- Reduce the risks to ecological receptors by reducing the concentration of PCBs in fish;
- Reduce PCB levels in sediments in order to reduce PCB concentrations in river (surface) water that are above applicable or relevant and appropriate requirements for surface water;
- Reduce the inventory (mass) of PCBs in sediments that are or may be bioavailable; and
- Minimize the long-term downstream transport of PCBs in the river.

In selecting its cleanup remedy, USEPA required that performance standards for resuspension during dredging, production rates during dredging, and residuals after dredging (together called the "Engineering Performance Standards") be established. This decision was made to address comments received from members of the public who expressed a wide spectrum of views on the project. Some suggested that the environmental dredging could "do more harm than good" and take much longer than stated, while others were concerned that the ROD was not sufficiently comprehensive in its requirements for the environmental cleanup. USEPA required these performance standards in its final cleanup decision to promote accountability and ensure that the cleanup meets the human health and environmental protection objectives set forth in the ROD.[1]

This Public Review Copy of the Draft Engineering Performance Standards document is published in four volumes. The standards are presented in three parts, each contained in a single volume; an Appendix is contained in the fourth volume. Each part discusses one performance standard: *Part 1* discusses the Performance Standard for *Dredging*

[1] Other performance standards will address public concerns related to potential impacts of the cleanup on the surrounding community, such as air emissions, navigation and noise; these are being developed separately.

Resuspension, Part 2 provides the Performance Standard for *Dredging Residuals*, and *Part 3* contains the Performance Standard for *Dredging Productivity*. Each of these parts includes a concise statement of the standard, discussion on the development approach, supporting analyses, and rationale used to derive the performance standard. Each part further provides a plan for refinement of the standard to account for additional data that may be obtained subsequent to publishing the standard, as well as to address evaluation of Phase 1. The Appendix contains a review of pertinent information derived from case studies of other environmental dredging projects considered in developing the draft Engineering Performance Standards. Some of the information was derived from research of the literature and public web sites, while additional information was developed from interviews with project managers and technical staff.

Consistent with the ROD, the Engineering Performance Standards were developed in consultation with New York State, the National Oceanic and Atmospheric Administration and the U.S. Fish and Wildlife Service. (New York State is developing substantive water quality certification requirements for the environmental dredging pursuant to the federal Clean Water Act; USEPA will review the requirements when they become available for any implications with respect to the Engineering Performance Standards). USEPA's consultants included a team of senior scientists and engineers who developed the standards, which then were reviewed by a separate team of recognized technical experts. General Electric Company reviewed a version of the draft standards previous to this one. Comments from these organizations were considered in preparing a Public Review Copy of the Draft Engineering Performance Standards.

Following the close of the public comment period on July 14, 2003, the Draft Engineering Performance Standards was revised to create the Draft Engineering Performance Standards – Peer Review Copy. This version of the standards will be peer reviewed by a panel of independent experts, modified as appropriate to address the peer reviewers' recommendations, and then implemented during the Phase 1 dredging. The results from the first season of dredging (Phase 1) also will be peer reviewed, and the Engineering Performance Standards will be refined or adjusted, if necessary, for the remaining dredging seasons (Phase 2).

It is important to note that the standards developed herein are intended only for application to the remedial environmental dredging of the Upper Hudson River called for in USEPA's 2002 ROD for the Hudson River PCBs Superfund Site at this juncture in time. The standards are not intended to provide general or universal guidance for environmental dredging. Other projects and locations may have specific features differing from those of the Hudson River, and the standards presented here may not be applicable to those projects.

Site Background

The Hudson River PCBs Superfund Site encompasses the Hudson River from the Fenimore Bridge in Hudson Falls (River Mile [RM] 197.3) to the Battery in New York Harbor (RM 0), a stretch of nearly 200 river miles (about 320 km). The Upper Hudson

River portion of the Site extends from the Fenimore Bridge to the Federal Dam at Troy (RM 153.9), a distance of just over 43 river miles. To facilitate effective project management and address Site complexities, the Upper Hudson River has been further divided into three major sections: River Sections 1, 2 and 3. River Section 1 extends from the former Fort Edward Dam just north of Rogers Island (RM 194.8) to the Thompson Island (TI) Dam (RM 188.5), a stretch of the river also known as the Thompson Island Pool; River Section 2 extends from the TI Dam to the Northumberland Dam (RM 183.4), which includes a 2.3-mile, non-navigable stretch of the river from the TI Dam to the Fort Miller Dam; and River Section 3 extends from the Northumberland Dam to the Federal Dam. Upstream of River Section 1 is a river segment between the Fenimore Bridge and the former Fort Edward Dam, a distance of about 2.5 river miles.

During an approximately 30-year period ending in 1977, General Electric (GE) used PCBs in its capacitor manufacturing operations at its Hudson Falls and Fort Edward, NY facilities. PCB oils were discharged both directly and indirectly from these plants into the Hudson River. This included both non-permitted and permitted discharges. Even after GE received a permit in 1975, permit exceedances occurred. Estimates of the total quantity of PCBs discharged directly from the two plants into the river from the 1940s to 1977 are as high as 1,330,000 pounds (about 605,000 kg).

Many of the PCBs discharged to the river adhered to sediments and accumulated downstream with the sediments as they settled in the impounded pool behind the former Fort Edward Dam, as well as other depositional areas farther downstream. Because of its deteriorating condition, the Fort Edward Dam was removed in 1973. Five areas of PCB-contaminated sediments were exposed due to the lowering of the river water level when the Fort Edward Dam was removed. These five areas are known as the Remnant Deposits. During subsequent spring floods, PCB-contaminated sediments from the Fort Edward Dam area were scoured and transported downstream.

In 1984, USEPA completed a Feasibility Study (FS) and issued a Record of Decision (ROD) for the site (the 1984 ROD). The 1984 ROD contained the following components:

- An interim No Action decision with regard to PCBs in the sediments of the Upper Hudson River;
- In-place capping, containment, and monitoring of exposed Remnant Deposits (in the area of RM 195 to 196) from the former impoundment behind the Fort Edward Dam, stabilization of the associated river banks and revegetation of the areas; and
- A detailed evaluation of the Waterford Water Works treatment facilities, including sampling and analysis of treatment operations to see if an upgrade or alterations of the facilities were needed.

Although commercial uses of PCBs ceased in 1977, GE's Fort Edward and Hudson Falls plants continue to contaminate the Hudson River with PCBs, due primarily to releases of PCBs via bedrock fractures from the GE Hudson Falls plant. In September 1991, GE detected an increase in PCB concentrations at the Upper Hudson River water sampling stations being monitored as part of the construction monitoring program associated with Remnant Deposits capping. GE ultimately attributed the higher levels to the collapse of a wooden gate structure within the abandoned Allen Mill located adjacent to the river bank near the GE Hudson Falls plant. As reported by GE, the gate structure had diverted water from a tunnel that had been cut into bedrock, thereby preventing oil-phase PCBs originating at the GE Hudson Falls plant, that had migrated to the tunnel via subsurface bedrock fractures, from flowing into the river. From 1993 to 1995, GE removed approximately 45 tons of PCBs from the tunnel under NYSDEC jurisdiction. In 1994, GE documented the presence of PCB-contaminated oils in bedrock seeps at Bakers Falls adjacent to its Hudson Falls plant. GE has instituted a number of mitigation efforts that have resulted in a decline, but not cessation, of PCBs entering the river through the seeps.

The 1984 ROD did not address the PCB-contaminated oil leaking through bedrock in the vicinity of the GE Hudson Falls plant, which was not known to USEPA at the time. GE is conducting remedial activities at the GE Hudson Falls Plant Site under an Order on Consent between the New York State Department of Environmental Conservation (NYSDEC) and GE. The changing upstream loading from the Hudson Falls site must be accounted for in any evaluation of PCB levels within the Hudson River. In addition, the GE Fort Edward Plant outfall area is likely a continuing source of PCBs to the Hudson River , although the Fort Edward outfall area currently is being remediated by the New York State Department of Environmental Conservation pursuant to state law.

In December 1989, USEPA announced its decision to initiate a detailed Reassessment Remedial Investigation/Feasibility Study (RI/FS) of the interim No Action decision for the Upper Hudson River sediments. This was prompted by the five-year review required by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), technical advances in sediment dredging and treatment/destruction technologies, as well as a request by NYSDEC for a re-examination of the 1984 decision. The February 2002 ROD is the result of the Reassessment.

Engineering Performance Standards Development

This document presents the development of the performance standards required by the ROD and discusses the major measure(s) of performance in each case, the technique(s) used to assess performance, the supporting analyses for the recommendations (including case studies), and major possible interactions among the performance standards.

To develop meaningful performance standards, it was necessary to envision a likely sequence of work for the major elements of the remediation project. It is understood that this "model sequence" may require adjustment as the remedial design is prepared. The model sequence of work outlined below is based on information in the ROD and emphasizes the points where the performance standards will interact with the work.

1. Extensive sediment sampling and analyses are conducted to identify locations where the Tri+ PCB mass per unit area (MPA) is 3 g/m^2 or greater in River

Section 1 and 10 g/m^2 or greater in River Section 2. In River Section 3, identification of target areas is based on removal of selected sediments with high concentrations of PCBs, high erosional potential and potential for uptake by biota. This information, in conjunction with other field investigation data, is used to determine target area boundaries for dredging and to delineate dredging "cut-lines." The dredging cut-lines are to be designed to remove all PCB-contaminated sediments within a particular targeted area (*i.e.*, the dredged bottom surface concentration is anticipated to be below 1 mg/kg).

2. Regular water column sampling and analysis is conducted to evaluate the PCB and total suspended solid (TSS) concentrations in the Hudson River prior to dredging (background concentrations).
3. Upon commencement of remediation, environmental dredging is employed to remove contaminated sediments from the targeted areas. Water quality monitoring is conducted continuously according to the requirements of the Dredging-Related Resuspension Performance Standard. Contingency actions are implemented to control resuspension releases if the action levels in the standard are contravened.
4. On completion of dredging in a particular targeted area, post-dredging sediment sampling is conducted according to the requirements of the Dredging Residuals Performance Standard to confirm that residual PCB concentrations are less than or equal to the anticipated residual concentration of approximately 1 mg/kg, as specified by the ROD. Contingency actions are implemented if sediment sample results from a particular targeted area are non-compliant. Following verification, backfill is placed where appropriate and shoreline stabilization is completed.
5. The progress of the dredging project is monitored according to the requirements of the Dredging Productivity Performance Standard. Contingency actions are implemented if the dredging production rate deviates significantly from that required by the performance standard.
6. At the completion of the first dredging construction season (Phase 1), remedial operations are assessed for compliance with the various performance standards. If necessary, adjustments to the remedial operations and performance standards are recommended, evaluated by the peer review panel, and implemented.
7. Phase 2 dredging commences and continues through project completion. Extensive monitoring (including that required to establish compliance with the performance standards) continues throughout the life of the project. Adjustments to the remedial operations and performance standards may also be implemented during Phase 2 consistent with the peer-reviewed approach.
8. Property restoration and decommissioning of the processing/transfer facility location(s) are conducted as expeditiously as practicable following completion of dredging and backfill activities. Habitat replacement and associated monitoring are performed in accordance with the approved plan.

Based on the analyses performed to develop the standards, USEPA believes that the standards are consistent with the human health and environmental protection objectives of the ROD. USEPA has determined:

- Compliance with the Resuspension Standard will limit the concentration of Total PCBs in river water one mile or more downstream of the dredging area to levels that are acceptable for potable water under the requirements of the Safe Drinking Water Act;

- Resuspension of PCBs in compliance with the Resuspension Standard will have a negligible adverse effect on Tri+ PCB concentrations in Hudson River fish, as compared to a scenario assuming no dredging-related PCB releases;[2]

- Compliance with the Control Level of the Resuspension Standard is expected to result in a Total PCB load (mass) transported downstream during remedial dredging that is similar to the range of Total PCB loads detected during recent baseline (*i.e.*, pre-dredging) conditions, as documented by weekly measurements from 1996 to 2001;

- The Residuals Standard specified in the ROD (approximately 1 mg/kg Tri+ PCBs prior to backfilling) is achievable based on case studies of other environmental dredging projects and can be applied in the Upper Hudson on an area-wide average basis;

- The Productivity Standard will result in completion of the dredging within the six dredging seasons called for in the ROD, based on an example conceptual schedule for project implementation; and

- The three Draft Engineering Performance Standards, including their respective monitoring programs, are achievable individually and in combination. The standards appropriately balance their points of interaction, allowing flexibility during design and implementation while ensuring protection of human health and the environment. For example, the requirements concerning additional dredging attempts in the Residuals Standard must consider the requirements for dredging production in the Productivity Standard.

Performance Standard for Dredging Resuspension

The Performance Standard for Dredging Resuspension (*i.e.*, Resuspension Standard) is designed to limit the concentration of PCBs in river water such that water supply intakes downstream of the dredging operations are protected, and to limit the downstream transport of PCB-contaminated dredged material. The attendant water quality monitoring program will be implemented to verify that the objectives of the Resuspension Standard have been met during dredging. The analytical results obtained from the water quality monitoring will be compared to the Resuspension Standard and associated lower action levels to monitor and control resuspension through appropriate actions. Such actions

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[2] A negligible effect is defined, in this case, as a predicted Tri+ PCB concentration in Upper Hudson fish of 0.5 mg/kg or less, and in Lower Hudson River fish of 0.05 mg/kg or less, within 5 years after the completion of dredging in the Upper Hudson.

could include, as appropriate, expanding the monitoring program, notifying public water suppliers, implementing operational or engineering improvements, and, if necessary, temporarily halting the dredging.

The ROD requires the development of a Resuspension Standard but does not set forth any framework or numerical value for the Standard. The Resuspension Standard and a series of tiered action levels were developed based on extensive modeling, review of environmental dredging case study data, and evaluation of applicable or relevant and appropriate requirements (ARARs) identified in the ROD for PCBs in river water. Thresholds for increased monitoring and engineering controls provide a basis for design and evaluation of a contingency plan in the event of a contravention of the action levels. Once a baseline monitoring program has been finalized and implemented for the project, new water quality data will be collected and evaluated. The improved understanding of baseline conditions will be used to prepare a more thorough description of the relationships between water quality parameters and to further refine or adjust the Resuspension Standard (primarily the associated monitoring program), as necessary, based on the peer-reviewed approach. A plan is presented for refinement of the standard and the associated monitoring program, both as a result of availability of ongoing baseline monitoring data prior to Phase 1, and following completion and evaluation of Phase 1.

Performance Standard for Dredging Residuals

The Performance Standard for Dredging Residuals (*i.e.*, Residuals Standard) is designed to detect and manage contaminated sediments that may remain after initial remedial dredging in the Upper Hudson River. The ROD calls for removal of all PCB-contaminated sediments in areas targeted for dredging, and anticipates a residual of approximately 1 mg/kg Tri+ PCBs (prior to backfilling). The "residual sediments" may consist of contaminated sediments that were disturbed but escaped capture by the dredge, resuspended sediments that were re-deposited/settled, or contaminated sediments remaining below the initial dredging cut elevations (*e.g.*, due to uncertainties associated with interpolation between core nodes of the design sediment sampling program or insufficient core recovery).

The Residuals Standard requires the implementation of a post-dredging sampling and analysis program to detect and characterize PCB concentrations in the residual sediments. The post-dredging sediment data are compared to the anticipated residual of approximately 1 mg/kg Tri+ PCBs stated in the ROD and a group of statistical action levels developed for the Residuals Standard. The approach to be taken to manage the residual sediments (including re-dredging) is then selected depending on the statistical analyses of the post-dredging data. The use of statistical analyses to evaluate environmental datasets is a scientifically accepted practice.

The development of the residuals performance standard was accomplished using information from remedial dredging project case studies, and consideration and implementation of statistical data evaluation tools. The standard also encompasses contingency options in the event of non-compliance, and the development of an approach to refine the standard following analysis and interpretation of Phase 1 data.

Performance Standard for Dredging Productivity

The Performance Standard for Dredging Productivity (*i.e.*, Productivity Standard) is designed to monitor and maintain the progress of the dredging to meet the schedule stated in the ROD. The project schedule stated in the ROD has a six-year duration and consists of the first dredging season designated "Phase 1" (with dredging at a reduced scale) followed by five dredging seasons collectively designated "Phase 2" (each with dredging at full production to remove the remainder of the contaminated sediments identified for removal). The Productivity Standard specifies the cumulative volume of sediment to be dredged during each dredging season, based on the current estimate of 2.65 million cubic yards of sediment to be removed. Following the completion of Phase 1, the data obtained from the monitoring program will be analyzed to determine if refinements to the Productivity Standard or changes to the Phase 2 remedial program are necessary.

Structure and Content of the Engineering Performance Standards

As stated above, the Engineering Performance Standards are presented in three parts, one for each of the three standards. To provide a comprehensive and consistent presentation of each standard, each part is subdivided into four sections, as follows:

Section 1 – Statement of the Performance Standard

This section provides a concise statement of the standard and associated lower-tier action levels with no rationale or background explanation. It simply states the standard as it is to be implemented during the dredging program.

Section 2 – Technical Basis of the Performance Standard

This section contains three major subsections describing the technical basis for development of the standard.

Background and Approach

The objectives, development processes, and methodology used in the development of these standards are presented in this section. A brief summary of the scope for the development of the standard is included in this section. Summaries of several case studies that are similar in nature to this project are also presented.

Supporting Analyses

This section analyses the available information for its applicability to this project. This section includes the statistical evaluations and modeling required in order to derive the standard. Evaluations of baseline monitoring data or performance data from previous case studies, as well as any conceptual design activities, that give substance to the derivation of the standard are provided.

Rationale for Determination of the Standard

Based on the supporting analyses performed, a determination is made as to what the performance standard should be, and the rationale for this determination is discussed. Analysis of case studies, along with reasoning and explanation of decisions and judgments made to arrive at the standard is provided in this section.

Section 3 – Implementation of the Performance Standard

This section is a full presentation of the standard, including conceptual information to be provided to assist the user to interpret application of the standard in unforeseen circumstances. Action levels, including the standard proper, along with monitoring requirements and the basis for engineering controls and contingencies to be required at each level, are laid out in detail.

Section 4 - Plan for Refinement of the Performance Standard

This section contains a plan for refinement of the standard that may be appropriate due to ongoing collection of baseline data, or to discovery of additional case studies that shed new light on the development of the standard prior to implementation of Phase 1. In addition, the plan will address the means by which data developed during monitoring of Phase 1 operations and impacts will be used to refine or adjust the standard prior to and during Phase 2.

Within each Section, the presentation may vary from Standard to Standard, in order to suit the needs of that particular Standard.

Key Project Personnel and Roles

In order to facilitate development of engineering performance standards that are consistent with the state-of-the-art dredging technologies and methods, scientific and statistical analysis, and the current level of knowledge about the Hudson River system, Malcolm Pirnie assembled a technical team of highly qualified professionals, many of whom had been involved with the Reassessment RI/FS for the site, or previous work on the river on behalf of New York State. In addition, the quality review normally conducted internally was delegated to a diverse team of technical experts assembled from a broader pool of candidates, recognized in their respective fields, and functioning independently of the technical team developing the standards.

Technical Team

The technical effort was divided among three teams corresponding to the three standards to be developed. Key senior members of the technical team are presented below.

Bruce Fidler, P.E. – Engineering Performance Standards Development Leader

Mr. Fidler obtained his master's degree in civil and sanitary engineering in 1979 and has more than 23 years experience in environmental engineering and hazardous waste remediation. He has been involved with the Hudson River PCBs Superfund Site since 1991, virtually the entire period of the Reassessment RI/FS and subsequent design-phase work. While with TAMS Consultants, Inc., Mr. Fidler led various pre-feasibility evaluations and served as Project Manager for Phase 3 of the Reassessment, including preparation of the Feasibility Study and the summary of the selected remedy presented to USEPA's National Remedy Review Board, and the final Reassessment Responsiveness Summary incorporating over 73,000 comment documents received from the public. Having joined Malcolm Pirnie in early 2002, Mr. Fidler is now providing consultation on various aspects of the design period activities in addition to leading the engineering performance standards development effort.

Edward Garvey, Ph.D., P.G. – Resuspension Standard Team Leader

Dr. Garvey is a senior environmental geochemist with TAMS Consultants, Inc., an Earth Tech Company. He has over 22 years of experience in environmental geochemistry, with additional experience in human health risk assessment and hydrogeology. His educational training includes a Ph.D. in geochemistry, a M.A. in geological sciences and a B.E. in chemical engineering. Dr. Garvey is a registered geologist/geochemist in the Commonwealth of Pennsylvania. Dr. Garvey's experience includes over 19 years of study specific to the Hudson River, including his Ph.D. dissertation and his efforts since 1991 as the chief scientist on the Hudson River PCBs Reassessment RI/FS for USEPA. For the Reassessment RI/FS, Dr. Garvey planned and directed the collection of environmental data, including extensive, multi-year sediment and water column sampling programs, coordinated the efforts of various scientists and consultants, and prepared several major reports on the investigation. His work on this project has produced several technical papers as well as many technical presentations on the fate of PCBs in the environment. In his role as the Resuspension Standard Team Leader, Dr. Garvey brings extensive experience on the geochemical interpretation of sediment contamination data and its implications for long-term PCB transport.

Neven Kresic, Ph.D. – Residuals Standard Team Leader

Dr. Kresic has more than 20 years of teaching, research and consulting experience in surface water and groundwater assessment, engineering and remediation for U.S. and international clients. He has designed site characterization and environmental sampling plans, and performed data analysis and evaluation of remedial design alternatives at numerous CERCLA, Resource Conservation and Recovery Act (RCRA) and other industrial sites throughout the US. His areas of expertise include subsurface modeling, geostatistical, probabilistic and stochastic analyses of spatial and time data series, and groundwater remediation. Dr. Kresic is a professional geologist and hydrogeologist, and teaches short professional courses in geographic information systems (GIS), Groundwater Modeling and Groundwater Remediation for the National Ground Water Association.

John Mulligan, P.E. – Productivity Standard Team Leader

Mr. Mulligan earned his master's degree in sanitary engineering from the School of Public Health at the University of North Carolina in 1967 and has over 35 years of experience in civil and environmental projects including a number of hazardous waste remediation projects involving dredging and disposal of contaminated sediments. He became involved in the Hudson River PCB project in 1974 when he served as Malcolm Pirnie's project engineer on the design of a new water main crossing the Hudson. This was required to replace existing mains damaged by the removal of the former Fort Edward Dam, and involved removing timber cribs from the former dam pool, and stabilizing the sediment deposits left behind the old dam when the water level fell. From 1975 through 1991, he served as Malcolm Pirnie's Project Manager for the preparation of studies and designs for the NYSDEC aimed at remediating the PCB contamination of the river sediments. In more recent years, Mr. Mulligan has designed a dredging project to remove and dewater PCB-contaminated sediments from the St. Lawrence River for General Motors Corp. and assisted in the design of the demonstration project for the remediation of PCB-contaminated sediments at Deposit N in the Fox River near Green Bay, WI.

Donald J. Hayes, Ph.D., P.E. – Consulting Expert

Dr. Hayes has been working with environmental aspects of dredging, dredged sediment disposal, and contaminated sediment management for over 20 years. He has published extensively in these areas. He also contributed to a number of guidance documents and authored software used to evaluate contaminated sediments management alternatives. He is especially recognized for his expertise in water quality impacts associated with dredging operations. Dr. Hayes served on the National Academies of Engineering Committee on Contaminated Marine Sediments and co-authored the resulting report. He is currently actively working on seven contaminated sediment projects and has contributed to many more projects over the past few years; many of these are Superfund projects. He previously contributed to the Reassessment Feasibility Study for this Site, as well as the final Reassessment Responsiveness Summary. Dr. Hayes worked as a research Civil Engineer at the USACE's Waterways Experiment Station for over 10 years and has been in academia for the past 11 years. Dr. Hayes received his Ph.D. in Environmental Engineering and Water Resources Planning and Management in 1990.

In addition to the expertise contributed by these team members, modeling for the project was conducted by LimnoTech, Inc. (HUDTOX model) and Menzie-Cura & Associates, Inc. (FISHRAND model).

Quality Review Team

Quality reviews for the project are being performed by a team of experts that functions independently of the technical team. Reviewers include the following:

Kenneth J. Goldstein, C.G.W.P - Quality Review Team Coordinator

Area of Expertise: Residuals Sampling

Mr. Goldstein is a professional hydrologist/hydrogeologist at Malcolm Pirnie, with over 20 years experience in contaminant hydrogeology and contaminant fate and transport. He has designed work plans, field sampling plans and quality assurance plans and directed numerous sampling and analytical programs for physical and chemical characterization of sediments, soil and groundwater.

Mr. Goldstein was responsible for the sampling and characterization of dredge spoil deposits and contaminated sediments in the Upper Hudson River through the late 1980s and early 1990s. In addition, Mr. Goldstein developed field sampling plans and performed sediment sampling on the Raritan River, Jamaica Bay, and Eastchester Bay. He has performed statistical and geospatial analysis of sediment quality data and physical characterization data. Mr. Goldstein's current focus is on remediation of contaminated media using in-situ remedial technologies.

Jonathan B. Butcher, Ph.D., P.H.

Areas of Expertise: Residuals, Resuspension, Reassessment RI/FS History

Dr. Jonathan Butcher is an environmental engineer and Professional Hydrologist with TetraTech, Inc., who has worked on the Reassessment RI/FS for the Hudson River PCBs Site since soon after its commencement. He has provided technical support in four key areas: (1) contaminant fate and transport modeling for PCBs within the river water and sediment; (2) predictive modeling of bioaccumulation of PCBs in fish; (3) data validation and reconciliation for historical data collection efforts, and (4) sampling design and statistical and geostatistical analyses of sample data.

Dr. Butcher developed the Phase 1 PCB fate and transport model application and Phase 2 model specifications for the study, and was responsible for internal model review during the FS. He developed a bivariate bioaccumulation factor method to predict PCB burdens in fish in systems where the water column and sediment fractions are not in equilibrium, and collaborated on development of mechanistic and stochastic bioaccumulation models. He was also responsible for an innovative study of the environmental partitioning behavior of PCB congeners in Hudson River water and sediments.

Dr. Butcher has taken a lead role in the review of GE's alternative modeling analyses of PCBs in the Hudson, and has developed methods for translating historical Aroclor quantitation results to a common Tri+ PCB basis. He has published several peer-reviewed papers on key scientific aspects of this work.

Gregory Hartman, P.E.

Areas of Expertise: Sediment Remediation, Environmental Dredging, Dredging Residuals

Mr. Hartman is a licensed Professional Engineer in Oregon and Washington, and is currently a consultant with the firm of Dalton, Olmsted & Fuglevand in Kirkland, WA. Mr. Hartman has a B.S. in Civil Engineering, and an M.S. in Coastal and River Engineering. He has 34 years experience working in the Coastal and Waterway Industry. As a Civil Engineer in the Navigation Division of the Portland District USACE, he was Chief of Dredging Operations, and gained direct working experience as a dredger. Since 1978 Mr. Hartman has been a consultant, working on coastal and river projects in the United States and overseas.

Mr. Hartman has taught the USACE Dredging Fundamentals Short Course every year since 1982. He has also taught courses intermittently on Dredge Cost Estimating, Dredge Contract Administration, and Dredge Inspectors Course to the USACE, and Dredge Remediation and Confined Disposal Site Design for the University of Wisconsin Short Course on Understanding Contaminated Sediment.

Mr. Hartman is Past President and Past Chairman of the Board for the Western Dredging Association, and Retired Board Member of the World Dredging Association. He is on the Board of Industry Advisors for the World Dredging, Mining and Construction Magazine. Relevant experience includes the remediation of the St. Paul Waterway in Tacoma, WA and the development, design and construction oversight for the Sitcum Waterway Remediation Project in the Port of Tacoma. Mr. Hartman was Dredge Consultant for various projects including: the design and contract oversight of navigation dredging and PCB remediation on the US Navy Puget Sound Shipyard in Bremerton, WA; Pilot Study 2000, to dredge PCBs for the New Bedford, MA remediation; preliminary design for remediation of PCBs in Fox River, WI; sediment remediation in Greens Bayou, TX and; Hylebos Waterway PCB remediation design and construction in Tacoma, WA.

Michael R. Palermo, Ph.D., P.E.

Areas of Expertise: Sediment Remediation, Environmental Dredging, Residuals

Dr. Palermo is a Research Civil Engineer and Director of the Center for Contaminated Sediments at the U.S. Army Engineer Research and Development Center, Waterways Experiment Station, where he manages and conducts research and applied studies concerning dredging and dredged material disposal and remediation of contaminated sediments. He has authored numerous publications in the area of dredging and dredged material disposal technology and remediation of contaminated sediments. He was the lead author of the USACE technical guidance for dredged material capping and the lead author of the USEPA ARCS program guidance for in-situ capping for sediment remediation. Dr. Palermo also serves on several technical advisory panels for superfund projects involving contaminated sediments.

Dr. Palermo is a Registered Professional Engineer and a member of the Western Dredging Association and the International Navigation Association. He is also Associate Editor for the Journal of Dredging Engineering. He received his B.S. and M.S. degrees in Civil Engineering from Mississippi State University and his Ph.D. degree in Environmental and Water Resources Engineering from Vanderbilt University.

William N. Stasiuk, Ph.D., P.E.

Areas of Expertise: Water Quality, Public Water Supply, Risk Assessment

Dr. Stasiuk is a Licensed Professional Engineer at Malcolm Pirnie, with experience in dealing with sites contaminated with PCBs. In 1975, he helped coordinate the NYSDEC's technical case in the original enforcement action against GE regarding Hudson River contamination. He directed the public health response to PCB contamination in the West Glens Falls, NY residential area in 1979 and the subsequent remedial action.

As Director of the Center for Environmental Health within the New York State Department of Health (NYSDOH) from 1985 through 1996, Dr. Stasiuk provided direction to the Bureaus which carried out exposure investigations, risk assessments and health studies at all contaminated sites in New York State. He was directly responsible for the post-cleanup assessment and further remedial actions leading to the reoccupancy of the Binghamton State Office Building. He provided oversight of assessment, response and remedial actions at the State University at New Paltz PCB contamination incident.

Also with NYSDOH in the late 1960s, Dr. Stasiuk was instrumental in development of a mathematical water quality model for the Hudson River from Corinth to the Battery. He also organized, staffed and supervised the first Toxic Substances Control Unit in NYSDOH in 1979, and assisted in development of drinking water standards for organic compounds, including PCBs. He was the NYSDOH's representative on the NYS Superfund Management Board.

In addition to providing executive direction to the Bureau of Water Supply (part of the Center for Environmental Health), Dr. Stasiuk's water supply experience includes serving from 1996-2000 as Deputy Commissioner and Director of the Bureau of Water Supply in the New York City Department of Environmental Protection, which is responsible for the New York City water supply system.

Quality Review Team Roles and Responsibilities

The above team of experts, collectively referred to as the Quality Review Team (or QRT), was charged with reviewing and evaluating the scope of work and approach for the development effort as well as a series of draft deliverables leading up to publication of the standards for review by the public and the peer review panel. The team members performed their reviews individually, but then sought to reach consensus and provide unified guidance to the technical team to the extent possible. All comments received from the QRT were considered carefully by the technical team and implemented in consultation with USEPA.

Although each of the five members of the QRT has a particular specialty (or specialties) relating to the project as indicated above, each was asked to review all three standards in the course of his work. The intention of this approach was to provide consistent review and evaluation of all standards individually and to provide evaluation of the interactions among the standards. While each of the QRT members has reviewed the standards[3], and concurs with their form and content, each has been operating solely within the framework of this project and not with the intention of providing generic or universal guidance on performance standards development related to other projects or sites.

Disclaimer Applicable to the Engineering Performance Standards Development

As indicated above, the standards developed herein are intended only for application to remedial environmental dredging of the Upper Hudson River called for in USEPA's 2002 ROD for the Hudson River PCBs Superfund Site at this juncture in time. The standards are not intended to provide general or universal guidance for environmental dredging. Other projects and locations may have specific features differing from those of the Hudson River, and the standards presented here may not be applicable to those projects.

[3] Gregory Hartman, PE was unavailable to review later drafts of the standards documents as issued for public comment and peer review, but participated in review of the technical approach, as well as internal drafts. He also addressed specific questions and issues posed by members of the technical team during preparation of later drafts.

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Draft Performance Standard for Dredging Residuals
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ATTACHMENTS

<u>Draft Engineering Performance Standards – Public Review Copy</u>
<u>Hudson River PCBs Superfund Site</u>
Performance Standard for Dredging Residuals

1.0 Statement of the Performance Standard for Dredging Residuals

The Performance Standard for Dredging Residuals (referred to as the Residuals Standard) is designed to detect and manage contaminated sediments that may remain after initial dredging in the Upper Hudson River. The ROD calls for removal of all PCB-contaminated sediments in areas targeted for dredging, and anticipates a residual of approximately 1 mg/kg Tri+ PCBs (prior to backfilling). The "residual sediments" may consist of contaminated sediments that were disturbed but escaped capture by the dredge, resuspended sediments that were redeposited/settled, or contaminated sediments remaining below the design dredging cut elevations (*e.g.*, due to uncertainties associated with interpolation between core nodes or insufficient core recovery).

The Residuals Standard requires the implementation of a post-dredging sampling and analysis program to detect and characterize PCB concentrations in the residual sediments. The post-dredging sediment data are compared to the anticipated residual of approximately 1 mg/kg Tri+ PCBs stated in the ROD and a group of statistical action levels developed for the Residuals Standard. The approach to be taken to manage the residual sediments (including re-dredging) is then selected depending on the statistical analyses of the post-dredging data. The use of statistical analyses to evaluate environmental datasets is a scientifically accepted practice.

Following the summary of the Residuals Standard in Section 1.0 of this document, subsequent chapters provide the technical basis for the development of the standard (Section 2.0), a full version of the Residuals Standard (Section 3.0), and a plan for adjustments to the Standard (Section 4.0). Section 1.1 below briefly describes the action levels, sampling requirements, and decision points included in the Residuals Standard.

1.1 Residuals Standard Criteria

The Residuals Standard refers to each dredged area to be evaluated as a "certification unit," and uses a group of action levels for evaluation of sediment quality in each certification unit after dredging. Certification units are defined as 5 acres in size, based on the average size of existing targeted areas. In each certification unit, 40 sediment cores (each at minimum 0-6 inches in length) are to be collected immediately after the dredging contractor has reached the design cut lines, as confirmed by USEPA oversight. Each core sample will then be analyzed for Tri+ PCB concentration and the results compared to the Residuals Standard's action levels, which are associated with the required actions summarized below. In addition, core samples may need to be collected and analyzed from deeper intervals until a compliant horizon is encountered (see below). This is necessary in specific instances to ensure that the vertical extent of contaminated residual sediment is adequately characterized prior to implementing the required actions of the Residuals Standard, such as re-dredging, if necessary.

The Residuals Standard requires the review of: 1) the Tri+ PCB concentrations in all 40 individual sediment samples within each 5-acre certification unit, 2) the arithmetic average (mean) Tri+ PCB concentration of the certification unit, 3) the median Tri+ PCB concentration of the certification unit, and 4) the arithmetic average of the mean Tri+ PCB concentrations of a 20-acre joint evaluation area (certification unit under review and the three previously dredged units within a 2 mile stretch of river). The following actions are required for Phase 1 of the dredging project (adjustments may be made for Phase 2 based on the findings collected during Phase 1, including statistical site-specific concentration values and increasing, if justified, the joint evaluation area to 40 acres):

1. Backfill (where appropriate) and Demobilize: At certification units with an arithmetic average residual concentration of 1 mg/kg Tri+ PCBs or less, no sediment sample result of 27 mg/kg Tri+ PCBs or greater, and not more than one sediment sample result of 15 mg/kg Tri+ PCBs or greater, backfill (where appropriate) and demobilize from the certification unit.

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 of 27 mg/kg Tri+ PCBs or greater, and not more than one sediment sample result of 15 mg/kg Tri+ PCBs or greater, jointly evaluate a 20-acre area.

   For the 20-acre evaluation, if the area-weighted arithmetic average of the individual arithmetic averages (means) from the certification unit under evaluation and the 3 previously dredged certification units (within 2 miles of the current unit, measured along the River's centerline) is 1 mg/kg Tri+ PCBs or less, backfill may be placed (with subsequent testing required). Otherwise, all or part of the certification unit must be re-dredged (see #4 below for actions required during and following re-dredging) or a sub-aqueous cap constructed. Re-dredging 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 re-dredging attempts, contingency actions may be implemented in lieu of further re-dredging attempts, as described in #5, below.

3. Re-dredge or Construct Sub-aqueous 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 sediment sample result of 27 mg/kg Tri+ PCBs or greater, and not more than one sediment sample result of 15 mg/kg Tri+ PCBs or greater, re-dredge or construct a sub-aqueous cap. The choice of two options is provided to maintain flexibility and productivity (*e.g.*, some areas may not be conducive to dredging). If re-dredging is chosen, the surface sediment of the re-dredged area must be sampled and the certification unit re-evaluated. If the certification unit does not meet the objectives of #1 or #2, above, following two re-dredging attempts,

contingency actions may be implemented in lieu of further re-dredging attempts, as described in #5, below.

4. Additional Sampling and Re-dredging 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 or to address individual sampling point(s) with concentrations of 27 mg/kg Tri+ PCBs or greater or more than one sampling point with concentrations of 15 mg/kg Tri+ PCBs or greater, additional sampling and re-dredging is required.

   Sampling at depths greater than 6 inches will be triggered by an arithmetic average residual concentration 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 core samples is required from deeper intervals over the entire certification unit (*e.g.*, 6-12 inch, 12-18 inch, etc.) as necessary to re-characterize 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 arithmetic average concentration. Additional sampling to characterize the vertical extent of contamination is contemplated only once.

   The Residuals Standard provides a mechanism for calculating the horizontal extent of re-dredging. All re-dredging attempts are to be designed to reduce the mean Tri+ PCB concentration of the certification unit to 1 mg/kg Tri+ PCBs or less. If after two re-dredging attempts, the arithmetic average Tri+ PCB concentration in the surface sediment is still greater than 1 mg/kg, then contingency actions are to be implemented as stated in #5, below.

5. Contingency Actions: At areas where two re-dredging attempts do not achieve compliance with the action levels, construct an appropriately designed sub-aqueous cap, where conditions allow, or choose to continue re-dredging.

In cases where re-dredging is required but fails to reduce the concentration below the action levels (after two additional attempts), there are two options available: (1) an appropriately designed sub-aqueous cap may be placed to isolate the PCB residuals, as provided in the contingency elements of the Residuals Standard (refer to Section 2.3.6), or (2) the Construction Manager (as defined in Section 2.3.4) may choose to continue dredging, based on cost considerations, consideration of impacts to the schedule, and knowledge of the dredging area and equipment.

The rationale for the action levels is provided in Section 2.1.1, Criteria in the Record of Decision and Section 2.2.1.3, Action Levels for Average and Individual Sample Concentrations. Based on an evaluation of currently available case study data, the action levels chosen represent the following statistical limits on the certification unit arithmetic averages and individual sample concentrations:

- 27 mg/kg Tri+ PCBs – 99% Prediction Limit (PL)
- 15 mg/kg Tri+ PCBs – 97.5% PL
- 6 mg/kg Tri+ PCBs – 99% Upper Confidence Limit (UCL)
- 3 mg/kg Tri+ PCBs – 95% UCL

The 99% PL and 95% PL are prediction limits considering individual samples, and the 99% UCL and 95% UCL are upper confidence limits on the mean (*i.e.*, arithmetic average; see Section 2.2.1.3.1 for further information).

Note that all PCB concentrations are to be rounded conventionally to whole numbers in mg/kg Tri+ PCBs. These values may be revised pending new data that may be available prior to the Phase 1 effort, or during or subsequent to the Phase 1 dredging effort (refer to Section 4.0).

1.2 Draft Residuals Standard Implementation

Post-dredging sediment sampling must be completed within seven days after dredging is completed within the certification unit. Dredging completion is defined as the entire certification unit meeting the design cut elevations. Post-dredging sediment sampling and analyses generally consists of the following tasks:

- Visual investigation of the dredging residuals in the certification unit using sediment profile imaging (SPI) equipment at approximately 25 percent of the sample locations.
- Collection of 40 uniformly spaced sediment cores from each certification unit less than or equal to 5 acres in size (refer to Section 2.2.7).
- Processing of each sediment core to obtain a 0-6 inch sample.
- Laboratory extraction of the samples and analysis of the extracts for PCBs. Analysis of deeper samples (6-12 inch, 12-18 inch, etc.) may be required, even if the collection of additional core samples is required, based on the arithmetic average concentration encountered in the 0-6 inch layer.
- Calculations of arithmetic average, area-weighted average for 20-acre area, and median from certification unit laboratory data.
- Comparison of individual results, arithmetic averages, area-weighted averages and median to Residuals Standard action levels.

Required actions following the tasks described above are shown in Figure 1-1 as a flowchart and summarized in Table 1-1.

1.3 Preference for Dredging

The selected remedy includes dredging of contaminated sediment, using the mass of PCB contamination as the primary means to target removal areas. The Residuals Standard specified in the ROD (approximately 1 mg/kg Tri+ PCBs prior to backfilling) is achievable based on case studies of other environmental dredging projects and can be applied on an area-wide average basis. However, review of case studies also indicates that, for some isolated areas, residual concentrations subsequent to the initial dredging attempt may exceed the standard. The non-compliant residuals will likely be associated with difficult-to-dredge bottom conditions such as bedrock outcrops and boulder fields. As a result, in limited areas of the Hudson River, it may be difficult to achieve the Residuals Standard. Capping of areas where the residual concentrations exceed the action levels following two re-dredging attempts has been added as an option to address this scenario.

Capping was assessed as a remedial action alternative during the Feasibility Study, but the use of a cap to contain the existing contaminant inventory was not found to provide the same degree of reliability as the dredging alternative. This finding was due to the potential for defects or damage to the cap, thereby reducing its effectiveness relative to dredging while still requiring the sediment handling, processing, and disposal activities needed for the removal alternatives. The option for capping allowed in the Residuals Standard differs significantly from the remedial action alternative in that the design dredging cut lines must be met and the targeted PCB inventory removed before this option can be considered (*i.e.*, the capping contingency in the Residuals Standard is an element of the dredging remediation, and not a stand-alone remedial action alternative). Because the mass of PCBs to be isolated is greatly reduced, the reliability of the cap in isolating the contamination is less critical. Were the cap breached in this situation, the potential spread of contamination would be much less because of the much lower contaminant mass and potential for mixing (dilution) with the greater volume of surrounding capping material.

Although application of an engineered cap for elevated residual concentrations has been added as an option in the standard, there is a decided preference for dredging alone. Capping is less reliable for long-term control than dredging, and there are long-term operation and maintenance requirements associated with this option. Factors for deciding if an area should be capped and preparation of the site-specific cap design must include the river conditions (sediment texture, water depth, location in the channel, compatibility with habitat, etc.) as well as cost and impact on productivity. The option for capping is not meant to compensate for any deficiency in the dredging design. A limit on the amount of area that can be capped without obtaining approval from USEPA may be added to the standard for Phase 2, based on information gathered during Phase 1. USEPA will be fully involved in the decision-making for areas to be capped. USEPA will review the residual sampling data collected for the areas, confirm that the dredging cut lines have been met, review field notes, and review and approve each site-specific cap design.

1.4 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 determining compliance with the Performance Standard for Residuals. The reports will need to summarize, at a minimum, the results of residual sediment sampling, exceedances of the Residual 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 CU, individual Certification Unit 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 determining compliance with the Performance Standard for Residuals. 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.
- SPI results.
- 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 attempt.
- Discussion of any contingency actions taken.
- Number of dredging attempts for residual concentration reduction.
- For each attempt, provide a map of the CU showing the concentration at each node and the non-compliant area to be re-dredged or capped.
- A signed attestation that the Certification Unit was closed in accordance with the requirements of the Residuals Performance Standard and the approved Remedial Design.

2.0 Technical Basis of the Performance Standard for Dredging Residuals

2.1 Background and Approach

2.1.1 Criteria in the Record of Decision

The 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)."

The Residuals Standard requires dredging residual concentrations to be compared to the ROD's anticipated residual of approximately 1 mg/kg Tri+ PCBs, which was 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+ PCBs 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]. This surface concentration also closely approximates the concentration that is likely to result from recontamination of the backfill surface by the continued low level releases from the 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 the backfill. The model indicated that fish tissue recovery trajectories are acceptable with a backfill Tri+ PCBs concentration of 0.25 mg/kg or less; however, model runs using higher backfill PCB concentrations yielded more elongated (*i.e.*, slower) recovery trajectories. Therefore, the Residuals Standard must control Tri+ PCBs concentrations in residuals that may impact the backfill, and the criterion of approximately 1 mg/kg Tri+ PCBs stated in the ROD is considered to be an appropriate threshold for evaluation of the dredging residuals. Areas where backfill is not to be placed (*e.g.*, navigation channel)

[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 top 6 inches of residual 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 be limited to the upper 6 inches of the backfill layer.

were modeled at 1 mg/kg Tri+ PCBs, therefore, this criterion is appropriate for such areas.

The Residuals Standard further builds on the ROD's stated objective of "an anticipated residual concentration of approximately 1 mg/kg Tri+ PCBs" by including a group of statistically derived action levels. The action levels are used to trigger specific responses (including re-dredging) 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.

2.1.2 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, the type of dredging (mechanical/hydraulic) conducted, the characteristics of the area, the presence of debris or boulders, post-dredging contaminant concentrations, the number of samples (sample density), depth of samples, type of samples (*e.g.*, grab, core, composite), sample location and the 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 the Appendix: Case Studies of Environmental Dredging Projects (provided under separate cover as Volume 4 of 4). A brief summary of project information for the case studies reviewed is provided in Table 2-1.

2.1.3 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), 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 Sampling Guidance (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 U.S. USEPA guidance documents on sampling design, including the Soil Screening Guidance (USEPA, 1996) and SW-846 (USEPA, 1986), but it includes innovative designs not covered in earlier USEPA's 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.

Systematic and Grid Sampling. In this 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.

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 this case, unaligned grid sampling is recommended. If nothing is known about the spatial characteristics of the target population, grid sampling is efficient in 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.

2.2 Supporting Analyses

2.2.1 Case Study Statistical Data Evaluation

2.2.1.1 Introduction

Case study data were acquired for a number of projects with related contamination and remediation strategies. 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 the certification units were derived using the case study data, as described below.

2.2.1.2 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 instance, projects where the excavation was done "in the dry" are not as relevant as are those done "in the wet;" 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-excavation dredging data were obtained for eight sites (described below). Table 2-1 contains project information for seven of these sites. The post-dredging sample data obtained are provided in Attachment A.

The sub-bottom sediments at these sites were fine grained with some exceptions. The sites located in the St. Lawrence River (General Motors Massena and Reynolds Metals) had gravel and cobbles. The Grasse River removal had rocky conditions. The majority of the target areas in the Upper Hudson River are likely to be fine grained, but there are some coarse-grained areas that will require dredging (not including the rocky areas exempted from dredging by the ROD, which consist of exposed bedrock). 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 the sites requiring multiple re-dredging attempts used technology that was incapable of meeting the remediation goals at certain areas of the site. For example, at Reynolds Metals, the most contaminated area had DNAPL contamination on cobbles. This 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 feet. Core samples were collected from all sites with the depth of collection varying from 4 to 12 inches 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 0-2 cm.

All of the sites listed on Table 2-1 have PCB contamination except for Marathon Battery, which has cadmium contamination. 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 Total PCB concentration. Of the four sites that had a target post-excavation concentration, two of the sites were able to achieve the goal.

The spatial distribution of the residual concentrations is shown in Figure 2-1 for several of the sites using polygonal declustering analysis. In most cases, the distribution of the residuals concentrations was heterogeneous with a few locations of higher concentration.

For Reynolds Metals, the "hottest" (most contaminated) quadrants were located in a small area relative to the entire site. This area was located 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 PCBs.

For the Marathon Battery site, most of the area had a pre-dredging cadmium concentration 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 pre-dredging samples were examined to determine if 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 pre-dredging 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 post-excavation 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 pre-dredging 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 0-1 foot layer appeared to coincide with the pre-dredging hotter areas. The pattern and magnitude of contamination in the 0-2 cm (corresponding to approximately 0-1 inch) layer is much different and higher than the 0-1 foot layer, which 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 percent 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 pre-dredging conditions. The length weighted average concentration (LWA) of the pre-dredging cores gives a measure of the concentration removed by dredging. The depth of the pre-dredging cores varied from 12 inches to 36 inches. 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.

2.2.1.3 Action Levels for Average and Individual Sample Concentrations

2.2.1.3.1 <u>Overview</u>

The Hudson River post-dredging residual sample concentrations are to be compared to action levels to determine if the certification unit concentrations are within acceptable limits (as explained in Section 1.1, certification units are defined as dredged areas 5 acres in size, based on the average size of existing targeted areas). These action levels were developed based on the case study residual 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 any 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 arithmetic average concentration. There will be two numerical action levels for the certification unit arithmetic average: 1) an acceptable upper limit below which the area could be backfilled (with conditions) without requiring re-dredging and 2) an "unacceptably high" limit, below which either re-dredging or construction of an engineered cap would be required, and above which re-dredging would be required. The second type of action level is an upper bound concentration for an individual sample. 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 re-dredging or capping, according to the average concentration of the certification unit and the number of re-dredging attempts already conducted.

The action levels were calculated based on the case study data, using a variety of statistical approaches to determine 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 percent 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 percent chance that it will be outside the 97.5% prediction level.

These interval estimates (along with the 99% UCL and the 99% PL) 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. 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. One point in a target area will be allowed to exceed the 97.5% PL value. Using these statistics indicates that 2.5 percent 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 then selected based on weight of evidence.

The first approach relies on direct 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 certification units (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.

2.2.1.3.2 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 2-2.

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 2-3. 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) value for nonparametric data was 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, and
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, and
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, and
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:

$$MVUE = \left[\exp(\bar{y})\right] \Psi_n\left(\frac{s_y^2}{2}\right) \qquad (6)$$

where:

$\exp(\bar{y})$	=	the geometric mean of the data,

s_y^2 = the variance of the logarithms of the data, and

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 = $\frac{s_y^2}{2}$

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 dense non-aqueous phase liquid (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 additional 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 (0-2 cm). Because the residual samples for the Upper Hudson River will be collected from the 0-6 inch interval to characterize residual concentrations that are not only a result of spillage (sloughing, homogenization of the sediment, etc.), the New Bedford Harbor grab samples are not comparable. The one-foot 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 Mahanalobis 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.

2.2.1.3.3 Results

The statistics for each case study are summarized in Table 2-3. 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 show a somewhat linear pattern with high correlation coefficients. Of the Q-Q plots shown, 7 of 10 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.

Values for multiple dredging attempts at the GM Massena site show the effect on the average concentration with each additional re-dredging 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 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.

UCL and PL estimates for the Upper Hudson River are also presented in Table 2-3. For each site, the value based on proportionality and the value based on substitution are presented. 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 and 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 and 10 to 48 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 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 2.2.1.3.2, 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 6. Substituting this standard deviation into the Chebyshev nonparametric UCL equation gives 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 and the appropriate value for $H_{1-\alpha}$ (2.731 for α = 0.05 and 4.560 for α = 0.01) into the UCL equation for lognormally distributed data (Equation 3).

This gives 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 and 2.023 for t. This gives 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, more simple approach will be taken for the PLs: the average PL of the seven sites calculated using substitution. The individual PL values are shown on Table 2-3. The average 97.5% PL is 15 mg/kg Tri+ PCBs and the average 99% PL is 25 mg/L Tri+ PCBs.

A summary of the UCL and PL values calculated using a single estimate of the variance from the case studies, where possible, is given in Table 2-4. 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 if the area weighted concentration is as high as the 95% UCL.

For the 99% UCL, both means of calculating this value 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.

2.2.1.3.4 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)
95% UCL	3
99% UCL	6
97.5% PL	15
99% PL	27

2.2.2 Relevance of the PL Criteria

The Residual Performance Standard is based on average Tri+ PCB concentrations in the certification unit. Because compliance with the residual 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 re-dredging. 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.

2.2.3 Estimate of Re-dredging Area by Percent Reduction in PCBs

Historical sediment sampling data can be used to estimate the Tri+ PCB concentrations in a hypothetical six-inch 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 re-dredging or capping. The NYSDEC 1984 sediment samples provide the most comprehensive coverage of the Upper River, with the samples concentrated in the Thompson Island (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 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 $\frac{g_{dryweight}}{cc}$, and
- 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 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 percent 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. Areas requiring additional re-dredging 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 Residual Standard's action levels are listed in Table 2-5. For a 6-inch thick residuals layer, if 99 percent removal can be achieved, only 9 percent of the area will require additional treatment (*e.g.*, re-dredging). If 95 percent removal can be achieved, 58 percent of the area will require no additional treatment, 25 percent of the area can be considered for backfilling (with backfill testing required), 5 percent could be capped immediately and 11 percent would require re-dredging. A remedial goal of this project has been inventory removal of between 95 and 98 percent (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).

The tiered action levels in the standard provide flexibility in the approach to the remediation, with a mandatory re-dredging requirement (certification unit mean, *i.e.*, arithmetic average > 6 ppm) for only 11 percent of the targeted area if 95 percent of the contamination is removed by meeting the design cut lines through the first dredging attempt. Capping or backfilling with testing is an option for the remaining 30 percent 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 re-dredging attempts.

2.2.4 Estimate of Re-dredging 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:

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

where:

p = probability of compliance (0.975 or 0.99),
n = number of trials (40),
y = number of samples less than the target, and
x = n – y, the number of non-compliant samples.

The probabilities for the non-compliance of 0-40 nodes at the PL action levels are listed in Table 2-6, 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 certification unit 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 equation above, there is a 73.6% probability (36.3% + 37.3%) that zero or only one 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 certification units with an areal average of 1 mg/kg Tri+ PCBs will not have exceedances of the PLs.

Assuming that each non-compliant node will require dredging to the surrounding nodes that are located 80 feet away, the area of re-dredging for each node is 0.38 acres. Using the probabilities given by the binomial distribution and assuming that a total of 100 CUs will be dredged, exceedances of the PL action levels will require re-dredging 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 percent 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.

2.2.5 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 (Part 3 of the ROD, USEPA, 2002). The goal of the remediation is a 96 to 98 percent reduction in 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% (0-1 foot layer)
- Marathon Battery 99.6%

- Lake Jarnsjon 99%

Two of the sites have comparatively lower percent reductions in contaminant concentration (Grasse River and Fox River). 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 2-1), 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 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.

2.2.6 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 certification units on this basis. For comparison, the HUDTOX modeling performed by USEPA to evaluate the recovery of the Upper Hudson River after sediment remediation used 20-acre river segments in the TI Pool as the base unit for the calculations (USEPA, 2001a, 2002).

2.2.7 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, and 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) is equal to:

$$n = \frac{Z_{1-\alpha}^2 S_y^2}{[\ln(d+1)]^2 + Z_{1-\alpha}^2 S_y^2 / N} \qquad (6)$$

where: S_y^2 = The 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 = The 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 percent 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 (5 acres), N is very large and approaches infinity. Estimates of the number of samples required using this equation are presented for each of the case studies in Table 2-7. 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 is also shown (GM Massena, including the capped area, and the New Bedford Harbor grab samples). For these sites, the number of samples required ranges from 34 to 92.

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 discussed above of 1.31, 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 equation from Gilbert (1987) given above 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 residual standard. The baseline condition occurs when the mean is below or equal to the residual 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 residual 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 actually true.
>
> A *false acceptance* decision error occurs when the sample data indicate that the baseline condition is probably true when it is actually 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 Residual Standard, which requires re-dredging or capping if the baseline conditions are not met, require a large number of samples and should 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 percent and a false acceptance rate of 5 percent, 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.

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. On a 5-acre certification unit, the uniform triangular grid spacing is 80 feet 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.

2.2.8 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 if these data exhibited any directional or spatial correlation. It should be noted that some of the figures associated with this section of the report show only the relative sampling positions and detected concentrations for case study residual sampling datasets because base maps being prepared as part of the remedial design are not available for use.

2.2.8.1 Reynolds Metals

The Reynolds Metals site has a number of characteristics that are similar to the Hudson River PCBs site; 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-foot spacing in the hot-spot area and 70 feet 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 feet.

Although the pre-dredging 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), and the available data cannot be used to assess the reason for the elevated residual PCB concentrations. Despite this data limitation, however, 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.

2.2.8.2 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-foot by 50-foot grid. One sample from the upper six inches 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 foot 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 foot 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 foot spacing could be statistically evaluated. Like the data on the finer 50 by 50 foot grid, these data showed no spatial correlation.

2.2.8.3 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 Figure 2-10, 2-11 (grab samples) and 2-12 (core samples). The samples were collected on an approximately 40-foot 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 at the New Bedford Harbor site have no spatial correlation.

2.2.8.4 New Bedford Harbor Core Samples

A total of 18 core samples were collected from the New Bedford Harbor site and analyzed for Total PCBs. Spatial distribution of the New Bedford core samples is shown on Figure 2-12. Samples were collected on a 40-foot triangular grid. 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.

2.2.8.5 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.

As shown on Figure 2-13, the non-directional (all directions) semi-variogram of these data shows 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 0, a contribution (sill) of 130, and a range of 280 feet.

2.2.8.6 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 feet perpendicular to the river channel and 75 to 150 feet 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 feet.

2.2.8.7 Fox River SMUs 56/57

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

2.2.8.8 GM Massena

A total of 111 samples were collected and analyzed for PCBs at the GM Massena site on the St. Lawrence River in New York. As shown on Figures 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 all located in an approximately 400 by 400 foot 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 feet.

2.2.8.9 Summary of Semi-Variogram Analysis

Of the seven post-dredging sediment sample data sets analyzed, four of these data sets showed spatial correlation in PCB concentrations. Only one of these data sets (Reynolds Metals) showed a specific directional correlation. This directional correlation 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, use of an asymmetrical sampling grid for the Upper Hudson River residual sediment samples is not supported by these case studies.

The statistical ranges of the semi-variograms from the four sites with spatial correlation ranged from 55 feet to 280 feet. This variability between 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 re-dredging attempts are required to meet cleanup objectives. No further analysis of pre-dredging sediment samples from the Upper Hudson River is planned. Further geostatistical evaluation will be conducted using residual sediment data obtained during Phase 1 (refer to Section 4.0).

2.2.9 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.

2.2.9.1 Coring

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 deep 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 that have 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 Design Support Sediment Sampling program (QEA, 2002) being implemented by GE 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.

2.2.9.2 Sampling with Small Dredges

Examples of small dredges used to collect sediment grab samples include the Peterson, Eckman, and Ponar dredges. These dredges are generally clamshell-type scoops that are lowered to the sediment surface and remotely closed. 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 centimeters (USACE, 1994).

Disadvantages of grab sample collection using dredges include their inability to collect an undisturbed sample. Shallow sediments collected from the first centimeter 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 other 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.

2.2.9.3 Underway Surficial Sediment Sampling

The University of Georgia, 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 4-6 cm for sampling, and at a recommended towing speed of 3 knots, a maximum collection of three samples per kilometer is possible (USGS, 2001). Based on these parameters, the towed sled does not appear to meet the project sampling requirements (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 is an emphasis on characterizing this layer separately from layers below the dredging cut line.

2.2.9.4 Discrete vs. Composite Sampling

A grab sample is a discrete aliquot that is representative of a specific location at a given point in time (USACE, 1994). For example, the collection of a number of grab 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 both 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 parameter of interest (USEPA, 2000).

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.*, re-dredging 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.

Discrete and composite sampling schemes can be combined. 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 0-6 inch 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 depth intervals can be collected. A composite sample representing a larger depth interval could "dilute" or obscure data of interest.

2.2.9.5 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 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.

The SPI camera is capable of obtaining a cross-sectional image of the sediment profile to a depth of 20 cm. Deployment of the 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; therefore, use of the SPI camera will be required during Phase 1 residual sampling events and possibly during Phase 2, depending on the outcome of Phase 1.

2.2.10 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 Residual Standard action levels. A Standard Operating Procedure (SOP) for data validation will be developed that is based on the selected laboratory analytical method.

2.3 Rationale for the Development of the Performance Standard

2.3.1 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 2.2.9.1, core sampling preserves the depositional sequence of the sediment sample, creates a comparatively minimal disturbance at the sediment-water interface, and maintains comparability with historic data sets collected by USEPA and the design support sampling being conducted by GE.

Composite sampling was rejected as a method of sample management. The Residual Standard objectives require a discrete sampling method for the collection of residual sediments. 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).

Residual sediment samples will be collected from 40 locations in each certification unit less than or equal to 5 acres in size. In larger dredging areas, 40 samples will be collected per five-acre area. The identification of a particular certification unit 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 5-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.
- Dredging areas smaller than 5 acres in size within ½ mile of one another can be "lassoed" into a single certification unit. The sum of the grouped dredging areas must be less than 7.5 acres. The sampling grid is to be proportionally sized so that a minimum of 40 cores are collected from within the dredging areas, and up to 60 cores are collected (by applying the 80-foot grid spacing within areas grouped into a single certification unit with a total dredged area of 7.5 acres).
- 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-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 certification units 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 into equally sized, approximately 5-acre certification units and a triangular grid with 80 foot 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 5-acre or smaller sampling area. The residual sampling grid will be offset from the pre-design sampling grid (the average distance between the locations of the design grid and the residual grid will be between 40 and 60 percent of the design grid nodal spacing). Acceptable criteria for relocating grid nodes in the event an obstruction is encountered (*e.g.*, a grid node "falls" on exposed bedrock) are defined as relocating the sample within a 20-foot radius of the original node location.

Observations will be made prior to and during core collection to evaluate the thickness of the veneer. SPI information, field assessment of penetration resistance, and visual classification of the material retrieved in the core tube will be used to quantify the thickness of the dredging residuals. The sediment core will be advanced as necessary to collect a representative 6-inch core (or to refusal, whichever is first encountered). It may be desirable to collect and archive deeper sediment intervals during sampling of the 0-6 inch layer, but it is not required by the Standard. If the average concentration of the samples representing the 0-6 inch 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 re-characterized. 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.

As part of performance standard development, an evaluation was performed to assess whether it was necessary or appropriate to include a "waiting period," meaning that the residuals sampling should not occur until at least 24 hours after the dredging operation ceased. The purpose of 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 on the TSS. The TSS concentration in a 5-acre certification unit 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 feet from the dredge). The PCB concentration on these 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.*, Thompson Island Pool). A "fluffy" bulk density of 1.1 g/cc was also assumed. The calculation is presented in Table 2-8. If a 6-inch 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.

2.3.2 Sample Management

Following core sample collection, each 0-6 inch sample will be adequately homogenized in preparation for laboratory analysis. The 0-6 inch sample is intended to characterize the layer of sediment that is subject to bioturbation in a freshwater environment (6 inches deep), and therefore available to biota. The selection of a 0-6 inch 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 foot thick. The 0-6 inch residuals sampling interval may, 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 un-dredged "PCB inventory"). In some instances, the post-dredging sediment may contain a thin, higher concentration veneer layer. As discussed in Attachment A, a 6-inch 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 certification unit average Tri+ PCB concentration is greater than the 99% UCL, deeper core sampling must be conducted to re-characterize 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 deficiencies in the design support characterization and cut-line design. In this case, deeper sampling (compared to the 0-6 inch depth interval) is required to investigate for the potential presence of deeper PCB-contaminated sediment inventory as a planning step for the required re-dredging attempt.

The deeper cores will be divided (segmented) into successive 6-inch depth-discrete grab 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 Section 2.2.5.4) and will provide flexibility for decision-making related to further remedial dredging. The rationale for segmenting the residual sampling cores into 6-inch intervals is based on likely minimum re-dredging depths and an evaluation of case study data from the New Bedford Harbor site that indicated that segments shorter than 6 inches would not provide useful data (refer to Attachment A).

2.3.3 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).

2.3.4 Data Evaluation and Required Actions

The results of the sediment sample analyses from the 0-6 inch 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+ PCBs concentration in a "moving" 20-acre area consisting of the certification unit under evaluation and the three previously dredged certification units within 2 river miles of the unit under evaluation (measured along the centerline);
- average Tri+ PCB concentration in the certification unit under evaluation;
- median Tri+ PCB concentration in the certification unit under evaluation; and

- individual sample concentrations in the certification unit under evaluation.

The Residuals Standard action levels are to be compared to the above-listed values as follows:

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

The values currently representing the UCLs and PLs were derived from statistical evaluation of the case study datasets, as discussed in Section 2.2.1, 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.

For a certification unit with 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, and no individual sample concentrations equal to the 99% PL or greater, the objective of the ROD has been demonstrably achieved and no further remedial action is required prior to placement of backfill (where appropriate) and demobilization of the dredge and ancillary equipment from the certification unit.

For a certification unit with a mean greater than 1 mg/kg Tri+ PCBs but less than or equal to the 95% UCL, not more than one individual sample concentration equal to the 97.5% PL or greater, and 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 (only a 5 percent probability that the true mean (arithmetic average) is 3 mg/kg or greater) to allow the option of placing backfill without requiring re-dredging attempts, provided that the 20-acre arithmetic average is 1 mg/kg Tri+ PCBs or less. This option is included in the Residuals Standard because the HUDTOX model used to assess the adverse impacts of PCB contamination in the sediments is based on 20-acre (Thompson Island Pool) and 40-acre (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. To further control potential impacts, testing of the placed backfill is required to demonstrate that the surface concentration is 0.25 mg/kg Tri+ PCBs or less (refer to Section 2.1.1). The backfill must be sampled using the same grid spacing as the residual sediment samples, via the collection of 40 0-6 inch cores (for a 5-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 re-dredged, replaced, and re-sampled (or additional backfill may be added, as approved by USEPA on a case-by-case basis). If the 20-acre arithmetic average 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 re-dredged or isolated with an appropriately designed sub-aqueous cap (both are examples of an engineering contingency; refer to Section 2.3.6). The selection of either the re-dredging or the capping option is to be decided by the Construction Manager (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 conducting re-dredging or capping in a certification unit is to commence with identification of the cluster(s) that are 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 conducting a re-dredging attempt. If after two re-dredging attempts, the residual concentrations do not comply with the action levels, the Construction Manager may choose to place an appropriately designed sub-aqueous cap over the clusters. The sub-aqueous cap top elevation is to be equivalent with the backfill elevation in the remainder of the certification unit.

For a certification unit with arithmetic average exceeding the 95% UCL and less than or equal to the 99% UCL, no 20-acre evaluation is permitted. The grid nodes contributing to the elevated arithmetic average in the certification unit must be re-dredged or isolated with an appropriately designed sub-aqueous cap (an instance of an engineering contingency; refer to Section 2.3.6); the selected option is to be chosen by the Construction Manager.

The option to place an appropriately designed sub-aqueous cap to isolate residuals (without attempting re-dredging) was included based on evaluation of case study data that showed continuous re-dredging of target areas decreased productivity without meeting the goals of the remediation. The cost of construction and maintenance of a sub-aqueous cap should be considered and compared to the costs and schedule impacts of re-dredging when selecting this option. The sub-aqueous 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 sub-aqueous cap is only intended to isolate recalcitrant residuals, and must be constructed so that the arithmetic average of the nodes in the uncapped area within the certification unit is 1 mg/kg Tri+ PCBs or less, no individual node is 27 mg/kg Tri+ PCBs or greater, and not more than one node is 15 mg/kg Tri+ PCBs or greater.

Re-dredging is required at certification units 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, and/or at any sampling locations with results equal to the 99% PL or greater (even in targeted areas where the arithmetic average concentration is equal to or below 1 mg/kg Tri+ PCBs) to reduce the uncertainty in the statistical evaluation and 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, and post-backfill levels of 0.25 mg/kg Tri+ PCBs or less). When the certification unit average exceeds the 99% UCL, additional core sampling must be conducted to re-characterize the vertical extent of contamination prior to re-dredging. The additional core sampling must consist of the collection and analysis of sufficient depth intervals 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 certification unit is greater than 6 mg/kg, the entire certification unit 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. For re-dredging of a sampling location that exceeds the PL action levels, or in any case where an elevated cluster is to be re-dredged, the re-dredging 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 Section 3.5.2). 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. Compliant nodes completely surrounded by non-compliant nodes should be treated as non-compliant, for the purposes of re-dredging.

2.3.5 Determining the Number of Re-dredging Attempts

Residual sediment samples will be collected after obtaining the design cut elevations and after each successive re-dredging 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 re-sampling may be required, as shown on Figure 1-1. Due to the impact on the productivity rate and project schedule as well as the diminishing returns reported in environmental dredging case studies, a contingency option must be provided after a selected number of re-dredging attempts have been conducted. The number of required re-dredging attempts was limited based on 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. 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. Based on case study data and engineering judgment, a limit of two re-dredging attempts following the initial residual sampling event was established for the Residuals Standard, unless the Construction Manager determines that additional re-dredging attempts could provide a desired reduction in contaminant concentrations. Necessary modification can be made based on the experience and observations collected on the Site during Phase 1 dredging.

2.3.6 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 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 certification unit, 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 re-dredging attempts, a contingency action will be implemented, consisting of the construction of a sub-aqueous cap. The use of a sub-aqueous cap and other technologies, which were surveyed but not specifically required by the Residuals Standard (*e.g.*, in-situ remediation and alternative dredges), are described in the following sections and will be considered for use as engineering contingencies by the Construction Manager.

2.3.6.1 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 cutterhead 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.

2.3.6.2 Capping

In areas where the residual level of approximately 1 mg/kg Tri+ PCBs cannot be achieved after two re-dredging 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 1-1), a sub-aqueous cap may be constructed over elevated clusters. Different technologies with regard to capping were evaluated and described in the FS (USEPA, 2000) and are summarized below. In addition to the capping technologies summarized, appropriately designed caps may be constructed from granular materials. The design of sub-aqueous 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 sub-aqueous 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 sub-aqueous cap is a desirable option to isolate the residual PCB concentrations. To accommodate the sub-aqueous 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 re-dredging attempts have failed, the area may need to be abandoned, subject to USEPA approval.

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 sub-aqueous 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 six-inch hydrated AquaBlok™ cap without the geogrid or stone-layer components present.

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. In consideration of this concern, use of this technology should be limited.

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.

2.3.6.3 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. 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.

Immobilization – In-situ immobilization methods 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, and its implementation should be limited on that basis.

2.3.6.4 Engineering Contingencies Used at Other Sites

Engineering contingencies have been designed and implemented at other dredging sites. Some examples are presented below:

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 re-dredging. The decision to utilize alternative dredging methods was based on the presence of 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 yd^3 clamshell bucket that could be used with the lattice boom cranes on the derrick barge. The bucket was 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 is that it did not have the 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 the 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 yd^3 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-inch separation layer, a 12-inch containment layer, and a greater than 9-inch 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.

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.

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.

3.0 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

3.1 Sampling Grid Establishment

Cores of the residual sediment will be collected at 40 locations in each 5-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 percent of the design grid 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-foot radius of the original location. For backfill testing (refer to Section 3.5, item no. 2 "Jointly Evaluate 20-acre Areas"), core samples will be collected using the same grid established for the residuals. The following guidelines are to be used to implement a sampling grid on certification units other than 5 acres in size:

- 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 triangular grid with a proportionate spacing.
- Dredging areas smaller than 5 acres in size within ½ mile of one another can be "lassoed" into a single certification unit. The sum of the grouped dredging areas must be less than 7.5 acres. The sampling grid is to be proportionally sized so that a minimum of 40 cores are collected from within the dredged areas, and up to 60 cores are collected (by applying the 80-foot grid spacing within areas grouped into a single certification unit with a total dredging area of 7.5 acres). If a number of 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 discussing 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-foot 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 certification units 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 foot spacing established in each certification unit. (For example, a 32-acre dredging area would be divided into 6 certification units, each 5.33 acres in size.)

3.2 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.

Visual observations of the thickness of the dredging residuals layer will be collected from approximately 25 percent of the sampling locations using sediment profile imaging (SPI) technology and the results will be recorded and submitted with the analytical results and core stratigraphic descriptions. Representative locations will be chosen to cover the sediment types and removal technologies that will be experienced during the remediation and to have a sufficient number of locations per differing conditions to evaluate the data.

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 the collection of core samples, sediment samples will be collected using small dredges or via grab sampling by divers. Both the core sampling and SPI locations are to be located using GPS and referenced to an appropriate horizontal coordinate system and vertical datum. The locational 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 two pieces of information: whether or not a core can be obtained, and what type of core tube material should be used to collect the core. In cohesive sediments, core samples will be collected using transparent polycarbonate (Lexan®) tubes. In non-cohesive sediments, core samples will be collected using aluminum tubes.

Sediment cores will be advanced as necessary for the collection of a representative 0-6 inch 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 Section 3.5, item no. 2) will also be collected as 0-6 inch 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 Residual Standard's action levels, additional core sampling may be required to re-characterize 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. Core recovery in aluminum tubes will be estimated by measuring the depth to the sediment-water interface using a dedicated or decontaminated probe. 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 collected in a Lexan® tube). If sediment probing indicates a sediment depth of less than 6 inches over a hard material, only 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.

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.

3.3 Sample Management

The retrieved core samples are to be photographed and prepared for laboratory analysis (if re-characterization of the vertical extent of contamination is required, the core samples must be divided into successive 6-inch 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, along with the results of the SPI investigation at the sampling location (where performed). 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. 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 0-6 inch 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 that will be mixed and analyzed. While the core tube is being cut, the areas above and below the cut will be supported. 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 0-6 inch 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.

3.4 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.

3.5 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:

- Area weighted average Tri+ PCB concentration in a moving 20-acre area consisting of the certification unit under evaluation and the three previously dredged certification units within 2 river miles of the current unit (measured along the centerline).
- 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.

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

<u>Certification Unit Arithmetic Average</u>

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

where:

n = the number of sample locations in the certification unit

$c_{i,\mathrm{int}}$ = 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 a sub-aqueous cap is constructed or certified backfill placed over a location, two evaluations must be conducted. For consideration of the affected certification unit in a subsequent 20-acre joint evaluation, the certification unit average is to be calculated using the PCB concentration of the upper layer capping material/backfill for the associated nodes, which should in all cases be 0.25 mg/kg Tri+ PCBs or less (or one-half the detection limit if it is non-detect). To verify the certification unit's compliance with the Residuals Standard following the

construction of a sub-aqueous cap, the Standard's action levels must be applied to the nodes in the uncapped area alone.

20-Acre Area-Weighted Average

$$m_{40,\text{int}} = \frac{\sum_{i=i}^{n} a_{t,i}\, m_{t,\text{int},i}}{\sum_{i=i}^{n} a_{t,i}}$$

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)

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

1. Backfill (where appropriate) and Demobilize: At a certification unit with an arithmetic average residual concentration of 1 mg/kg Tri+ PCB or less, no single sediment sample result of 27 mg/kg Tri+ PCBs or greater, and not more than one sediment sample result of 15 mg/kg Tri+ PCBs or greater, backfill (where appropriate) and demobilize from the certification unit.

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 of 27 mg/kg Tri+ PCBs or greater, and not more than one sediment sample result of 15 mg/kg Tri+ PCBs or greater, jointly evaluate a 20-acre area.

   For the 20-acre evaluation, if the area weighted arithmetic average of the individual arithmetic averages (means) from the certification unit under evaluation and the 3 previously dredged certification units (within 2 miles of the current unit, measured along the River's centerline) is 1 mg/kg Tri+ PCBs or less, backfill may be placed (with subsequent testing required). Otherwise, all or part of the certification unit must be re-dredged (see #4 below for actions required during and following re-dredging) or a sub-aqueous cap constructed. Re-dredging 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 re-dredging attempts, contingency actions may be implemented in lieu of further re-dredging attempts, as described in #5, below.

3. Re-dredge or Construct Sub-aqueous 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 sediment sample result of 27 mg/kg Tri+ PCBs or greater, and not more than one sediment sample result of 15 mg/kg Tri+ PCBs or greater, re-dredge or construct a sub-aqueous cap (see Figure 1-1 and further description in Table 1-1). The choice of two options is provided to maintain flexibility and productivity (*e.g.*, some areas may not be conducive to dredging). If re-dredging is chosen, the surface sediment of the re-dredged area must be sampled and the certification unit re-evaluated. If the certification unit does not meet the objectives of #1 or #2, above, following two re-dredging attempts, contingency actions may be implemented in lieu of further re-dredging attempts, as described in #5, below.

4. Re-dredging 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 or to address sampling node(s) where more than one concentration was 15 mg/kg Tri+ PCBs or greater, and to address any sampling node(s) where concentrations of 27 mg/kg Tri+ PCBs or greater were detected, re-dredging is required (see Figure 1-1 and further description in Table 1-1).

   Sampling at depths greater than 6 inches will be triggered by an arithmetic average residuals concentration 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.*, 6-12 inch, 12-18 inch, etc.) as necessary to re-characterize 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. Re-sampling for vertical characterization is contemplated only once.

   The Residuals Standard provides a mechanism for calculating the horizontal extent of re-dredging. All re-dredging attempts are to be designed to reduce the mean Tri+ PCB concentration of the certification unit to 1 mg/kg Tri+ PCBs or less. If after two re-dredging attempts, the certification unit is still non-compliant, contingency actions are to be implemented as stated in #5, below.

5. Contingency Actions: At areas where two re-dredging attempts do not achieve compliance with the action levels, as verified by USEPA, construct an appropriately designed sub-aqueous cap, where conditions allow, or choose to continue re-dredging.

Portions of a contiguous 5-acre certification unit may be backfilled after the cut lines are met as long as the area will not be re-contaminated, 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 and 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.

3.5.1 Re-dredging and Required Number of Re-dredging Attempts

Re-dredging must be conducted at locations where more than one sediment sample result is greater than or equal to the 97.5% PL (in which case, all must be re-dredged), any sediment sample results are greater than or equal to the 99% PL, and in part (elevated clusters) or all of certification units as necessary to address residual sediments with an arithmetic average concentration greater than the 99% UCL. Re-dredging 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, depending on the 20-acre joint evaluation area average (refer to Figure 1-1 and Table 1-1).

Prior to conducting a re-dredging 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 is detected in the 0-6 inch sediment interval, this is considered indicative of the presence of un-dredged contaminated sediment inventory, which should have been removed during implementation of the initial remedial dredging design. Re-dredging attempts to remove such inventory will not be counted towards the required two re-dredging attempts in a certification unit.

Sediment coring will be conducted after each completed re-dredging attempt. Following re-dredging, the re-dredged locations will be re-sampled (10-foot offset from the original locations) using the same coring and sample management procedures required in Sections 3.2 and 3.3. The analytical results will be substituted into the original data set and compliance with the standard's action levels re-evaluated through calculations of the appropriate arithmetic average concentration(s) and review of single sampling locations.

Up to two re-dredging attempts are required under this standard. If the Residuals Standard action levels are not met after three dredging attempts (including the initial dredging event), engineering contingencies may be implemented as described in Section 3.6. If, in the Construction Manager's judgment, additional dredging attempts are reasonably expected to realize the desired reduction in residual sediment concentrations, additional re-dredging may be conducted before resorting to the implementation of a contingency such as a sub-aqueous 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.

3.5.2 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 re-dredge 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 re-dredge 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 3-1. If the node is next to the boundary of the certification area, the non-compliant area should follow the boundary because there is no information to reduce the area.

3.6 Engineering Contingencies

The Residuals Standard contains the option to place an appropriately designed sub-aqueous cap if a certification unit arithmetic average concentration following dredging exceeds 1 mg/kg Tri+ PCBs but is less than the 99% UCL, or where re-dredging attempts to reduce more elevated concentrations are unsuccessful after two attempts (refer to Figure 1-1 and Table 1-1 for further detail). Depending on the concentration and thickness of the residual sediment requiring capping, an appropriately designed sub-aqueous cap can be constructed. Note that if the Tri+ PCB concentration exceeds 1 mg/kg, but is less than the 95% UCL, 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. An appropriately designed sub-aqueous 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 the above-listed 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.
- The equipment and placement techniques to be used for cap construction.
- An 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.).
- Chemically isolate the contaminated sediments such that the concentration of Tri+ PCBs in the upper 6 inches of the cap remains 0.25 mg/kg or less in the long term.

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 is to be placed, where appropriate, over a dredged surface that meets the residual standard of 1 mg/kg Tri+ PCBs or less. Backfill will consist of a 1-foot thickness of material. Where a certification unit arithmetic average is greater than 1 mg/kg and less than the 95% UCL, and the 20-acre joint evaluation area weighted average is less than or equal to 1 mg/kg Tri+ PCBs, backfill may also be placed, with testing to certify that the upper 6 inches of placed backfill contains less than 0.25 mg/kg Tri+ PCBs.

An **isolation cap** is defined as the placement of an engineered sub-aqueous 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 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 conditions, etc., or Tri+ PCB concentrations are elevated over the action levels.

The sub-aqueous 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 99% PL, and not more than one uncapped node is greater than or equal to the 97.5% PL.

The placement of backfill and sub-aqueous 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 sub-aqueous cap is a desirable option to isolate the residual PCB concentrations. To accommodate the sub-aqueous 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.

4.0 Plan for Refinement of the Performance Standard for Dredging Residuals

There will be two opportunities to modify the Residuals Standard developed for the Phase 1 operations in response to peer review recommendations: before and during Phase 1, and between Phase 1 and the start of Phase 2. It is possible that additional case study data will become available prior to the commencement of Phase 1 activities that could be used to modify the Standard. This scenario is not expected to occur given the current state of dredging projects at other sites.

Data gathered during Phase 1 will characterize the implementation and efficiency of the remedial design by quantifying residual Tri+ PCB concentrations after various dredging and re-dredging attempts, tracking actual dredging productivity, quantifying water column Tri+ PCB concentrations during dredging and other activities, etc. 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 being accomplished. 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.

All corrective action requests will be shared with the public upon receipt at USEPA via the agency's project website (www.epa.gov/hudson) in accordance with the intent of the Community Interaction Plan.

It is anticipated that a significant amount of information will be gathered from the Phase 1 remedial operations. Following Phase 1, the residual sample data will be analyzed in the same manner as the case study data to determine if the size of the certification unit, the number of sample locations per certification unit, and sample depths are appropriate for the Upper Hudson River sediments. Another aspect of the standard that will be scrutinized is the extent of re-dredging for different patterns of concentration exceedances. The sampling parameters developed for the Phase 1 standard have been developed using case study data that may have different sediment textures, spatial distributions and contaminants. The use of the Phase 1 residuals data will allow site-specific parameters to be developed for comparison to, and possible modification of, the performance standard. The SPI data gathered during Phase 1 will be used to evaluate the Residual Standard's core sampling intervals and required depths.

Semi-variograms will be generated for residual sediment sampling results in certified units from Phase 1. The semi-variograms will be used to determine whether the data are spatially correlated, and if so, calculate the distance at which the spatial correlation is statistically significant. This information will be used to refine USEPA's understanding of the spatial distribution of the residual contamination and adjust, as necessary, the scheme for re-dredging around individual samples that exceed the criterion.

The spatial distribution of Phase 1 residual sediment sampling results will be evaluated using the polygonal declustering method. This method includes the calculation and mapping of Theissen polygons, which are based on the spatial distribution of sample locations. For each Theissen polygon, an average Total PCB concentration will be calculated. The results of this analysis will be used to evaluate the degree to which samples containing Total PCB concentrations greater than the action levels are clustered, and indicate if adjustments are needed to the procedures for re-dredging in certification units that do not initially satisfy the Residual Standard action levels.

Statistical analysis of the Phase 1 residual sediment analytical data will be conducted to test the assumptions used for selecting the sampling frequency. The spatial distribution and correlation analyses will be used to refine residual sampling in areas where re-dredging attempts may be required. The distribution of the residual sediment data in each target area will be determined using goodness of fit tests. The action levels (UCLs and PLs) may be adjusted according to the site-specific variance of the residual concentrations, although it is unlikely that these values will be changed without substantial modifications to the framework of the standard.

The size of the 20-acre joint evaluation areas included in the Residuals Standard may be revisited during Phase 2. The joint evaluation area concept was based on the approximate size of the HUDTOX segments used to model recovery of the Hudson River after remediation. Since the model used approximately 20-acre segments in the TI Pool and approximately 40-acre segments in River Sections 2 and 3, the Standard may be modified to include the use of 40-acre joint evaluation areas in appropriate River Sections during Phase 2.

The areas capped (if any) during Phase 1 will be evaluated to review the decisions that were made given river conditions in the capped area and impact on productivity. Using the information gathered during Phase 1 and the data gathered during the design sampling *(e.g.*, subbottom profiling results), a limit on the amount of area that can be capped without prior approval from USEPA may be added to the standard for Phase 2, if warranted.

The engineering contingency plan developed for Phase 1 may be altered for Phase 2. The trigger for implementation of contingency actions is based on a set number of dredging attempts (2 re-dredging attempts), which may occur after the design cut-lines are met. Subsequently, contingency actions, specifically capping, may be implemented in areas where the required residual PCB concentration cannot be achieved by dredging alone.

The number of dredging attempts required and the efficacy of the non-dredging technologies will be examined, as implemented. The analysis will consist of a review of the results of the Phase 1 operations and will require engineering judgment.

In summary, the parameters of the standard developed for the Phase 1 are open to modification, however, the framework of the standard is expected to remain substantively the same as presented in this document. Data from the design samples and the Phase 1 operations will be analyzed. If the conclusions drawn from these analyses are substantially different, the Residuals Standard may be modified for Phase 2.

5.0 List Of Acronyms

CAB	Cellulose Acetate Butyrate
CERCLA	Comprehensive Environmental Response and Compensation Liability Act
CLP	Contract Laboratory Program
cm	centimeter
CU	certification unit
DNAPL	Denser Non-Aqueous Phase Liquid
EMP	Environmental Monitoring Plan
FS	Feasibility Study
ft	foot
GE	General Electric Company
GEHR	General Electric Hudson River SOP
GCL	Geosynthetic Clay Liners
GM	General Motors
GPS	Global Positioning System
JMP	a commercial software package for statistical analysis
mg/kg	milligrams per kilogram (equivalent to ppm)
LWA	length-weighted average
MPA	Mass per Unit Area
MVUE	minimum unbiased estimator of the mean
NJDEP	New Jersey Department of Environmental Protection
NTCRA	Non-Time-Critical Removal Action
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
PAHs	Polycyclic Aromatic Hydrocarbons
PCBs	Polychlorinated Biphenyls
PCDFs	Polychlorinated Dibenzofurans
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
REP	Report
RCRA	Resource Conservation and Recovery Act
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
SMU	Sediment Management Unit
SOP	Standard Operating Procedure
SPI	Sediment Profile Imaging
SQV	Sediment Quality Value
TAT	Turn Around Time
TI	Thompson Island
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

6.0 References

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TABLE 1-1
SUMMARY OF DRAFT PERFORMANCE STANDARD FOR DREDGING RESIDUALS

Case	Certification Unit Arithmetic Average (mg/kg Tri+ PCBs)	No. of Sample Results ≥15 mg/kg Tri+ PCBs AND < 27 mg/kg Tri+ PCBs	No. of Sample Results ≥ 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 re-dredge. 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 re-dredge. 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.

Table 2-1
Case Study Information

Site	Dredge	Subbottom	Number of Passes	No. of Samples	Sample Grid Size	Sample Method	Sample Depth	Analytical Method	PostDredge Avg. Conc. ppm	Target Conc. ppm
Reynolds Metals	Cable Arm; Rock Bucket & Hydraulic Clamshell	Mud, clay, sand, gravel and cobbles underlain by till	Maximum of 10	263	50x50' & 70x70'	Core	0-8"	Aroclors 8082 & Immunoassay	2 Excluding the one quadrent with conc. 5,941	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"	Aroclors 8082	3	1
New Bedford PreDredge Test	Hydraulic Excavator with a Clamshell	Soft Clay	1	18	~40x40'	Cores and Grabs	0-1 ft. 0-2 cm	NOAA 18 Congener	29 (0-1')	None
Cumberland Bay	Hydralic Cutterhead	Sand	Multiple	69	50x50'	Cores and Grabs	0-2 ft. 0-2 cm	Aroclor Method 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" and 4-12"	Aroclors SW846 8082	2 (0-4")	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"	Aroclors	8	None
Grasse River *Inventory Removal*	Horizontal Auger	Rocky with a Boulder field	Multiple	12	Random	Cores	0-6" to 0-8"	Aroclors	80	None

Notes:
1. The Marathon Battery site is omitted from this table because a report was not available .
2. PCBs are a contaminant for each site listed.

Table 2-2

Summary Statistics for Case Studies **Reynolds Metals**

Units: mg/kg

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

Table 2-2

Summary Statistics for Case Studies | **East Foundry Cove Marathon Battery**

Units: mg/kg

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

Table 2-2

Summary Statistics for Case Studies **New Bedford Harbor (0-1 ft.)**

Units: mg/kg

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	

Table 2-2

Summary Statistics for Case Studies — **New Bedford Harbor (0-2 cm)**

Units: mg/kg

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

Table 2-2
Summary Statistics for Case Studies **Fox River Deposit N**
Units: mg/kg

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	

Table 2-2

Summary Statistics for Case Studies **Fox River SMU 56/57**

Units: mg/kg

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

Table 2-2

Summary Statistics for Case Studies **Cumberland Bay**

Units: mg/kg

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

Table 2-2

Summary Statistics for Case Studies — **GM Massena Uncapped Areas**

Units: mg/kg

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

Table 2-2

Summary Statistics for Case Studies **GM Massena Pass 1**

Units: mg/kg

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

Table 2-2

Summary Statistics for Case Studies — **GM Massena Pass 2**

Units: mg/kg

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

Table 2-2
Summary Statistics for Case Studies — **GM Massena Pass 3**
Units: mg/kg

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

Table 2-2

Summary Statistics for Case Studies **GM Massena Pass 4**

Units: mg/kg

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

Table 2-2

Summary Statistics for Case Studies **GM Massena Pass 5**

Units: mg/kg

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

Table 2-2

Summary Statistics for Case Studies **GM Massena Pass 6**

Units: mg/kg

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

Table 2-2

Summary Statistics for Case Studies **GM Massena Pass 7**

Units: mg/kg

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

Table 2-2

Summary Statistics for Case Studies **GM Massena Pass 8**

Units: mg/kg

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

Table 2-2
Summary Statistics for Case Studies | **Grasse River Non-Time-Critical Removal Action**
Units: mg/kg

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	

Table 2-3
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 Site	95% UCL Hudson River (Proportional)	95% UCL Hudson River (Using Eqn.) (2)	99% UCL Site	99% UCL Hudson River (Proportional)	99% UCL Hudson River (Using Eqn.) (2)	97.5% PL Site	97.5% PL Hudson River (Proportional)	97.5% PL Hudson River (Using Eqn.) (3)	99% PL Site	99% PL Hudson River (Proportional)	99% PL 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 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 the 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 $\bar{x}$ and the case study standard deviation for S_x .

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

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

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

substituting 40 for n, 0 for $\bar{y}$ and the case study variance for s_y^2 .

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 GM passes 1 through 8 include the capped area.

Table 2-4

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

Units are ppm.

Linear Regression Mean vs. Sx [1]	
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 3) [1]	
Equation	Parametric Assymetric PL (Eqn. 4)
97.5% PL	15
99% PL	27
Average Sy of the Case Studies	
Sy [2]	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 on Table 3)	
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. Excludes the Grasse River Site because both the mean and standard deviation of the untransformed data are outliers.
2. Includes the Grasse River Site because the standard deviation of the transformed data is not an outlier.

Table 2-5
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 2-6
Non-Compliant Areas 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 2-7

Estimate of the Number of Samples/Target Area

	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 2-8
Impact of Settled Material on Surface Sediment Concentrations

TSS Conc.	**50**	**mg/L**	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	49339317.12	L
TSS Mass	2466965856	mg	1.00E-06	kg/mg	2466.965856	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						
Thickness	6	inches				
Concentration in the remaining			5.996	inches		
	1	mg/kg				
Concentration of the settled material						
	100	mg/kg				
Length Weighted Average Concentration						
	1.072	**mg/kg**				