# Second Five-Year Review Report
# Hudson River PCBs Superfund Site

## APPENDIX 4

## SURFACE SEDIMENT CONCENTRATIONS

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**HUDSON RIVER PCBs SUPERFUND SITE**

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# 1 INTRODUCTION

As stated in the 2002 Record of Decision (ROD) (EPA, 2002), one of the Remedial Action Objectives (RAOs) is to 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. The reduction in fish tissue PCB concentrations that will be achieved by the overall reduction in the PCB mass that may become bioavailable is closely related to the surface sediment PCB concentration throughout the Upper Hudson. In the selected remedy, reduction of PCBs in surface sediment is achieved through two important processes: 1) sediment removal by dredging and backfilling, and 2) monitored natural attenuation (MNA). Both processes are required to achieve the goals of the ROD. In general, fish body burdens are expected to track with the changes in surface sediment PCB concentrations (*i.e.*, if residues decrease in the surface sediment, then they should also decrease in the overlying water column, and with reductions in sediment and water, the residues in fish should decline as well). Bioaccumulation relationships are site-specific, and in any given setting, if a 10-fold reduction in fish body burden is targeted, then, at a minimum, a 10-fold reduction must be achieved in the media to which fish are exposed (sediments and overlying water). This may be achieved directly by reducing contaminant concentrations in sediments composing the feeding/home range of the fish, or as in River Section (RS) 3, indirectly by reducing water column concentrations impacting prey downstream of sediment remediation areas. This appendix focuses primarily on surface sediment. Overall sediment mass reduction is covered in Appendix 2.

The Upper Hudson River is one of the most extensively monitored PCB contamination sites, with a data record spanning a period of more than 30 years. The various monitoring studies provided numerous sediment data sets. This appendix presents the surface sediment concentrations from the pre-dredging, dredging and post-dredging periods available to date and compares the data sets to examine concentration trends with time. The most recent sediment data sets permitted the calculation of the post-remediation mean surface sediment PCB concentration for each river section.

MNA rates can be assessed by examining the rate of decay of surface sediment PCB levels. However, comparisons of surface sediment surveys across time to determine the rate of decay in PCB concentrations are complicated by comparability challenges among the data sets. Each survey has unique features that make direct comparisons potentially uncertain, yielding inconsistent rates of change when various combinations of data sets are evaluated in a pairwise fashion. When evaluated comprehensively across longer time spans with statistical adjustments to mitigate elements known to confound conclusions, uncertainty is reduced.

The long-term sediment recovery rate (post-remediation) is being assessed as part of the Operation, Maintenance, and Monitoring (OM&M) program. Under the Consent Decree, General Electric Company (GE) must collect surface sediment PCB data in the dredged and non-dredged areas using standardized methods so that recovery rates can be reliably estimated in the future. GE initiated this OM&M program in November 2016, collecting approximately 226 surface sediment samples in non-dredged areas, and it is anticipated that GE will collect additional samples from dredged areas in the 2017 field season. These data will be used to: 1) quantify post-remedial average PCB concentrations in sediment, 2) quantify changes in sediment concentration over time, and 3) support investigation of relationships between fish, water and sediment during the post-remedial monitoring time period. Samples collected in 2011-2013 under the Downstream Deposition Study (DDS) represent approximately the top two inches of sediment, which is consistent with the depth interval represented by EPA's HUDTOX model used to support remedy development, and is also consistent with depth intervals available for comparison with other historic data sets. Although EPA considers Tri+ PCBs[1] in the top one foot of sediment to be representative of exposures, the top two-inch interval provides a more sensitive indicator of how recent perturbations to the river system are impacting surface sediments. Understanding of the

[1] Tri + PCBs represents the sum of all measured PCB congeners with three or more chlorine atoms per molecule. PCBs are a group of chemicals consisting of 209 individual compounds known as congeners. The congeners can have from one to ten chlorine atoms per molecule, each with its own set of chemical properties.

rate of decline in the top two inches can also be used to estimate changes in the top foot of sediment based on relatively simple mixing calculations, so questions of exposure assessment can also be evaluated, albeit less precisely than with direct measurements of the top foot.

In this report, temporal changes in surface Tri+ PCBs are evaluated in two ways: first, using a matched location comparison approach to develop overall pool-wide estimates of central tendency using proximal locations that have been occupied across multiple surveys, and second, by fitting first-order decay models to the full time record with data stratified by sediment texture. As will be seen below, both approaches produce results that show the sensitivity of estimates of temporal change to variability in methods of sample collection, analysis, and handling, which are unavoidable, given the various data sets being compared due to their varied individual sampling designs and sediment sample collection methods.

Data collected in 2016 under the OM&M program were used to quantify post-dredging concentrations and were also compared with empirical first order decay model predictions for 2016. None of the trend analyses reported here are definitive, but are included to maximize the usefulness of the existing data, with the understanding that the multiple rounds of sediment sampling carried out between 1976 and 2016 were designed for varying purposes and do not support precise estimates of recovery rates.

Using methods relatively robust to aforementioned data limitations, the following analyses show that:

1) Based on measured Tri+ PCB concentrations, there is evidence of natural recovery occurring in surface sediments in all three sections of the Upper Hudson River,
2) Best estimates of recovery rates ranged from 5 to 7 percent annual reductions in both cohesive and non-cohesive sediments, for all three river sections, for the period 1976-2012,
3) Uncertainty bounds in the estimates were generally on the order of 3 to 10 percent per year, indicating that the 8 percent decay rate simulated by HUDTOX for the pre-dredging MNA period is within the margins of error of the current estimates,

4) Estimated mean concentrations in sediment generally fall within 95 percent confidence limits of best-fitting trend lines, starting at mean 1976 levels, followed by river-section-specific decay rates on the order of 3 to 10 percent, in both cohesive and non-cohesive sediments, and
5) Tri+ PCB concentrations measured in 2016 appear to be at or below levels that would be predicted by these empirical recovery time trends.

# 2 SEDIMENT INVESTIGATIONS

Sediment data are inherently spatially limited, and are typically obtained from samples collected using a coring device or a grab sampler. In trying to characterize large areas of the river bottom, care must be taken to obtain spatially representative samples. Because of the highly variable nature of PCB sediment concentrations, even over short distances (less than 2 meters), a statistically appropriate number of samples and an appropriate sample design are needed to accurately measure the mean concentration in a given area. Thus, any program to monitor temporal changes in surface sediments must be designed accordingly and, in addition, multiple sample rounds need to be collected over time in a consistent way.

None of the sediment sampling programs conducted to date was designed specifically with this objective (*i.e.,* to represent changes in sediment PCB concentrations over time), with the exception of the 2016 data collection. As a result, conclusions about concentration trends should be drawn cautiously and their limitations clearly discussed. The six available data sets and their limitations have been carefully evaluated. The primary sediment data sets examined in this appendix are:

- NYSDEC 1976-1978 sediment survey
- GE 1991 sediment survey
- GE 1998 sediment survey
- GE 2002-2005 Sediment Sampling and Analysis Program (SSAP)
- GE 2011-2013 Downstream PCB Deposition Study (DDS)
- GE 2016 OM&M surface sediment sampling program

Except for samples analyzed by EPA in 2016 for PCB congeners, these sediment data were all quantified using Aroclor-based methods. The NYSDEC contract lab analyzed the samples from 1976 to 1978, while GE conducted all subsequent Aroclor-based analyses. The 1991 and 1998 data were reported as congener (peaks) only via the modified Green Bay method, which was developed based on Aroclor standards. The primary basis of analysis for the SSAP was PCBs as Aroclors. A subset of the SSAP (2002-2005) data was also analyzed for PCBs as congeners based on Aroclor standards. The DDS data were exclusively quantified for PCBs as Aroclors. Results from samples with paired analyses by Aroclor method and by Aroclor-based congener methods were used to develop estimates of Tri+ PCB[2] concentrations for all samples that were not directly analyzed for PCB congeners[3]. These transformed data were then used for the sediment data evaluations in this appendix. The specifics of these sampling programs and their differing objectives are summarized in the following sections. Each survey was either reasonably spatially unbiased, or known spatial biases were generally lesser in upstream areas (RS1) than in downstream areas (RS2 and RS3). Also, within any given river section, finer-grained sediments tended to be more heavily studied than coarser-grained sediments, particularly in RS2 and RS3. As a result, it is expected that analyses of finer-grained sediments would yield more reliable statistical estimates than those based on coarser-grained sediments and, further, that statistical estimates in both finer- and coarser-grained sediments would be more reliable in RS1 than in RS2 or RS3.

## 2.1 NYSDEC 1976-1978 Sediment Survey

This data set comprises sediment grabs (0-5 inch) and core samples sectioned into various layers between 1 and 10 inches thick at the surface and deeper segments (Tofflemire and Quinn, 1979). This program was intended to characterize PCB concentrations in surface and deeper sediments across the entire Upper Hudson River (RS1, RS2 and RS3), and was the basis for the original identification of the Upper Hudson River "hot spots" by NYSDEC. However, selection of sampling locations was not statistically-based. Samples were obtained from approximately 762 individual locations located in cross sections distributed along the length of the river, extending over the entire Upper Hudson below the Fort Edward Dam. Samples were also characterized for sediment type. This data set was

[2] The sum of PCB congeners with three or more chlorine atoms.

[3] For all data sets collected in 2002 or later, all sediment samples were analyzed via M8082. In the period 2002-2005, a subset of samples was analyzed via the mGBM. Estimation (via regression equation) of Tri+ PCB concentrations from Aroclors concentrations using the matched pairs of M8082 and mGBM is discussed in Appendix 5. The congener-specific analyses conducted in 2016 as part of the OM&M program are still undergoing evaluation. See Appendix 5.

only used in the examination of long-term trends in surface sediment concentrations described in Section 4 of this appendix.

## 2.2 GE 1991 Sediment Survey

This data set comprises sediment core samples sectioned into 0-2 inch surface samples and deeper segments (EPA, 2000a). This program was intended to characterize average PCB concentrations in surface and deeper sediments across the entire Upper Hudson River (RS1, RS2, and RS3). However, selection of sampling locations was not statistically-based. Samples from approximately 950 individual locations were composited to form 124 surface samples, extending over the entire Upper Hudson below the Fort Edward Dam. Samples were composited to match sediment type and general geographic area. Sample depths were uniform within composites (*i.e.,* a composite sample would include sediment from several locations, but only include segments from a single sampling depth (*e.g.,* 0-2 inches).

## 2.3 GE 1998 Sediment Survey

This data set comprises sediment core samples sectioned into 0-1 inch surface samples, 1-2 in near surface samples, and deeper segments (EPA 2000a; 2000b, Book 2). Like the 1991 survey, the stated objective was to characterize the average sediment concentrations of PCBs across the entirety of a river section, however, and selection of sampling location was not statistically-based. In some instances, the survey attempted to reoccupy the 1991 sampling locations. Samples from approximately 160 individual locations were composited to form approximately 30 samples, and were only obtained from RS1, encompassing the Thompson Island Pool (TIP). Also like the 1991 survey, samples were composited to match sediment type and general geographic area. However, unlike the 1991 survey, composites were restricted to only eastern shoal, western shoal, or center channel sediments. As a result, the 1998 survey does not include composites that cross the river and potentially blend depositional locations (inside of turns) with erosional ones (outside of turns). For use in the calculations below, the matched composite samples (e.g. Composite A, 0-1 in and Composite A, 1-2 in) were combined into a single value for the composite (e.g. Composite A, 0-2 in), to maintain comparability between the 1998 survey and the other surveys, which routinely sampled 0-2 inch segments.

## 2.4 GE 2002-2005 SSAP

The GE SSAP was designed under EPA direction to characterize both surface and deeper sediment contamination throughout the Upper Hudson as part of the remedial design (General Electric 2005a; 2005b; 2007). Specifically, its purpose was to identify and delineate areas whose sediment concentrations or inventories of PCBs exceeded the ROD-specified thresholds (Tri+ PCB mass greater than 3 g/m$^2$ or surface Tri+ PCB concentration greater than 10 mg/kg). Unlike the two prior programs, this program was not intended to provide estimates of average sediment concentrations across entire river sections. Also unlike the two previous data sets, site selection for this program was statistically-based, with sampling locations defined by spatial grids.

In River Section 1 (Thompson Island Pool) these grids were virtually bank to bank and represent a nearly unbiased representation of pool-wide surface sediment. In RS2 and RS3, sampling grids were spatially biased by centering on areas of suspected contamination and extended to areas where contamination fell below the ROD removal thresholds. In this manner, measurements are generally representative of contaminated areas in RS2 and RS3, but not of these entire river sections, and areas expected to have low contamination in RS2 and RS3 were not sampled in an unbiased fashion. This focus on contaminant hotspots would be expected to result in more accurate estimates in fine-grained sediments than in coarse-grained areas, which were not the focus of the designs. Because this sampling program was implemented to support dredging design, sampling density decreased from upstream to downstream. This pattern reflected the higher removal thresholds, and smaller areas of contamination relative to those thresholds, in RS2 and RS3 versus RS1.

The SSAP program used vibracoring to obtain samples, including surface sample segments (0-2 inches).

## 2.5 GE 2011-2013 DDS

GE's DDS program was designed under EPA direction to address the monitoring goals of the Engineering Performance Standards (EPS) (General Electric, 2011; EPA, 2012, Appendix B). The primary data quality objective (DQO) for this special study was to identify the spatial extent, concentration, and mass of PCBs that were deposited in non-dredging areas downstream of dredging activities. A secondary purpose of the sampling effort was to further evaluate sediment concentrations over time to the extent possible. As such, the DDS was not specifically designed to provide reach-wide estimates of average surface concentrations. However, like the other sediment surveys, it provides a limited basis to estimate changes in average surface concentrations.

The DDS program was completed between 2011 and 2013, and examined surface sediment in all three river sections. The study was done sequentially, with RS1 completed in 2011, RS2 completed in 2012, and RS3 completed in 2013.

The general procedure used by EPA in establishing DDS sampling locations is as follows:

- Step 1 - Potential locations for sampling were established on cross-section-based transects. Transects were sited from upstream to downstream through RS1, 2, and 3. Transects in RS1 were spaced approximately 500 feet apart starting in the west channel of Rogers Island and extending downstream approximately 1 mile to certification unit 4 (CU4). South of CU4 in RS1, transects were spaced approximately 1,500 feet apart. Transects in RS2 were spaced approximately 1,000 feet apart, and those in RS3 were spaced approximately 2,000 feet apart. Samples taken for use in composites were collected within the same sediment type and either located exclusively inside or exclusively outside dredging target areas.
- Step 2 - Sample locations were considered relative to CU boundaries. Preference was given to sample locations outside the CU, since the DQO for the study was designed to focus on impacts to non-dredging areas. However, in some cases, siting a sample within a CU boundary was unavoidable. Specifically for RS2 and RS3, samples were located both inside and outside of dredging target areas.
- Step 3 - Consideration was given to distributing the sample locations between the different sediment types. Fine-grained sediments and sands (*i.e.,* Type 1, Type 2, and Type 4) and coarse sand to gravel/rocky substrates (*i.e.,* Type 3 and Type 5) were sampled. In general, the limited amount of Type 3 and Type 5 sediments resulted in focusing the locations primarily on Types 1, 2, and 4 (the sands and fine-

grained sediments). Some Type 3 and Type 5 sediments were targeted, but samples were not easily collected in these sediment types.

- Step 4 - When possible, preference was given to siting sampling locations to coincide with SSAP locations.

Although the sampling locations for this study were chosen subjectively as opposed to using an unbiased selection procedure, consideration was given to collecting representative samples throughout the 40 miles of the Upper Hudson River. The net effect was a relatively even spatial coverage along the length of the river which could be considered a nearly unbiased design, particularly for finer-grained sediments, and therefore suitable to evaluate changes in surface sediment concentrations – albeit not rigorously. In addition to the light they shed on the effects of dredging, changes in surface sediment concentrations were also of interest to EPA as they helped to monitor the effects of the major flood events of 2011.[4]

The DDS program involved the use of sediment grab samplers to obtain surface sediments between 0 and 2 inches, with most samplers collected by a Van Veen sampler equipped with a lander to aid in obtaining reproducible sampling depths. The DDS program varied in its sample handling by river section. In RS1, individual sampling locations were treated as discrete samples, yielding approximately 60 samples representing 60 locations. In RS2 and RS3, samples were composited so that each sample result represented two to four locations. Approximately 25 sample results represented 75 locations in RS2, and 30 sample results represented 90 locations in RS3. Samples were obtained both inside and outside the CUs to characterize sediment deposition due to resuspension in areas targeted for dredging (typically fine-grained sediment areas), as well as in areas outside the CUs (typically coarse-grained sediment areas). To this end, samples were obtained at these locations both before and after the dredging season in RS1 and RS2. Thus, discrete samples were obtained in RS1 in June of 2011, prior to the start of dredging, and in November 2011, after dredging was completed. The sampling in RS2 followed the same regimen in 2012. In creating

[4] The Upper Hudson River was subject to a 1-in-100 year return flow event in late April of 2011. In the Lower Hudson River, hurricanes Irene and Lee (August-September 2011) caused major flow events from its tributaries.

composites in RS2, the nodes used in each composite assembled in the June 2012 sampling were also used in assembling parallel composites in November 2012. The single sampling event in RS3 was conducted in August 2013, and did not examine pre- and post-dredging impacts in that river section. Note that in RS1 and RS2, pre- and post-dredging sampling inside CUs in nearly all cases was conducted in CUs that had not been dredged prior to the spring of the respective year and were not dredged during the respective intervening season.

One of the important observations from the DDS program came from the matched samples collected before and after dredging. For both RS1 and RS2, and for locations inside and outside of the CUs, there was no discernible change in the average Tri+ PCB concentration in the 0-2 inch layer between the June and November sampling events. This set of observations suggests that dredging-related resuspension did not have a measurable impact on surface sediment concentrations. Because the spring and fall values agree on average, EPA believes that the DDS data are not significantly confounded by dredging impacts for the purpose of estimating recovery trends, so the averages of the individual matched pairs of the spring and fall samples were used in the comparisons to the SSAP data discussed below.

Notably, in April 2011, just prior to the start of the DDS program and the start of Phase 2 dredging, the Upper Hudson River experienced a 1-in-100-year return flood event. Estimates of the impacts of such an event were highly uncertain, but were forecast by the EPA models to potentially re-expose high levels of PCBs found at depth via sediment scour during high storm flow. When compared to the SSAP program, the results of the DDS sampling suggest this was not the case. This is further discussed below.

See Section 2.6.1 and Figures A4-1 through A4-9 and Figure A4-12 for a discussion of DDS data and a comparison of DDS samples with SSAP results.

## 2.6 GE 2016 OM&M Surface Sediment Sampling Program

GE's 2016 surface sediment sampling program was designed under EPA direction as part of the OM&M sediment monitoring program to assess long-term recovery following the completion of the dredging remediation via the collection and analysis of surface sediment samples from both non-dredged and dredged areas in the Upper Hudson River. The 2016 sampling event establishes the initial year of the required sampling design in non-dredged areas. The required sampling of the dredged areas will occur in 2017. Determination of the required number of samples and their locations was based on EPA's sampling design analysis.

The OM&M surface sediment sampling design[5] is a probability-based program developed around the objective of supporting rigorous, unbiased estimates of overall post-dredging average PCB concentrations, and associated uncertainty bounds, in RS1, RS2, and RS3. The data collection will be used to quantify changes in overall average surface sediment concentrations over time by river section and to support investigation of relationships among fish, water and sediment during the post-remedial monitoring period.

Sampling locations were selected so that the design is both unbiased and provides a degree of spatial balance along the length of the Upper Hudson River. The sampling design method represents three domains of potential interest: 1) dredged and filled areas, 2) non-dredged areas, and 3) areas which are unsafe to sample, such as along or near the faces of dams, or where no sediment recovery is expected, such as submerged rocky areas. To accommodate these separate populations where mean and variance of PCB concentrations may differ, a stratified random sampling design (Cochran, 1997) was used.

5 For purposes of this appendix, "sampling design" refers to the number of samples, sampling grid layout and procedure for selecting locations from which sediment will be collected. In this context a "sample" is a group of locations at which sediment is to be collected for measurements. A statistical procedure is unbiased if the individual members of the population being sampled are available to be selected for measurement with known quantifiable probability and statistical calculations incorporate those probabilities as weighting factors.

Estimation of changes in mean PCB concentration will be achieved through comparison of data from samples collected at multiple points in time throughout the monitoring period. Sample sizes are expected to be sufficient to support temporal comparisons within each river section, as well as within dredged and non-dredged areas.

# 3 ANALYSIS OF TEMPORAL TRENDS IN SURFACE SEDIMENTS FROM SEDIMENT SURVEY PAIRS

The premise of the selected remedy is that reducing PCB sediment concentrations will directly reduce transfer of PCBs from sediments to the water column and biota, thereby allowing fish tissue concentrations to decline, the penultimate goal. Expectations for long-term remedial effectiveness are based in part on the assumption that natural recovery processes would reduce PCB concentrations in sediment before and after construction was completed. At the time of the ROD, recovery rates were predicted to be on the order of 8 percent per year and now that new sediment data are available, it is useful to evaluate the accuracy of those predictions. Deviations from the predicted recovery rate would change the time frame for PCB concentrations in fish tissue to reach their target goals. In total, there are five surveys which are generally unimpacted by active dredging operations and, therefore, are candidates for estimation of natural recovery rates. In this section, average Tri+ PCB concentrations from independent pairs of sampling surveys are compared to estimate natural recovery rates in sediment. As shown below, estimates of temporal rates of decline in surface sediment concentration vary with the pairs selected for comparison.

In the following sections, the results of the DDS program conducted between 2011 and 2013 are contrasted with the 2002-2005 SSAP results. In addition, estimates of the rates of decline between all possible pairings of the various surface sediment surveys from RS1 are compiled. The results of this compilation show that the estimates can vary widely, but that the most frequent estimates are consistent with the rates of decline observed in the fish tissue and water column during the predredging MNA period, as described in Appendices 1 (Evaluation of Water Column PCB Concentrations and Loadings) and 3 (Assessment of PCB Levels in Fish Tissue).

## 3.1 Analysis of Temporal Trends in Surface Sediments Using 2002-2005 SSAP *vs.* 2011-2013 DDS Data

In this section, the DDS and SSAP data are compared to estimate intervening rates of decline based on these two surveys alone.

The surface sediment data from the 2002-2005 survey and the DDS program were collected by different methods, *i.e.*, coring and grab sampling, respectively, and were not intended to characterize long-term trends. With some care, however, the DDS and SSAP results can be matched to yield an estimate of the rate of decay of surface sediment PCB levels. The results are discussed below and compared in Figures A4-1 through A4-3, corresponding to RS1, RS2 and RS3, respectively. The results are also summarized in Table A4-1. Because the DDS program focused on long-term post-dredging monitoring and the impacts of dredging on areas outside the CUs, most of the locations selected for DDS sampling were reoccupied SSAP locations, so that EPA could assess how PCB concentrations had changed at fixed locations.

The reoccupied SSAP locations were not selected to be representative of the entire river section or how much PCBs had changed on average in a river section. Nonetheless, the temporal change in sediment concentrations in the areas studied under the DDS can be examined by comparing them with the SSAP results for these same areas, with caveats.

Rigorous statistical inference of temporal changes in true PCB concentrations in river sediment requires that each of the surveys under comparison were developed using probability-based sampling designs that are either unbiased or have known unequal probability basis. The SSAP and DDS surveys were not fully unbiased, so substitutes for the mean, median, and variance of PCB concentrations for the subset of targeted SSAP locations reoccupied during the DDS survey were compared with those for the whole population of SSAP locations in each river section, to understand potential spatial biases between the two surveys.

In the event that the selected subset of locations were found to have a higher mean (or median) PCB concentration than the entire SSAP data population, based on probability theory, the mean and median of the PCB concentrations from the resampled locations (*i.e.,* the DDS location results) are likely to be lower than the mean and median of the original targeted location samples. This is referred to as “convergence to the mean,” and is likely to occur absent of any actual change in the mean or median of the overall population. In the same way, if concentrations in the targeted areas are consistently lower than those of the entire population, then concentrations of the resampled locations can be expected to increase relative to the mean and median of the targeted samples.

A comparison of the medians and their 95 percent confidence intervals was prepared for each river section, separated into inside CU and outside CU areas, for a total of six comparisons. Medians were chosen for comparison to reduce the effects of skewness on the power to detect temporal changes, due to the limited numbers of DDS samples available in some river sections and the skewness of the PCB concentration distributions.[6] In each comparison, the median for all SSAP data in the subdivision (*e.g.,* all 2002-2005 samples in RS1 inside CUs) is compared to the median of the SSAP values for the targeted sites (*e.g.,* 2002-2005 locations in RS1 inside CUs that were selected to be reoccupied) and to the median of the DDS samples from those same targeted locations (2011-2013 data). The comparison of the medians and their 95 percent confidence intervals was based on a bootstrap analysis of the various populations to determine the confidence intervals. Intervals that do not overlap were taken as statistically significantly different. These comparisons are presented in Figures A4-1 to A4-3, corresponding to RS1 to RS3, respectively. The results are also summarized in Table A4-2.

In RS1, the comparisons show that the median of the SSAP targeted locations agrees within error with the median Tri+ PCB concentration for all SSAP RS1 locations, so that the reoccupied locations are arguably representative of all SSAP location and DDS convergence to the mean apparently will not confound the comparison between surveys. For both the inside CU and outside CU comparisons, the median PCB concentrations of the DDS samples are statistically significantly lower than the entire set of SSAP results, and significantly lower than the targeted locations for the inside CU subdivision.

[6] Medians are considered a more reliable estimate of the central tendency of a population when the sample size is small and the data set exhibits substantive skewness, as was the case in this analysis.

In RS2, SSAP-based Tri+ PCB concentrations at targeted locations are statistically higher than SSAP-based Tri+ PCB concentrations in the population as a whole for both inside CU and outside CU subdivisions. Thus, one might anticipate a change in the DDS concentrations relative to the targeted locations due to convergence to the mean and not necessarily indicative of a change in true sediment concentrations. However, Tri+ PCB concentrations from the DDS survey were statistically significantly lower than concentrations at both the target SSAP locations and the overall set of SSAP locations inside CUs, as well as outside CUs.

Finally, in RS3, the medians of the targeted locations are the same as or lower than the entire population of SSAP samples for the river section, minimizing concerns about convergence to the mean. Here again, the DDS locations are lower than the entire population of SSAP samples as well as the targeted SSAP locations, both inside and outside of CUs.

Overall, these results show that the DDS samples are consistently lower than SSAP results for each river section, for areas both inside and outside the CUs. In most instances, the DDS results are lower than the subset of the targeted SSAP locations as well. The tests of significance of differences between the DDS results and the entire SSAP sample groups are not impacted by any convergence to the mean issues. In total, these results suggest that surface sediment concentrations declined between 2002-2005 and 2011-2013 in the SSAP areas that were reoccupied for the DDS.

Before presenting any estimates of the rates of decay in sediment PCB concentration between the dates of the SSAP and DDS programs, please note that the use of the available sediment data as a basis to determine the rate of decay of surface sediment Tri+ PCB concentrations between any two survey years could conflate real temporal changes in Tri+ PCB concentrations with the impacts of differences in sampling design, physical sample collection methodology and, in some cases, composite sample preparation and handling between surveys on the data comparison. The effects of these differences on decay rate estimates is not known. Unlike the fish and water column data, which were specifically collected to monitor changes over time, each of the sediment surveys was originally focused on other objectives. As such, their comparisons can only provide a general and uncertain indicator of the rate of change. See Appendices 1 and 3, respectively, for water column and fish concentrations decay rate discussions.

The data for the DDS and SSAP programs are presented in a box-and-whisker format for each of the subdivisions described above. Figures A4-4 to A4-9 present the comparisons of the SSAP data, both the entire data set and the targeted subset, against the DDS data for each river section, for both inside CU and outside CU areas. Figures A4-4 to A4-9 show the distributions of the entire data set in each instance, as opposed to uncertainty of the median, as was shown in Figures A4-1 to A4-3. The latter figures identified the statistically significant differences between the data sets, whereas Figures A4-4 to A4-9 provide visual comparisons of the sample populations themselves. Also shown are the rates of decay between the surveys, expressed as half-lives (the number of years required for the PCB surface sediment concentration to reduce to one-half of the current concentration). In all instances, the half-life falls between 3 and 9 years, with an average half-life of 5 years across all areas and river sections. These estimates are consistent with those obtained from the examination of the fish tissue and water column data, typically in the range of 5 to 10 years. The decay rates and half-lives of the sediment comparisons are summarized in Tables A4-2a and A4-2b, respectively, and are further discussed below.

## 3.2 Analysis of Temporal Trends in Surface Sediments Across all 1991 – 2013 Surveys

To further support EPA's view that the sediment surveys can only provide rough estimates of the rate of decay in surface sediment PCB concentrations, apparent decay rates (half-lives) were computed across nearly all possible pairings of the four available 1991-2013 surveys. The pairings were made both on a whole river section basis, as well as on various subsets, such as inside or outside CUs or based on fine-grained areas only. Comparisons to the GE 1998 survey were limited because this survey only covered RS1. The results based on comparing changes in the median concentration in each group are provided in Tables A4-2a and A4-2b. The median was chosen as a basis to estimate change, rather than the mean, due to the smaller sample sizes in the DDS and 1998 GE data sets. Given the high variability that is characteristic of these data sets (for example, see Figures A4-4 to A4-9), the median is less sensitive to outliers, while still providing an estimate of the central tendency of the data set.

A wide range of half-life estimates is shown in Tables A4-2a and A4-2b, including a number of pairings which indicate increases over time (as opposed to declines), yielding a doubling time estimate (highlighted in red in the tables). Notably, these occur when both of the earlier GE studies are paired with the SSAP program. Also notable is the shorter half-lives obtained by comparing the SSAP to DDS programs. These half-lives fall between 3 and 9 years (see Table A4-2b) within the range of the fish and water column trends. Figures A4-10 and A4-11 present the information contained in Table A4-1 graphically. In Figure A4-10, the half-lives for each survey comparison are presented as a distribution, showing the wide range of estimates, as well as the frequency of estimates in the 5 to 10 year half-life range. Note that some pairs in Tables A4-2a and A4-2b were averaged, so that each survey pair is not represented by more than two values for each river section.[7]

Figure A4-11 presents the rates of decay expressed as a percentage (as opposed to a half-life). This figure shows annual rates of change ranging from a decline of more than 18 percent per year to an increase of more than 9 percent per year. Again, these figures serve to emphasize that sediment surveys that were not designed to define temporal trends are not a reliable way to determine the rates of decay and, as such, will provide a highly uncertain estimate for this parameter. Figure A4-12 provides further emphasis of this point. It combines the results of all four sediment surveys superimposed on the original Figure I-3-22 from the Phase 1 Evaluation Report (EPA 2010). The figure presents the estimated mean Tri+ PCB concentration for all sediments in RS1 for all four sediment surveys and contrasts it with model forecast prepared by EPA in 1998. Notably, the 2011 DDS results for inside and outside CUs in RS1 bracket the model trajectory for that year, which is an

[7] Specifically the DDS-SSAP pairs were averaged by river section to yield 6 instead of 12 estimates for this comparison. Other cells with double entries were also averaged.

encouraging finding. However, this diagram was not prepared to indicate that the sediments track with modeled recovery trends, but rather to emphasize that comparison of these sediments data sets does not provide a definitive answer regarding the changes through time.

Relationships among the various studies were explored, examining in particular the TIP, where data from the 1991, 1998, and SSAP studies are available. Irrespective of how the surveys are compared (on a matched location basis, by sediment texture, or on a pool-wide basis), the relationship among the three studies remains approximately the same. Mean Tri+ PCB concentrations in 1991 and in 2002-2005 are approximately the same, while those in 1998 are substantially lower. (See Figures A4-13 and A4-14, which compare the surveys on the basis of matched sample locations, while accounting for two different fine sediment definitions.)

Based on these comparisons, we are faced with several questions that cannot be discerned from pairwise comparison of pool-wide averages, specifically:

- Are surface sediments subject to large swings in PCB concentration over short time periods?
- Is one or more of the surveys not representative?
- Which trend among the studies represents the correct relationship?
- Are there correlates such as sediment texture that may explain apparent inconsistencies in pool-wide averages?
- Can inconsistencies be explained by unintended sampling biases introduced into the study through sample placement, sample extraction techniques, compositing and subsampling (issues discussed at length by Gy and Royle, 1998)?

No single pairwise comparison among the studies can provide a satisfactory answer to these questions. Ultimately, the pairing of sediment surveys to determine the rate of decay in Tri+ PCB concentrations in surface sediments is challenged by the lack of comparability among the data sets. Each survey has unique features that make direct comparison difficult and yield inconsistent rates of change. The 1991 and 1998 surveys utilized composite samples which mask the spatial heterogeneity that is more clearly defined in the dense sampling grid used during the collection of the 2002-2005 discrete samples. In particular, analysis based on sediment compositing is challenged by the difficulties of achieving true homogeneity among discrete portions when concentrations can vary by orders of magnitude, and sediment textures can vary significantly in the proportion of coarse *vs.* fine particles. The use of the available sediment survey data as an independent basis to determine the rate of decay of Tri+ PCB concentrations in surface sediments in the Upper Hudson is highly uncertain.

# 4 SIMPLE SEDIMENT TREND ANALYSIS

In an effort to overcome the apparent limitations of temporal analysis of multiple rounds of sediment data collection as described in Section 3, this section develops reasonably comparable subsets of sediment data for “naïve” (or simple) estimation of empirical temporal trends. These trends may then be compared with recently collected data, as an assessment of current surface PCB concentrations relative to what might have been expected absent the remedy. The method is naïve in the sense that it does not attempt to control for differences in sampling, analysis, and sample compositing and handling methods, although it does recognize and take into account the important role of sediment texture. It is generally understood that PCB concentrations vary with sediment texture, so the surface sediment samples were subdivided based on texture and trends were estimated separately for groups identified as generally fine or coarse sediment. The method also does not attempt to control for changes in the sediment transport that occurred between the time of dam removal in 1973 and subsequent years. The method assumes a constant annual percentage change in sediment concentrations from 1975 to the present, prior to dredging impacts. This method produces an average time trend, and no attempt is made to account for any intermediate changes in the sediment processes affecting surface sediment PCB concentrations. The intent of this approach was to reduce potential unintended biases due to differences between surveys in sampling density/representation of coarse and fine fractions relative to their actual proportions in the river. It is not anticipated that segregating by grain size would cure all of the potential biasing factors in the various studies; nonetheless, it is expected that by analyzing the data separately by sediment texture groupings, some biases may be reduced and temporal patterns may become more interpretable with reduced uncertainty.

## 4.1 Sediment Texture Classification

Two side scan sonar (SSS) surveys were conducted in the Upper Hudson River, in 1992 and in 2004. The SSS survey conducted in 1992 covered river sections RS1 and RS2 and the results were post-processed into a binary variable, defining finer-grained sediments as “cohesive” and coarser-grained sediments as “non-cohesive” textures. The 2004 SSS survey also covered river sections RS1 and RS2, as well as RS3, and classified textures into five types. The surface sediment concentration data could therefore be stratified into two bins, using the 1992 texture categories, or five bins, using the 2004 categories. For this analysis, the two-category classification was preferred because it was straightforward to assign composite samples collected in 1991 and 1998 to cohesive and non-cohesive categories. It would have been more difficult to accurately assign those composite samples to the five more highly resolved 2004 texture categories, because the composites often included sample locations representing multiple categories, as defined in 2004, and would have likely introduced additional uncertainty into the analysis.

Thus, for RS1 and RS2, each sample was classified (based on the 1992 SSS survey results) as either cohesive or non-cohesive, and statistical analyses proceeded within these two subgroups separately. Because the 1992 survey was not conducted in RS3, an empirical relationship predicting the binary 1992 texture classification as a function of the five-group texture from the 2004 SSS survey was developed and applied to samples in RS3. The predictive model was a type of machine-learning algorithm known as a random forest or bagged classification tree (Brieman 1996 and Brieman 2001). Machine learning methods are modern classification techniques motivated by the need to accurately predict consumer interests from internet searches. These methods excel for prediction of binary responses when relationships are non-linear. A hallmark of the method is that it relies upon cross-validation, wherein random subsets of samples are removed from the data set (approximately 10 percent) and those data are used as prediction targets to validate models based on the remaining 90 percent of the data. Models that perform best in out-of-sample validation sets are used to make predictions. Reliability in RS3 was inferred based on how well the random forest predicted cohesive or non-cohesive set membership in the validation sets from RS1 and RS2. It was found that within these randomly chosen sets, sediment texture class membership was properly identified in 76 percent of samples, and similar accuracy can be expected for classifying samples in RS3. Classification errors can be expected to propagate into the analysis as measurement error, which would tend to reduce texture-specific differences in estimated temporal trends.

## 4.2 Data Summary

After subdividing Tri+ PCB concentrations into sediment texture groups within river sections, sample sizes (N), means, medians, bootstrap variances and 95 percent confidence limits were calculated (Table A4-3). Confidence limits were based on the bias-corrected accelerated method ([BCA] Efron 1987).

Estimated mean Tri+ PCB and 95 percent confidence limits were plotted against year of sampling event, and a first order decay function ($C_t = C_0 e^{kt}$) was fit to each combination of river section and sediment texture (Figure A4-17a-f). The models were fit using weighted least squares, with weights inversely proportional to relative error, expressed as the bootstrap standard error of the mean divided by the mean $\left(\sqrt{var(\bar{x})}/\bar{x}\right)$. This weighting accounts for the fact that not all sediment surveys are equally reliable, weighing surveys with more precise estimates more heavily. This approach reduces the relative impact of more uncertain estimates, but cannot correct for any unintentional biases in the data that could adversely affect trend estimates. Trends were fit to data from 1976 through 2011 in RS1 and RS2 and through 2012 in RS3. Mean Tri+ PCB concentration and 95 percent confidence limits were overlain on the plots for comparison.

### 4.2.1 Cohesive Sediments

Fitted exponential decay curves showed declining Tri+ PCB sediment concentrations with time, exhibiting evidence of recovery since the 1970s in cohesive sediments. This may represent a combination of source control efforts and natural recovery processes. For cohesive sediments, Tri+ PCBs declined on average by 5, 6 and 7 percent per year in River Sections RS1, RS2 and RS3, respectively. Confidence bounds were markedly similar for each river section, with upper confidence limits of 6, 9 and 12 percent and lower confidence limits of 3, 3 and 2 percent in RS1, RS2 and RS3 respectively (Table A4-4). These rates are generally consistent with the approximately 8 percent decay rate simulated by EPA's HUDTOX model for the pre-dredging period at the time of development of the ROD. These decay rates correspond to half-lives in the range of 10 to 14 years with uncertainty bounds ranging from 6 to 34 years.

Confidence bands for fitted regression models show that for all three river sections, the first order decay function fits the sample Tri+ PCB concentration means reasonably well, with most mean values within the 95 percent confidence bands and with confidence limits for individual means also overlapping the confidence bands, and often the regression line itself.

### 4.2.2 Non-cohesive Sediments

Fitted exponential decay models for non-cohesive sediments also displayed declining Tri+ PCB sediment concentrations with time, exhibiting evidence of recovery, although a zero rate of decline was within the confidence bounds for RS1 and RS3. Tri+ PCBs declined on average by 5 percent in all three river sections (Table A4-4; Figures A4-17 b, d and e). Confidence bounds for decay rates[8] were -12 to +2 percent, -8 to -3 percent and -12 to +1 percent in RS1, RS2 and RS3, respectively. The consistency of the estimated average decline of 5 percent across river sections suggests that significant recovery has occurred, but that sample sizes are not quite adequate to precisely resolve these decay rates in the more variable non-cohesive sediments.

### 4.2.3 Recent Tri+ PCB Concentrations

Means of 2011-2012 and 2016 surface sediment PCB data were compared to the estimated trend lines to assess their consistency with long-term trends. Data collected in 2011 and 2012 from locations that had not been dredged were found to be unimpacted by upstream dredging (based on previously discussed DDS sample pairs) and are suitable for inclusion in the model fit.

Generally, the regression lines in cohesive and non-cohesive sediments passed reasonably close to these points, and the means concentrations were generally less than would be predicted by the regression line. Thus, regression lines that depict decay rates only slightly less than those predicted by HUDTOX are generally consistent with observed levels in the

[8] Negative rates indicate decline in PCB concentration through time and positive rates indicate increases through time.

1970s and pass within the margins of error of data collected much more recently, from 2003 through 2005, and again in 2011.

The estimated means and confidence limits for data collected in 2016 (as discussed previously, these data are only from non-dredged areas) were overlain on the plots to compare them with what might have been expected based on the empirical trends. Had the remedy not been conducted, one would expect the 2016 data to fall within the confidence bands for the regression line. Given that the remedy was conducted and also understanding that the 2016 data represent an unbiased sampling of sediments in non-dredged areas only, one might anticipate the 2016 mean to be above the regression line, due to the effects of dredging-related resuspension at upstream locations. Instead, the 2016 data are below the regression line, suggesting that negative effects of resuspension and redeposition on surface sediment concentrations were not in evidence and may have been minimal, contrary to expectations but consistent with the DDS data pairs. An important caveat is that the 2016 data are based on a spatially unbiased, probability-based sampling program, whereas the empirical regression model was fit to sample data collected with a range of sampling objectives and generated by programs that did not select their sampling locations according to a spatially unbiased approach, and this difference could influence how the 2016 sampling results compare to a trend based on prior samples/sampling programs.

# 5 REDUCTION IN SURFACE SEDIMENT CONCENTRATIONS AFTER DREDGING

The ROD anticipated that the remedy would reduce sediment PCB concentrations. Since publication of the ROD, sediment surveys have been conducted in 2002-2005 (predredging), 2011-2013 (within the period of dredging) and 2016 (post-dredging). The SSAP survey conducted in 2002 -2005 was used as a baseline in the first five-year review (EPA, 2012) to re-estimate expected reductions in average Tri+ PCB concentrations, assuming reductions in surface sediment concentrations in areas targeted for dredging and assuming no natural recovery between 2002 and completion of the remedy. Since then, data from 2011-2013 and 2016 suggest that concentrations in non-dredged areas have declined, presumably due to recovery processes, and the availability of 2016 data make it possible to re-evaluate the net change in surface sediment concentrations with regard to both the impacts of remedy implementation (in non-dredged areas only) and recovery processes.

The ROD anticipated that remediation goals will be met through a combination of active remediation by dredging (with limited capping to address residuals as subsequently permitted by the Engineering Performance Standards) and the processes of natural recovery. The OM&M sediment survey conducted in November 2016 provides data to estimate post-remedial surface sediment Tri+ PCB concentrations in the non-dredge areas, replacing the predicted post-dredging surface sediment concentrations in the 2012 five-year review that were based on the SSAP data and assumed no natural recovery. Thus, this update in the calculations has the effect of removing the assumption of no natural recovery through the remedial time period.

Calculations in this section are based on stratification of the Site by river section and by sediment texture classification (cohesive or non-cohesive) within each river section. Apparent percentage changes in surface sediment PCB concentrations due to the combined effects of natural recovery and remedy implementation should be interpreted cautiously, due to the challenges inherent in comparing pairs of surveys described in previous sections.

Generally, estimates of percentage change for RS1 are the most robust because of denser coverage and more certainty in associating samples with cohesive and noncohesive classifications, whereas estimates in RS2 and, to a greater degree, RS3, are likely to be influenced by differences in spatial representation of the surveys. Recall that in RS2 and RS3, the focus of SSAP sampling was on depositional areas with decreasing sampling effort in areas not expected to be depositional. This bias could inflate river-section-wide estimates of mean concentration in 2002-2005 relative to those based on unbiased sampling in 2016, potentially resulting in overstatement of the effects of natural recovery in non-dredge areas.

With these caveats, estimated percentage changes are reported here. In 2016, average Tri+ PCB concentrations in cohesive surface sediments were 1.7 mg/kg, 1.3 mg/kg and 0.8 mg/kg in RS1, RS2 and RS3, respectively. In comparison, these values were estimated to be 3.9 mg/kg, 7.3 mg/kg and 3.0 mg/kg, respectively, in 2002-2005, based on the SSAP data. In non-cohesive sediments in 2016, Tri+ PCBs were 1.7 mg/kg, 1.7 mg/kg and 0.9 mg/kg in RS1, RS2 and RS3, respectively. In 2002-2005, these averages were estimated to be 4.4 mg/kg, 9.6 mg/kg and 4.2 mg/kg.

Based on the comparisons of SSAP and OM&M surveys, the apparent percent declines in average Tri+ PCB concentrations in surface sediments were 96, 88 and 80 percent in RS1, RS2 and RS3, respectively (Table A4-5). these percent reductions are greater than predicted in the first five-year review (87, 36 and 5.1 percent in RS1, RS2 and RS3, respectively). Taken at face value, the updated rates suggest that the net effect of the remedy and natural recovery has continued in non-dredged areas during the dredging period, despite some expected releases of PCBs during dredging (as discussed in Appendix 1). Changes in the overall Tri+ PCB concentrations were most strongly influenced by natural recovery in RS2 and RS3 where larger proportions of the Site were not dredged, and the influence of non-dredged areas on overall averages was the greatest. Based on the temporal analysis presented above in section 4, a natural recovery rate of approximately 5 percent was estimated, which corresponds to a half-life of approximately 14 years. Under this scenario, one would expect slightly less than 50 percent decline between 2003 and

2016, approximately one half life. These changes are also consistent with many recovery rates estimated in other appendices based on fish tissue and water column data.

As discussed previously, data from the 2002-2005 SSAP survey were essentially spatially unbiased in RS1, whereas in RS2 and RS3, the SSAP data tended to over-represent non-dredged sediments that were in close proximity to dredging areas. By virtue of its probability-based design, the 2016 OM&M survey was spatially unbiased in all three river sections. This suggests that a recovery rate based on comparison of the SSAP and OM&M data in non-dredged areas of RS1 may provide a more reasonable basis for estimating the natural recovery rate during the dredging period. Understanding potential uncertainties, simple estimates of the percentage decline in RS1 in non-dredged cohesive and non-cohesive sediments are (1-1.7/3.9)x100% = 55% and (1-1.68/4.4)x100% = 62%, respectively (Table A4-5). Taken at face value, these are equivalent to approximate annual recovery rates of 6% [ln (0.45)/(2016-2003)] and 7 percent [ln(0.38)/(2016-2003)] respectively. These are equivalent to half-lives of 9 and 11 years in cohesive and non-cohesive sediments, respectively. These apparent rates of recovery are well within the range of recovery rates estimated elsewhere for fish (Appendix 3) and water (Appendix 1) and also consistent with the 8 percent natural recovery predicted by HUDTOX outside the dredging period.

In an effort to understand the bias associated with uneven spatial representation in the data set, an alternative estimate of percentage recovery between 2003 and 2016 was constructed based on a hindcast of 2003 concentrations assuming approximately 56 percent and 7 percent annualized recovery rates respectively in cohesive and non-cohesive sediments in non-dredged areas. This approach is based on the assumption that the rates of decline in Tri+ PCB concentration in RS2 and RS3 were similar to those estimated for RS1. These rates of decline were applied to unbiased 2016 estimates of non-dredged area averages in cohesive and non-cohesive sediments, "hindcasting" 2003 concentrations in place of the potentially biased SSAP estimates.

The hindcast estimates of Tri+ PCBs were calculated by applying an exponential decline assumption to estimated 2016 averages

$$Tri + PCB_{2003} = (Tri + PCB_{2016})e^{-k\times(2003-2016)}$$

Where k=0.06 for cohesive sediments and k=0.07 for non-cohesive sediments. This approach led to hindcast estimates of non-dredged averages of 4.0 mg/kg and 2.1 mg/kg in RS2 and RS3, respectively (Table A4-6). These are lower than area weighted averages based on SSAP data of 9.2 mg/kg and 4.0 mg/kg in cohesive and non-cohesive sediments, respectively. The hindcast estimates lead to overall percentage reductions of 82 percent and 62 percent in RS2 and RS3, respectively.

These revised estimates suggest that, when based solely on SSAP data without consideration of sampling distribution, the effect of the remedy may be overstated in RS2 and RS3. However, if the rate of recovery observed in the more representatively sampled RS1 is applied to the downstream river sections, the anticipated reduction from 2002-2005 to 2016 is fairly similar to the simple calculation results for RS2 and RS3. Specifically, the hindcast estimate for RS2 is 82 percent, as compared to 88 percent based on simply comparing the sample data. In RS3, the hindcast estimates a 62 percent reduction as compared to 80 percent by comparing data. These differences are not dramatic considering the uncertainties in both sets of estimates, and do not change the overall conclusion that meaningful reductions in surface sediment Tri+ PCBs were readily quantified in RS2 and RS3 shortly after completion of the dredging and backfilling operations.

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# Second Five-Year Review Report
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## APPENDIX 4

## SURFACE SEDIMENT CONCENTRATIONS

### Tables and Figures

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# Table A4-1

## Comparison Among Concentrations for SSAP and DDS cores based on bootstrap analysis

| River Section | Location | All SSAP n | All SSAP Median Surf. Tri+ PCB (upper, lower 95% CI)[1] | Co-located SSAP n | Co-located SSAP Median Surf. Tri+ PCB (upper, lower 95% CI)[1] | Co-located DDS n | Co-located DDS Median Surf. Tri+ PCB (upper, lower 95% CI)[1] |
|---|---|---|---|---|---|---|---|
| RS1 | Inside CU | 2486 | 13.4 (13.0, 14.2) | 35 | 12.0 (6.8, 19.5) | 35 | 2.4 (1.7, 3.7) |
| RS1 | Outside CU | 1007 | 3.1 (2.9, 3.4) | 25 | 2.1 (0.77, 3.7) | 25 | 1.1 (0.29, 1.9) |
| RS2 | Inside CU | 700 | 14.4 (13.2, 15.7) | 18 | 20.6 (18.6, 30.8) | 18 | 4.5 (2.7, 6.4) |
| RS2 | Outside CU | 959 | 5.7 (5.3, 6.1) | 31 | 16.4 (13.0, 17.5) | 31 | 3.0 (2.4, 4.1) |
| RS3 | Inside CU | 724 | 2.5 (2.3, 2.6) | 24 | 1.7 (1.2, 2.1) | 24 | 0.7 (0.5, 1.1) |
| RS3 | Outside CU | 2608 | 1.8 (1.7, 1.9) | 50 | 2.2 (1.4, 2.5) | 50 | 0.5 (0.36, 0.67) |

[1]Bootstrap based on 1000 re-samples of the sample distribution (with replacement).

Orange: Median significantly higher than result for all SSAP locations in category

Blue: Median significantly lower than result for all SSAP locations in category

Dark blue: Median significantly lower than result for all SSAP locations and all Co-located SSAP locations in category

# Table A4-2a

## Tri+ PCB Sediment Concentration Decline Rates Expressed as Yearly Percent Change Based on Various Sediment Survey Comparisons

(Median Half-Life Rates of Change Estimates in Percent)

| Survey | Pairing | Survey / River Section | GE 1991 | GE 1998 | SSAP 2002-2005 All Data | SSAP 2002-2005 Sediment Type or Pair Match |
|---|---|---|---|---|---|---|
| GE 1998 | All Data | 1 | -10 | | | |
| | Sediment Type or Pair Match | | -5.3 (coarse), -14 (fine) | | | |
| SSAP 2002-2005 | All Data | 1 | -1.8 | 9.1 | | |
| | | 2 | 0.62 | | | |
| | | 3 | 1.7 | | | |
| | Sediment Type or Pair Match | 1 | -1.0 -0.43 | 11, 5.3 | | |
| DDS 2011 | Inside CUs | 1 | -8.8 | -7.9 | -23 | -21 |
| | Outside CUs | | | | -14 | -8.8 |
| DDS 2012 | Inside CUs | 2 | -4.2 | | -14 | -18 |
| | Outside CUs | | | | -7.5 | -20 |
| DDS 2013 | Inside CUs | 3 | -4.6 | | -13 | -9 |
| | Outside CUs | | | | -13 | -16 |

**Notes:**

1. Positive values and red shading indicate increasing rate of change.
2. Sediment Type or Pair Match indicates samples were compared between surveys after matching for sediment category or by sample location.
3. Multiple entries indicate different sample pairing bases.
4. Grey cells indicate not calculated or already contained elsewhere in the table.
5. Sediment texture-based comparisons for RS2 and RS3 were not performed due to data limitations.

# Table A4-2b

## Tri+ PCB Sediment Concentration Decline Rates Expressed as Half-Life Estimates Based on Various Sediment Survey Comparisons

(Median Half-Life Estimates in years)

| Survey | Pairing | Survey / River Section | GE 1991 | GE 1998 | SSAP 2002-2005 All Data | SSAP 2002-2005 Sediment Type or Pair Match |
|---|---|---|---|---|---|---|
| **GE 1998** | All Data | 1 | 7 | | | |
| | Sediment Type or Pair Match | | 13 (coarse), 5 (fine) | | | |
| **SSAP 2002-2005** | All Data | 1 | 38 | -8 | | |
| | | 2 | -112 | | | |
| | | 3 | -42 | | | |
| | Sediment Type or Pair Match | 1 | 67, 160 | -6.2, -13 | | |
| **DDS 2011** | Inside CUs | 1 | 8 | 9 | 3 | 3 |
| | Outside CUs | | | | 5 | 8 |
| **DDS 2012** | Inside CUs | 2 | 16 | | 5 | 4 |
| | Outside CUs | | | | 9 | 3 |
| **DDS 2013** | Inside CUs | 3 | 15 | | 5 | 7 |
| | Outside CUs | | | | 5 | 4 |

**Notes:**

1. Negative values and red shading indicate increasing trends and associated doubling times in years.
2. Sediment Type or Pair Match indicates samples were compared between surveys after matching for sediment category or by sample location.
3. Multiple entries indicate different sample pairing bases.
4. Grey cells indicate not calculated or already contained elsewhere in the table.
5. Sediment texture-based comparisons for RS2 and RS3 were not performed due to data limitations.

## Table A4-3
## Estimated Arithmetic Mean and Median Tri+ PCBs in Cohesive and Non-Cohesive Surface Sediments With 95% Bias Corrected Accelerated Bootstrap Confidence Limits and Variance Estimates

| | | | | Median Tri+ PCBs (mg/kg) | | | | Arithmetic Mean Tri+ PCBs (mg/kg) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| River Section | Year | Texture Classification[1] | N | 95% Lower Limit | 95% Upper Limit | Median | Bootstrap Variance | 95% Lower Limit | 95% Upper Limit | Mean | Bootstrap Variance |
| RS1 | 1976 | COHESIVE | 42 | 13 | 43 | 28 | 46 | 44 | 188 | 82 | 746 |
| | 1976 | NON-COHESIVE | 163 | 20 | 31 | 24 | 7.5 | 38 | 125 | 58 | 289 |
| | 1977 | COHESIVE | 21 | 11 | 66 | 25 | 176 | 28 | 79 | 46 | 119 |
| | 1977 | NON-COHESIVE | 81 | 12 | 36 | 18 | 54 | 35 | 106 | 55 | 164 |
| | 1991 | COHESIVE | 33 | 8.3 | 22 | 13 | 7.3 | 13 | 29 | 18 | 9.7 |
| | 1991 | NON-COHESIVE | 23 | 5.7 | 14 | 9.8 | 4.2 | 7.9 | 13 | 10 | 1.1 |
| | 1998 | COHESIVE | 12 | 3.1 | 23 | 5.8 | 33 | 7.6 | 33 | 15 | 29 |
| | 1998 | NON-COHESIVE | 18 | 2.9 | 7.3 | 4.3 | 1.2 | 3.5 | 7.4 | 5.4 | 0.78 |
| | 2002 | COHESIVE | 253 | 8.4 | 11 | 9.2 | 0.23 | 14 | 19 | 16 | 1.4 |
| | 2002 | NON-COHESIVE | 601 | 9.5 | 12 | 11 | 0.35 | 18 | 24 | 20 | 1.4 |
| | 2003 | COHESIVE | 560 | 6.7 | 8.8 | 7.5 | 0.24 | 14 | 19 | 16 | 1.3 |
| | 2003 | NON-COHESIVE | 713 | 8.6 | 12 | 9.9 | 0.45 | 17 | 20 | 18 | 0.74 |
| | 2004 | COHESIVE | 239 | 4.8 | 7.9 | 6.6 | 0.50 | 10 | 18 | 12 | 2.3 |
| | 2004 | NON-COHESIVE | 735 | 7.0 | 8.8 | 8.0 | 0.18 | 14 | 18 | 15 | 0.81 |
| | 2005 | COHESIVE | 162 | 5.8 | 9.4 | 8.1 | 0.60 | 12 | 20 | 15 | 2.3 |
| | 2005 | NON-COHESIVE | 220 | 7.8 | 13 | 10.0 | 1.0 | 14 | 20 | 16 | 2.0 |
| | 2011 | COHESIVE | 24 | 0.94 | 2.4 | 1.6 | 0.11 | 2.5 | 41 | 9.7 | 44 |
| | 2011 | NON-COHESIVE | 60 | 1.3 | 2.0 | 1.7 | 0.03 | 1.6 | 2.9 | 2.1 | 0.07 |
| | 2016 | COHESIVE | 6 | 0.30 | 4.3 | 0.90 | 1.1 | 0.61 | 4.9 | 1.7 | 0.77 |
| | 2016 | NON-COHESIVE | 27 | 0.60 | 2.1 | 1.2 | 0.16 | 1.1 | 3.4 | 1.7 | 0.15 |

## Table A4-3
## Estimated Arithmetic Mean and Median Tri+ PCBs in Cohesive and Non-Cohesive Surface Sediments With 95% Bias Corrected Accelerated Bootstrap Confidence Limits and Variance Estimates

| | | | | Median Tri+ PCBs (mg/kg) | | | | Arithmetic Mean Tri+ PCBs (mg/kg) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| River Section | Year | Texture Classification[1] | N | 95% Lower Limit | 95% Upper Limit | Median | Bootstrap Variance | 95% Lower Limit | 95% Upper Limit | Mean | Bootstrap Variance |
| RS2 | 1976 | COHESIVE | 5 | 2.5 | 141 | 85 | 2,638 | 20 | 128 | 74 | 734 |
| | 1976 | NON-COHESIVE | 17 | 12 | 56 | 25 | 95 | 26 | 228 | 67 | 1,107 |
| | 1977 | COHESIVE | 61 | 19 | 76 | 26 | 192 | 61 | 178 | 92 | 471 |
| | 1977 | NON-COHESIVE | 114 | 13 | 25 | 18 | 6.7 | 39 | 74 | 54 | 56 |
| | 1991 | COHESIVE | 5 | 4.3 | 28 | 7.0 | 25 | 5.6 | 25 | 11 | 15 |
| | 1991 | NON-COHESIVE | 5 | 2.2 | 37 | 8.0 | 116 | 4.0 | 33 | 15 | 41 |
| | 2002 | COHESIVE | 179 | 4.8 | 7.6 | 6.5 | 0.53 | 8.2 | 12 | 9.7 | 0.63 |
| | 2002 | NON-COHESIVE | 9 | 2.5 | 21 | 3.2 | 20 | 4.7 | 26 | 10 | 18 |
| | 2003 | COHESIVE | 558 | 8.5 | 11 | 9.7 | 0.23 | 13 | 16 | 15 | 0.45 |
| | 2003 | NON-COHESIVE | 279 | 6.8 | 9.7 | 8.0 | 0.37 | 11 | 15 | 12 | 0.69 |
| | 2004 | COHESIVE | 296 | 5.8 | 8.9 | 7.4 | 0.47 | 12 | 18 | 14 | 1.6 |
| | 2004 | NON-COHESIVE | 219 | 6.3 | 9.9 | 7.8 | 0.69 | 13 | 22 | 16 | 3.0 |
| | 2005 | COHESIVE | 72 | 6.6 | 15 | 11 | 3.3 | 11 | 18 | 14 | 2.2 |
| | 2005 | NON-COHESIVE | 99 | 9.1 | 14 | 12 | 1.1 | 14 | 23 | 18 | 3.6 |
| | 2012 | COHESIVE | 48 | 2.1 | 4.8 | 3.4 | 0.22 | 4.2 | 20 | 7.2 | 7.5 |
| | 2012 | NON-COHESIVE | 48 | 2.2 | 4.0 | 2.8 | 0.12 | 3.5 | 7.7 | 4.8 | 0.77 |
| | 2016 | COHESIVE | 31 | 0.68 | 1.7 | 0.98 | 0.03 | 0.96 | 2.1 | 1.3 | 0.05 |
| | 2016 | NON-COHESIVE | 39 | 0.79 | 1.9 | 1.4 | 0.05 | 1.3 | 2.4 | 1.7 | 0.06 |

**Table A4-3**
**Estimated Arithmetic Mean and Median Tri+ PCBs in Cohesive and Non-Cohesive Surface Sediments With 95% Bias Corrected Accelerated Bootstrap Confidence Limits and Variance Estimates**

| | | | | Median Tri+ PCBs (mg/kg) | | | | Arithmetic Mean Tri+ PCBs (mg/kg) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| River Section | Year | Texture Classification[1] | N | 95% Lower Limit | 95% Upper Limit | Median | Bootstrap Variance | 95% Lower Limit | 95% Upper Limit | Mean | Bootstrap Variance |
| RS3 | 1976 | COHESIVE | 7 | 5.1 | 37.9 | 10 | 81 | 7.4 | 31 | 17 | 28 |
| | 1976 | NON-COHESIVE | 16 | 1.0 | 14.1 | 9.8 | 6.5 | 6.7 | 25 | 12 | 13 |
| | 1977 | COHESIVE | 44 | 5.1 | 27.1 | 16 | 25 | 17 | 39 | 25 | 25 |
| | 1977 | NON-COHESIVE | 172 | 3.7 | 9.0 | 6.1 | 1.9 | 16 | 49 | 24 | 34 |
| | 1991 | COHESIVE | 27 | 1.5 | 2.9 | 2.3 | 0.20 | 2.1 | 4.2 | 2.7 | 0.16 |
| | 1991 | NON-COHESIVE | 29 | 0.5 | 1.6 | 1.2 | 0.07 | 1.1 | 3.1 | 1.9 | 0.18 |
| | 2003 | COHESIVE | 1995 | 2.1 | 2.3 | 2.2 | 0.003 | 3.4 | 4.1 | 3.6 | 0.02 |
| | 2003 | NON-COHESIVE | 388 | 3.0 | 4.3 | 3.9 | 0.08 | 5.5 | 7.8 | 6.4 | 0.24 |
| | 2004 | COHESIVE | 629 | 1.5 | 1.8 | 1.6 | 0.01 | 3.0 | 5.2 | 3.5 | 0.17 |
| | 2004 | NON-COHESIVE | 298 | 1.6 | 2.4 | 2.0 | 0.03 | 3.3 | 5.4 | 4.0 | 0.20 |
| | 2005 | COHESIVE | 80 | 0.9 | 2.2 | 1.3 | 0.14 | 2.7 | 7.1 | 3.9 | 0.66 |
| | 2005 | NON-COHESIVE | 83 | 1.9 | 4.3 | 2.6 | 0.49 | 3.9 | 9.8 | 5.1 | 0.89 |
| | 2013 | COHESIVE | 51 | 0.3 | 0.6 | 0.51 | 0.01 | 0.52 | 0.93 | 0.67 | 0.01 |
| | 2013 | NON-COHESIVE | 23 | 0.4 | 1.0 | 0.70 | 0.03 | 0.55 | 1.2 | 0.79 | 0.02 |
| | 2016 | COHESIVE | 21 | 0.3 | 1.0 | 0.62 | 0.05 | 0.52 | 1.3 | 0.80 | 0.03 |
| | 2016 | NON-COHESIVE | 88 | 0.3 | 0.6 | 0.42 | 0.003 | 0.55 | 2.0 | 0.87 | 0.08 |

Note:

1) Texture classification for RS1 and RS2 was based on the 1992 side scan sonar classification. RS3 texture classification was based on predictive model relating 2003 side scan sonar to 1992 side scan sonar (see text for discussions).

**Table A4-4**

**Regression Coefficients for Exponential Decay Functions Fit to Mean Tri+ PCBs in Cohesive and Non-Cohesive Surface Sediments. Decay Rates that Differ from Zero are in Bold**

| River Section | Texture Class | Parameter | Estimate | StandardError | Lower 95% Limit | Upper 95% Limit |
|---|---|---|---|---|---|---|
| RS1 | COHESIVE | Intercept | 96 | 15 | | |
| | | Decay Rate | **-0.046** | **0.007** | **-0.06** | **-0.03** |
| | NON-COHESIVE | Intercept | 101 | 56 | | |
| | | Decay Rate | -0.049 | 0.028 | -0.12 | 0.02 |
| RS2 | COHESIVE | Intercept | 127 | 26 | | |
| | | Decay Rate | **-0.062** | **0.013** | **-0.09** | **-0.03** |
| | NON-COHESIVE | Intercept | 114 | 21 | | |
| | | Decay Rate | **-0.055** | **0.011** | **-0.08** | **-0.03** |
| RS3 | COHESIVE | Intercept | 145 | 40 | | |
| | | Decay Rate | **-0.072** | **0.020** | **-0.12** | **-0.02** |
| | NON-COHESIVE | Intercept | 111 | 53 | | |
| | | Decay Rate | -0.055 | 0.026 | -0.12 | 0.01 |

**Table A4-5**
**River Section Wide Average Tri+PCBs (mg/kg) and Percentage Reduction based on 2016 Survey and Previous Forecast based on 2002-2005 SSAP Survey**

| River Section | In CU | 1992 Sediment Classification[1] | Area (Acres) | Pre-Dredge SSAP Survey 2003 | | | Post Dredge (Backfill &OMM Survey 2016) | | | Percent Reduction | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Mean | Variance | Overall Weighted Average | Mean[2] | Variance[3] | Overall Weighted Average | Remediation Alone[4] | Remediation +Recovery (95% CI) |
| RS1 | Dredge | COHESIVE | 105 | 18 | 0.6 | 14 (13.5,14.8 ) | 0.01 | 0.00001 | 0.77 (0.5,1.1) | 87% | 96% (92%, 97%) |
| | | NON-COHESIVE | 195 | 24 | 0.5 | | 0.11 | 0.00040 | | | |
| | NonDredge | COHESIVE | 29 | 3.9 | 0.1 | | 1.75 | 0.77 | | | |
| | | NON-COHESIVE | 199 | 4.4 | 0.0 | | 1.68 | 0.15 | | | |
| RS2 | Dredge | COHESIVE | 58 | 20 | 0.8 | 12 (11.0, 12.3) | 0.04 | 0.0004 | 1.34 (1.0, 1.7) | 36% | 88% (85%,92%) |
| | | NON-COHESIVE | 26 | 30 | 6.7 | | 0.22 | 0.02 | | | |
| | NonDredge[5] | COHESIVE | 76 | 7.3 | 0.1 | | 1.26 | 0.0 | | | |
| | | NON-COHESIVE | 302 | 9.6 | 0.2 | | 1.71 | 0.1 | | | |
| RS3 | Dredge | COHESIVE | 87 | 5.2 | 0.2 | 4 (3.7, 4.4) | 0.04 | 0.00 | 0.83 (0.5,1.3) | 5.1% | 80% (63%, 96%) |
| | | NON-COHESIVE | 11 | 13 | 3.5 | | 0.04 | 0.00 | | | |
| | NonDredge[6] | COHESIVE | 658 | 3.0 | 0.0 | | 0.8 | 0.0 | | | |
| | | NON-COHESIVE | 2634 | 4.2 | 0.1 | | 0.9 | 0.1 | | | |

Notes:

1) Cohesive and non-cohesive classifications in RS3 are based on predictive model relating 2003 side scan sonar to 1992 side scan sonar.
2) Mean Tri+ PCB concentration in dredge areas was based on post dredge backfill sampling and in non-dredge areas was based on the OM&M Survey 2016.
3) Variance of Tri+ PCB concentration in dredge areas was based on post dredge backfill sampling and in non-dredge areas was based on the OM&M Survey 2016.
4) Based on SSAP data and reported previously in the 2012 five year review report.
5) RS2 NonDredge area weighted average is 9.1 mg/kg. Calculated as follow: (7.3x76+9.6x302)/(76+302).
6) RS3 NonDredge area weighted average is 4.0 mg/kg. Calculated as follow: (3.0x658+4.2x2634)/(658+2634).

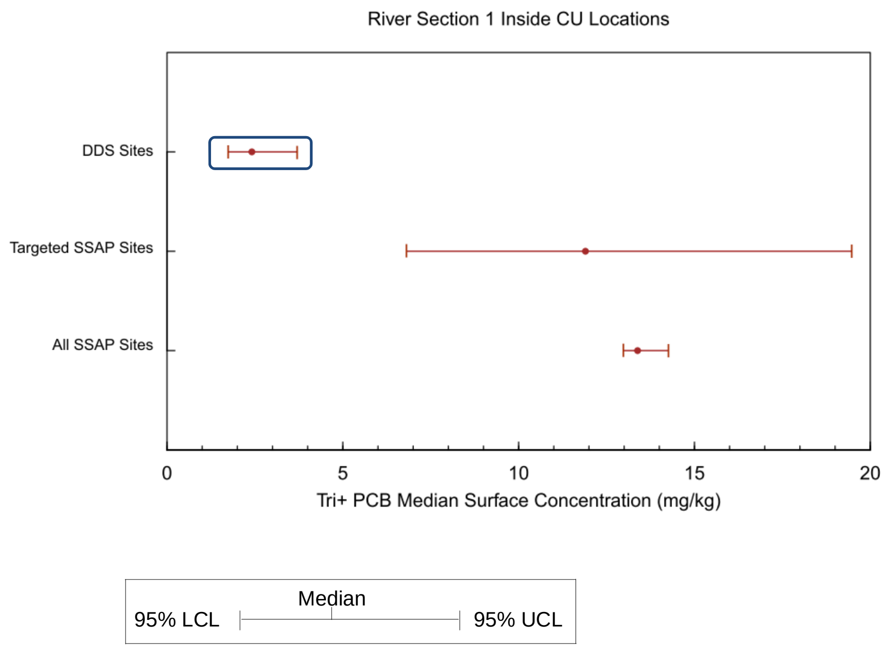
**Table A4-6**

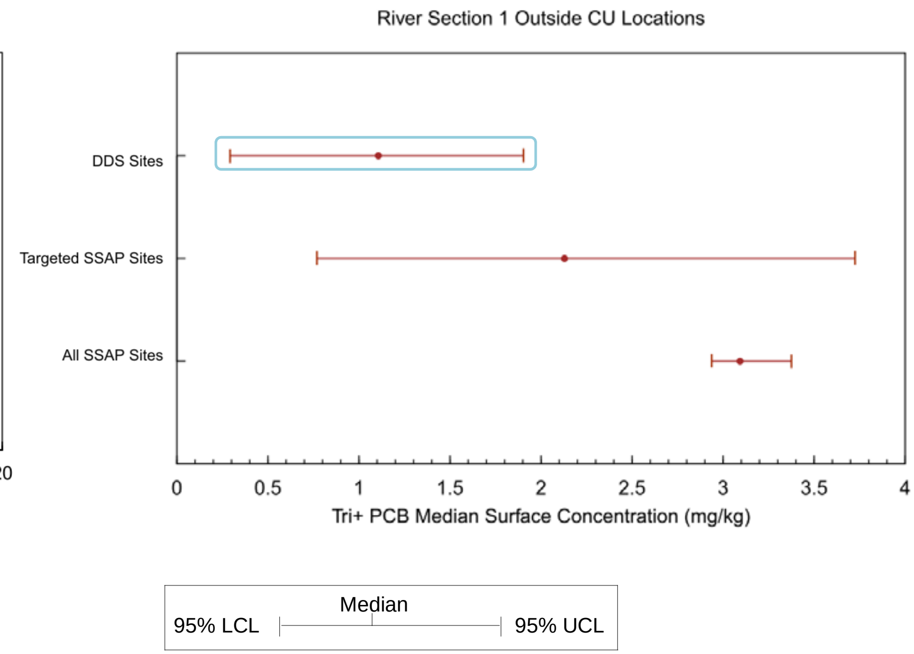
**River Section Wide Average Tri+ PCBs (mg/kg) and Proportional Reduction based on 2003 and 2016 Surveys in Dredge Areas and based on 2016 Survey and Hind Cast of 2003 Tri+ PCBs in Non-Dredge Areas**

| | | | | | 2003 Estimates | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| RS | InCU | 1992 Sediment Classification[1] | Area (Acres) | 2016 Mean[2] | Dredge Area Samples | Hindcast | Non-dredge 2003 Hindcast[3] | Overall Weighted Average (2003) | Overall Weighted Average (2016) | Proportional Reduction |
| RS2 | Dredge | COHESIVE | 58 | 0.04 | 20 | | | 7.5 | 1.34 | 0.82 |
| | | NON-COHESIVE | 26 | 0.22 | 30 | | | | | |
| | NonDredge | COHESIVE | 76 | 1.3 | | 2.8 | 4.0 | | | |
| | | NON-COHESIVE | 302 | 1.7 | | 4.3 | | | | |
| RS3 | Dredge | COHESIVE | 87 | 0.04 | 5.2 | | | 2.2 | 0.83 | 0.62 |
| | | NON-COHESIVE | 11 | 0.04 | 13 | | | | | |
| | NonDredge | COHESIVE | 658 | 0.80 | | 1.8 | 2.1 | | | |
| | | NON-COHESIVE | 2634 | 0.87 | | 2.2 | | | | |

Notes:

1) Cohesive and non-cohesive classifications in RS3 based on predictive model relating 2003 and 1992 side scan sonar
2) Mean Tri+ PCB concentration in post dredge areas was based on post dredge and backfill sampling.
3) Based on assumption of 5% annualized rate of decline from 2003 through 2016.

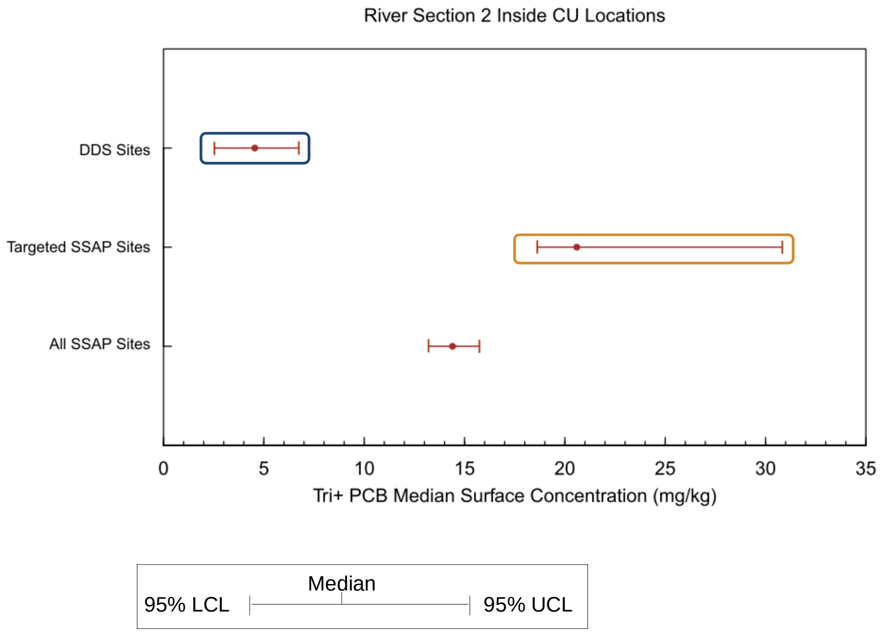


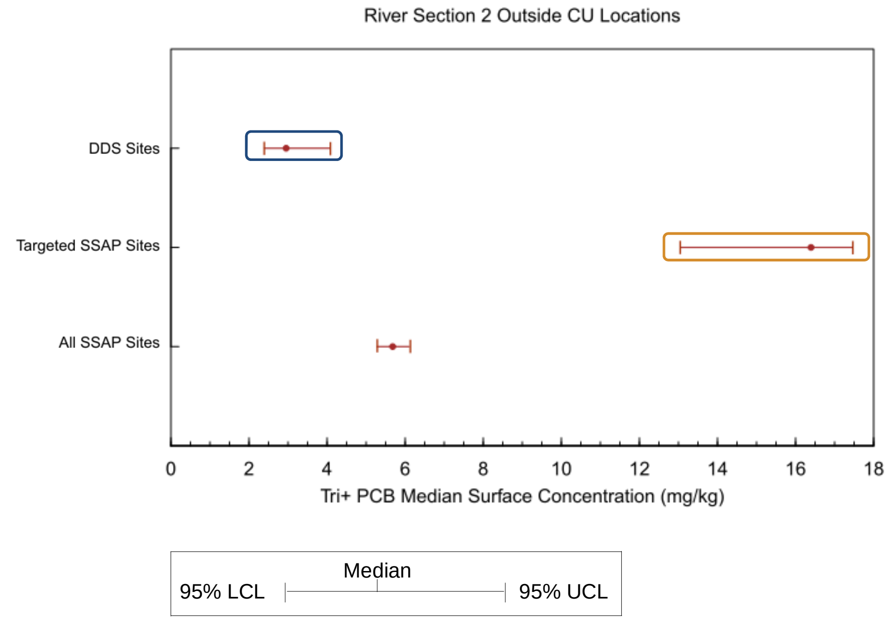




Ellipse colors correspond to the following:

- (Orange) Median significantly higher than result for all SSAP locations in category
- (Light blue) Median significantly lower than result for all SSAP locations in category
- (Dark blue) Median significantly lower than result for all SSAP locations and all Co-located SSAP locations in category

| Comparison of DDS Samples with SSAP Results<br>River Section 1 Median Values | Figure A4-1<br>May 2017 |
|---|---|



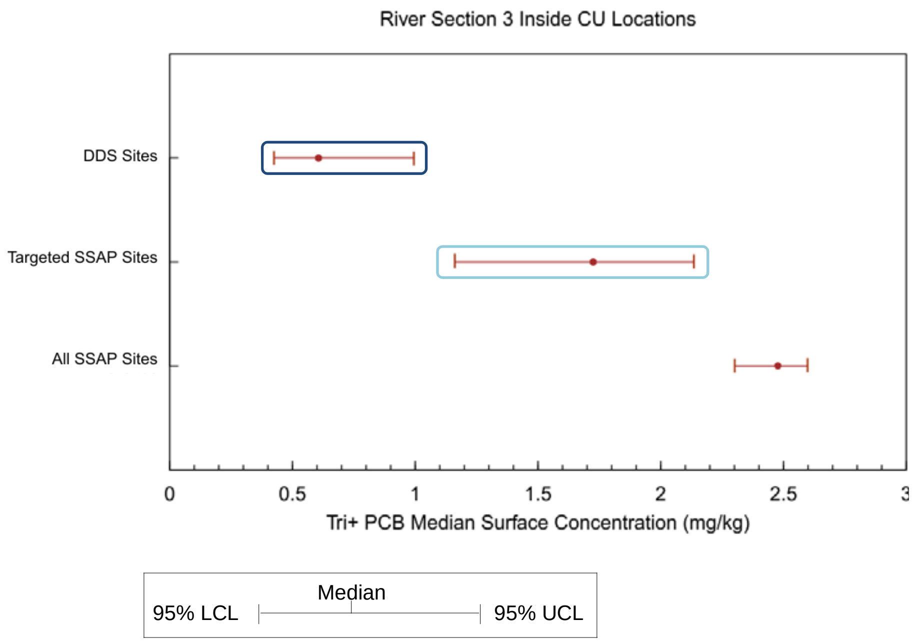

Ellipse colors correspond to the following:

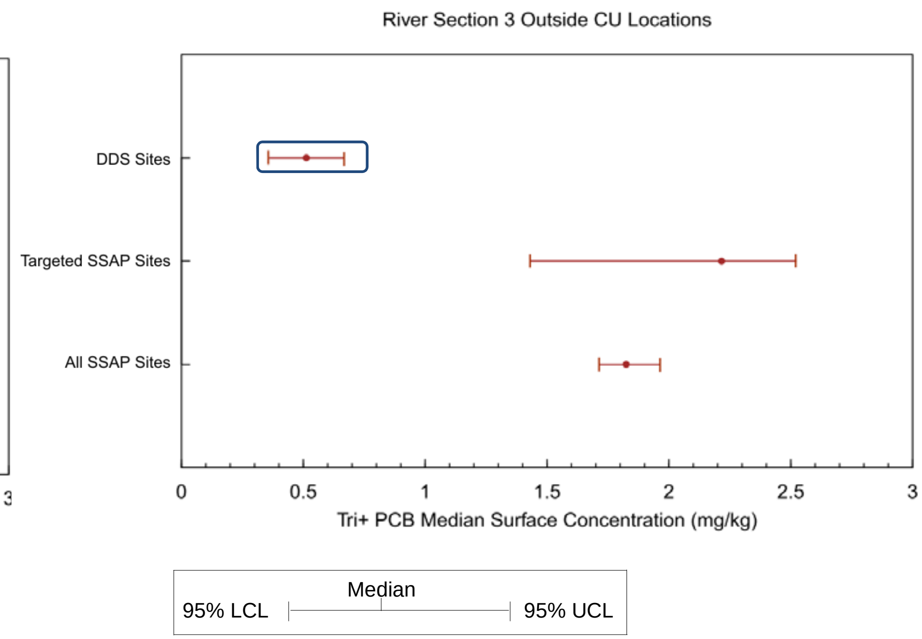
- (orange) Median significantly higher than result for all SSAP locations in category
- (light blue) Median significantly lower than result for all SSAP locations in category
- (dark blue) Median significantly lower than result for all SSAP locations and all Co-located SSAP locations in category

# Comparison of DDS Samples with SSAP Results
# River Section 2 Median Values

Figure A4-2

May 2017



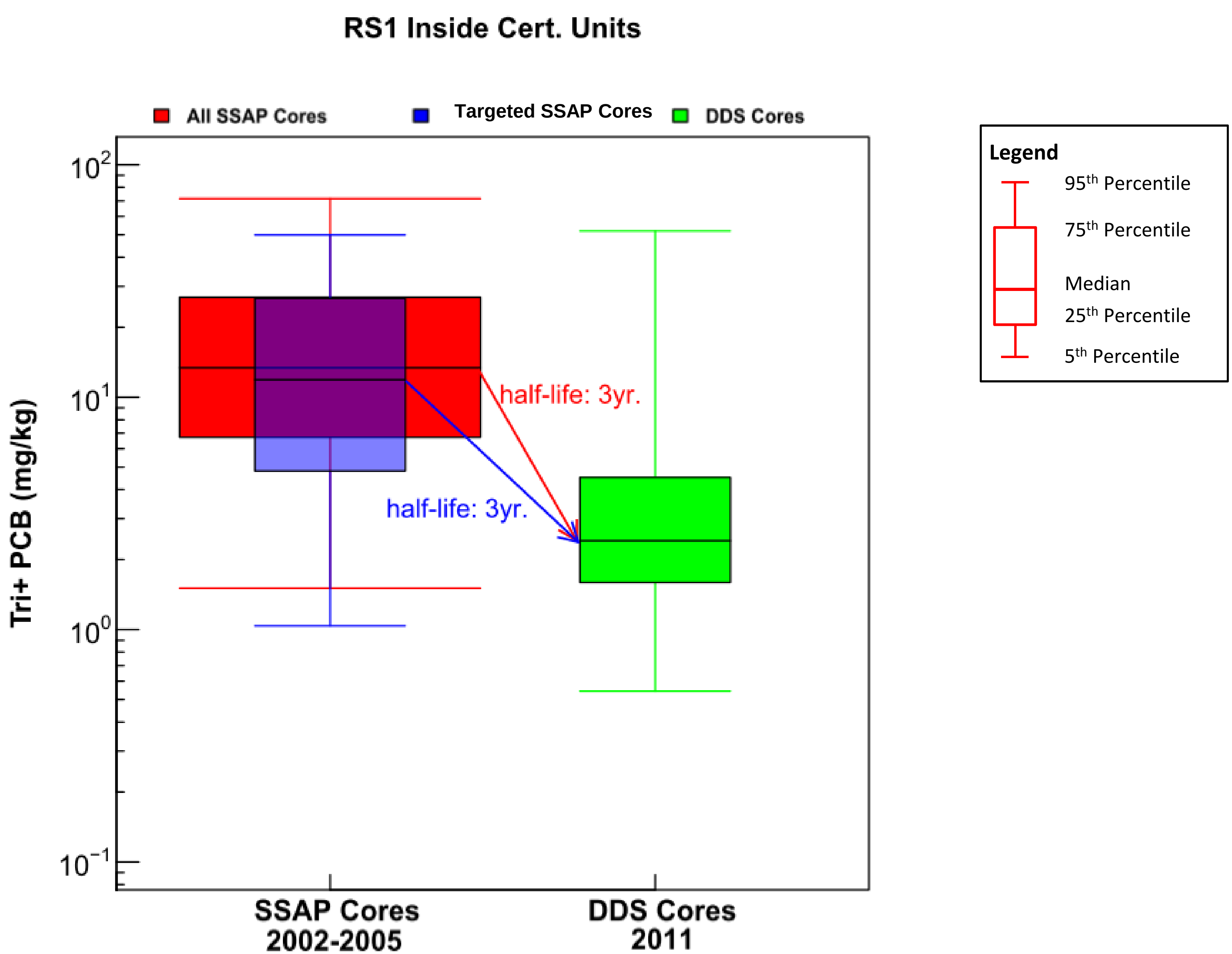

Ellipse colors correspond to the following:

- Median significantly higher than result for all SSAP locations in category
- Median significantly lower than result for all SSAP locations in category
- Median significantly lower than result for all SSAP locations and all Co-located SSAP locations in category

# Comparison of DDS Samples with SSAP Results
# River Section 3 Median Values

Figure A4-3

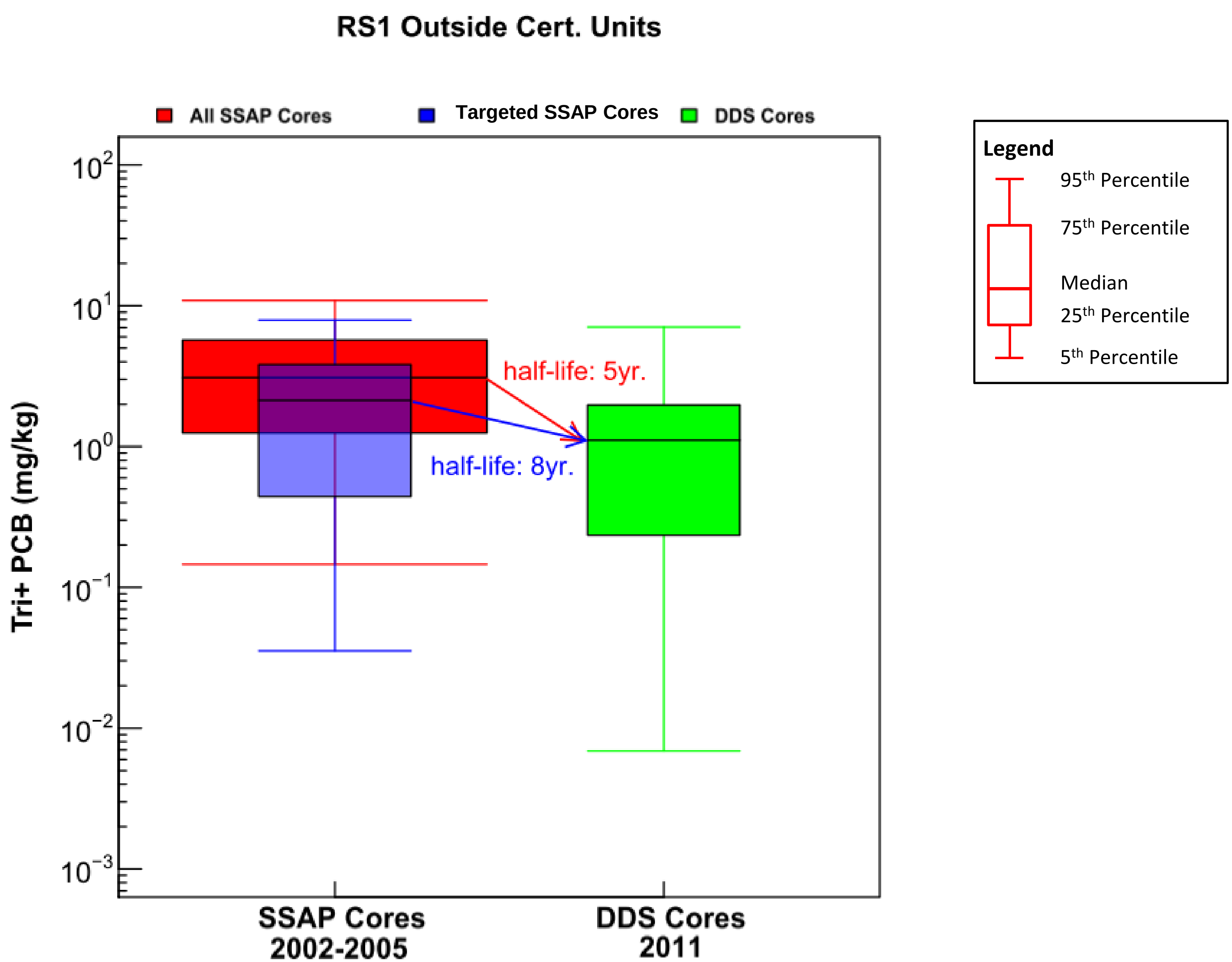
May 2017




Comparison between SSAP and DDS Data
River Section 1 Inside Certification Units

Figure A4-4

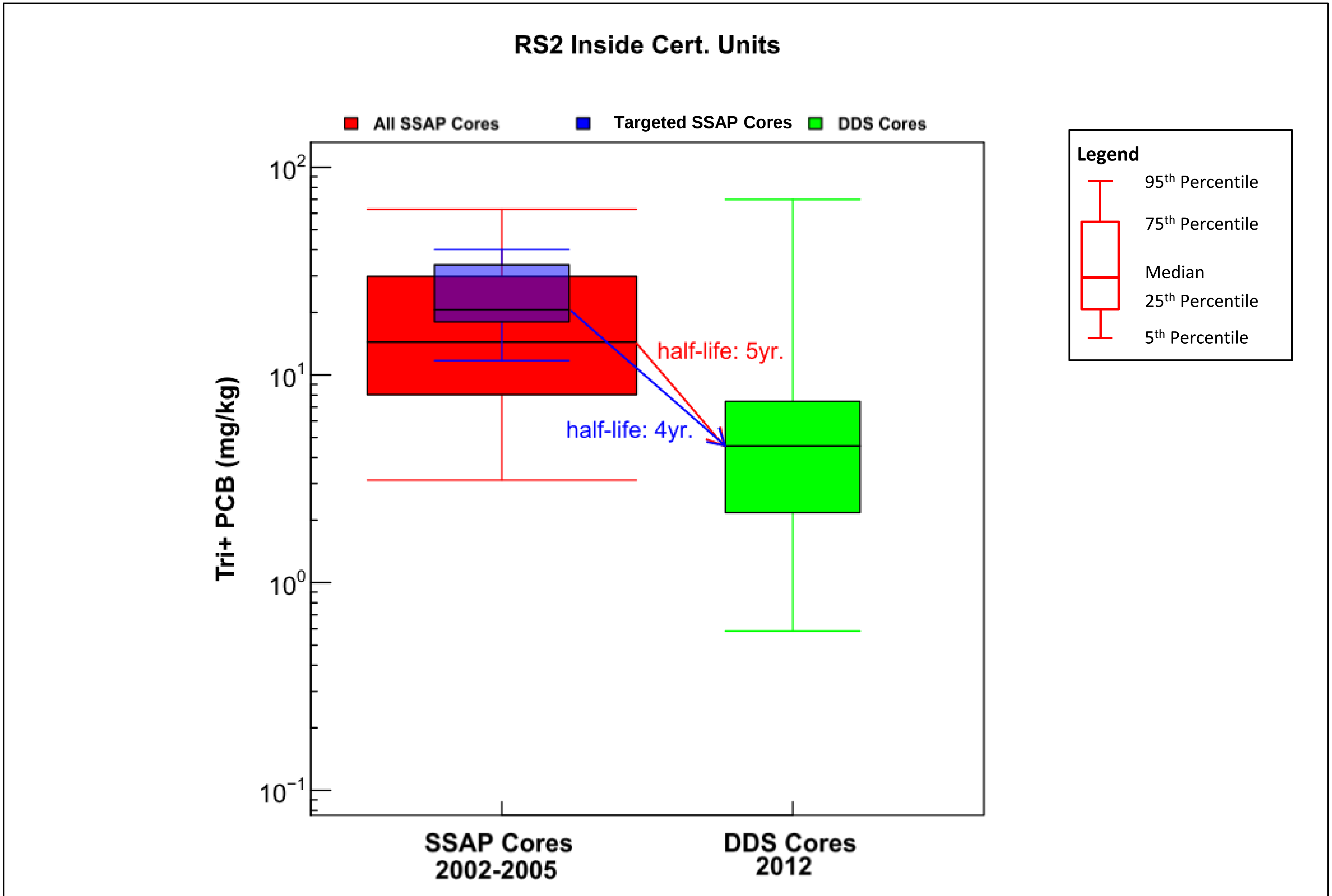
May 2017




Comparison between SSAP and DDS Data
River Section 1 Outside Certification Units

Figure A4-5

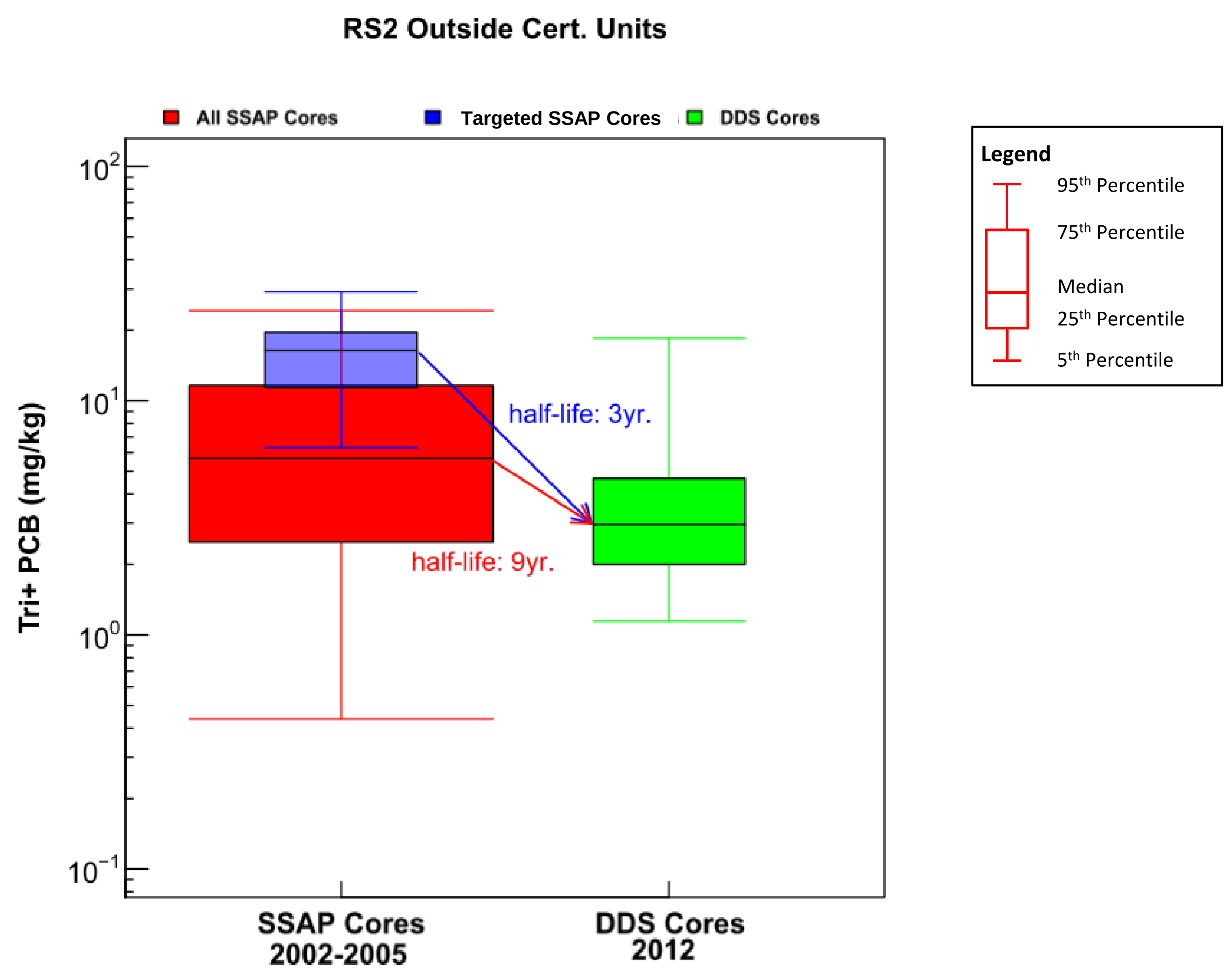
May 2017




Comparison between SSAP and DDS Data
River Section 2 Inside Certification Units

Figure A4-6

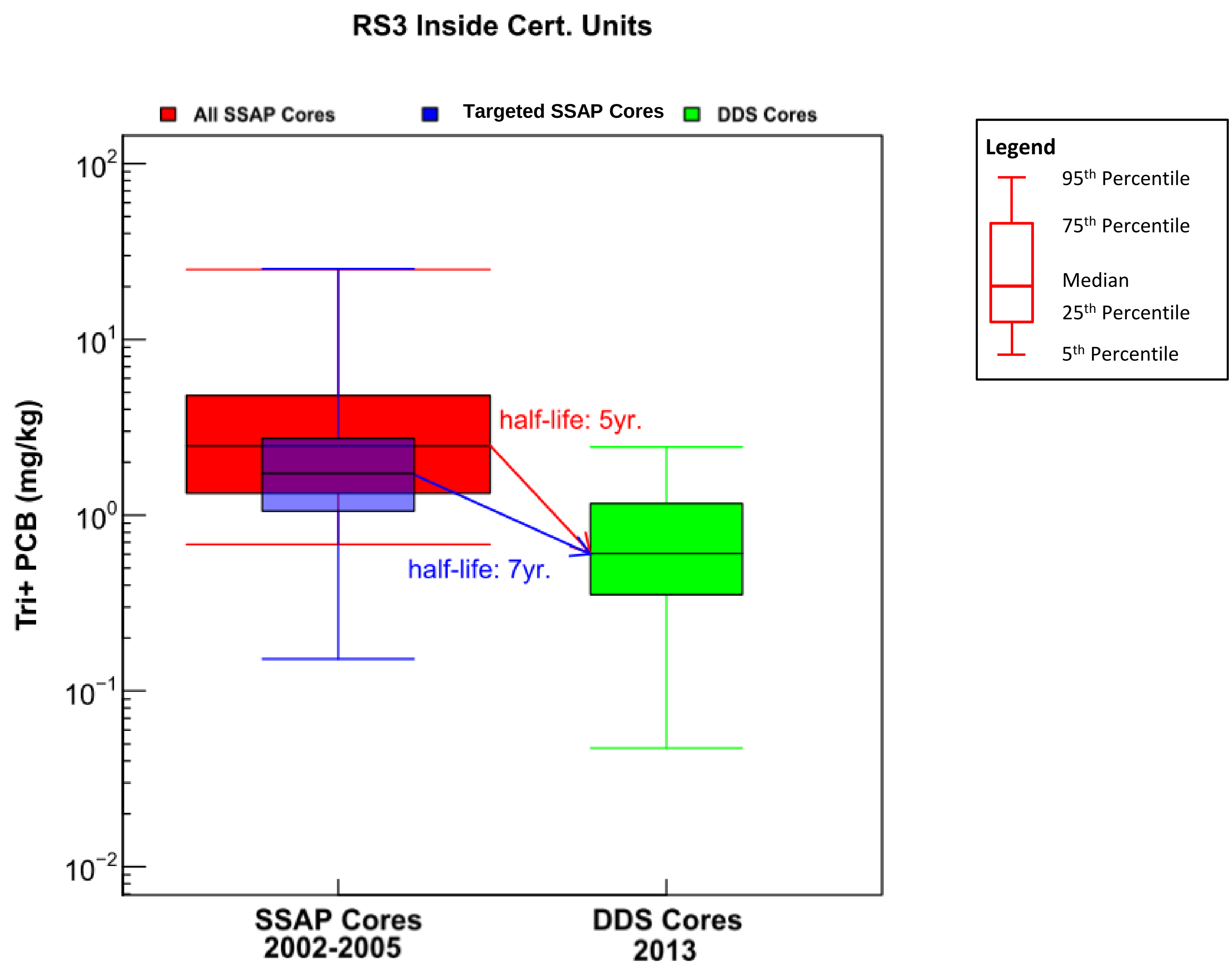
May 2017




Comparison between SSAP and DDS Data
River Section 2 Outside Certification Units

Figure A4-7

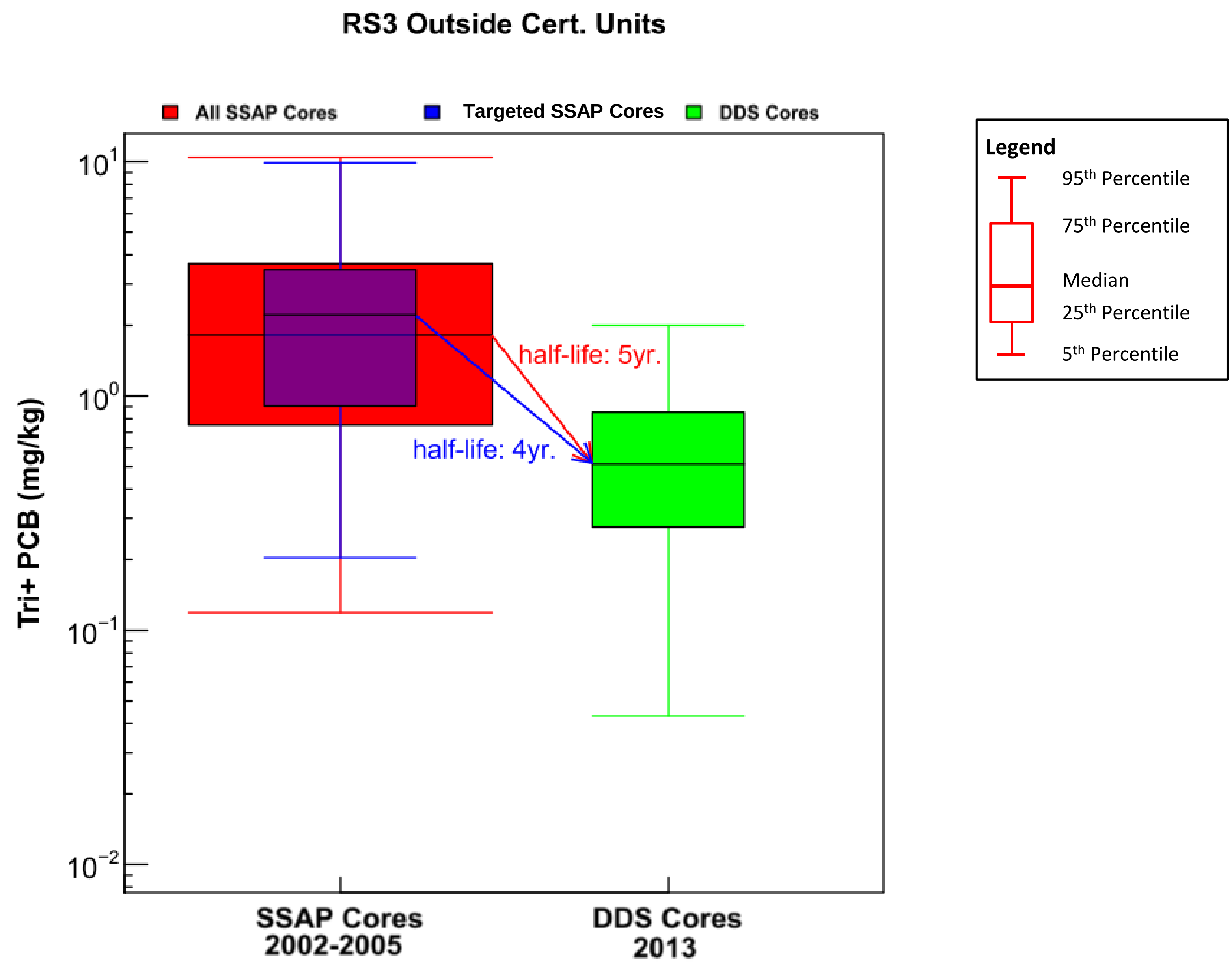
May 2017



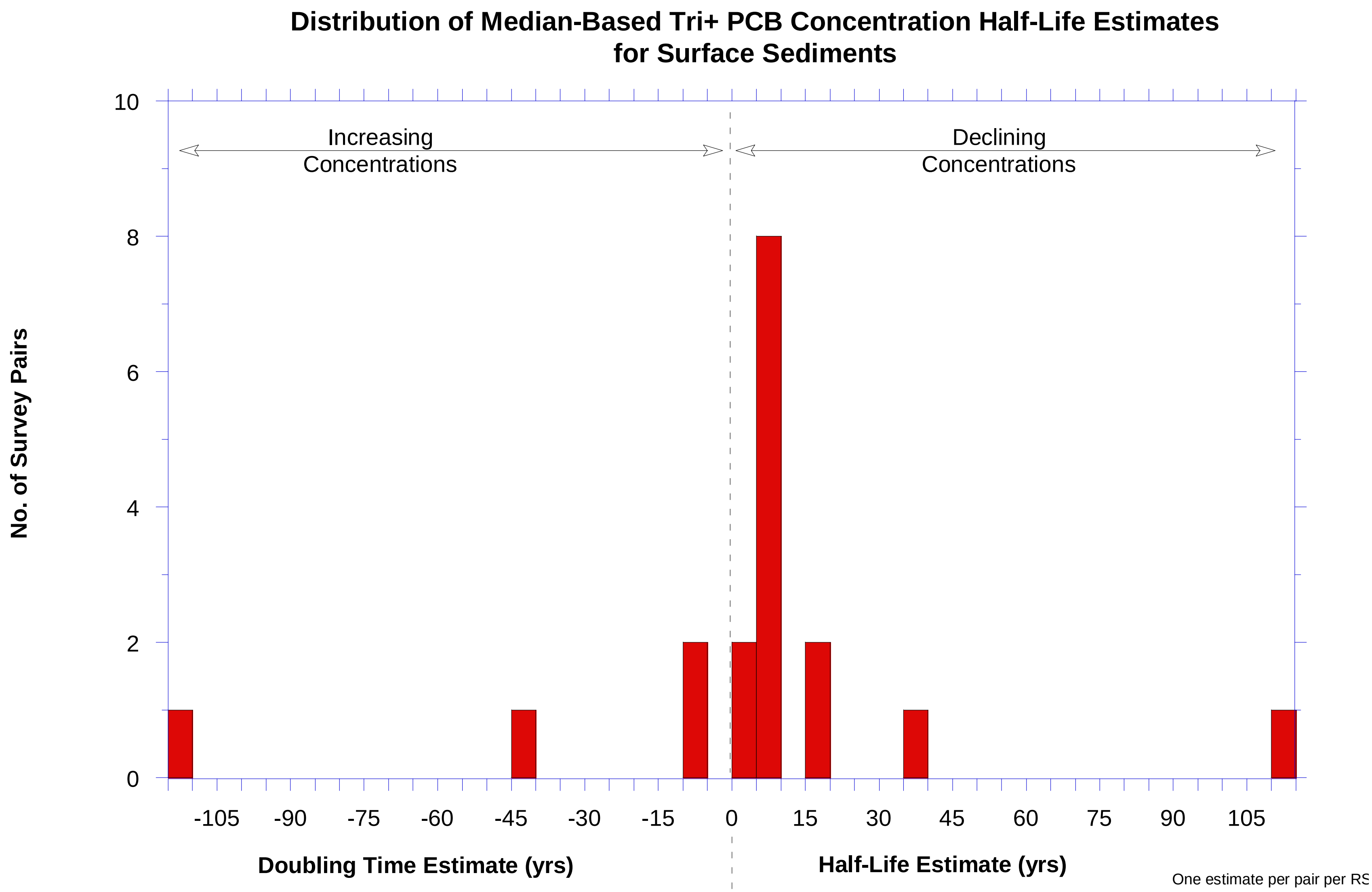

Comparison between SSAP and DDS Data
River Section 3 Inside Certification Units

Figure A4-8

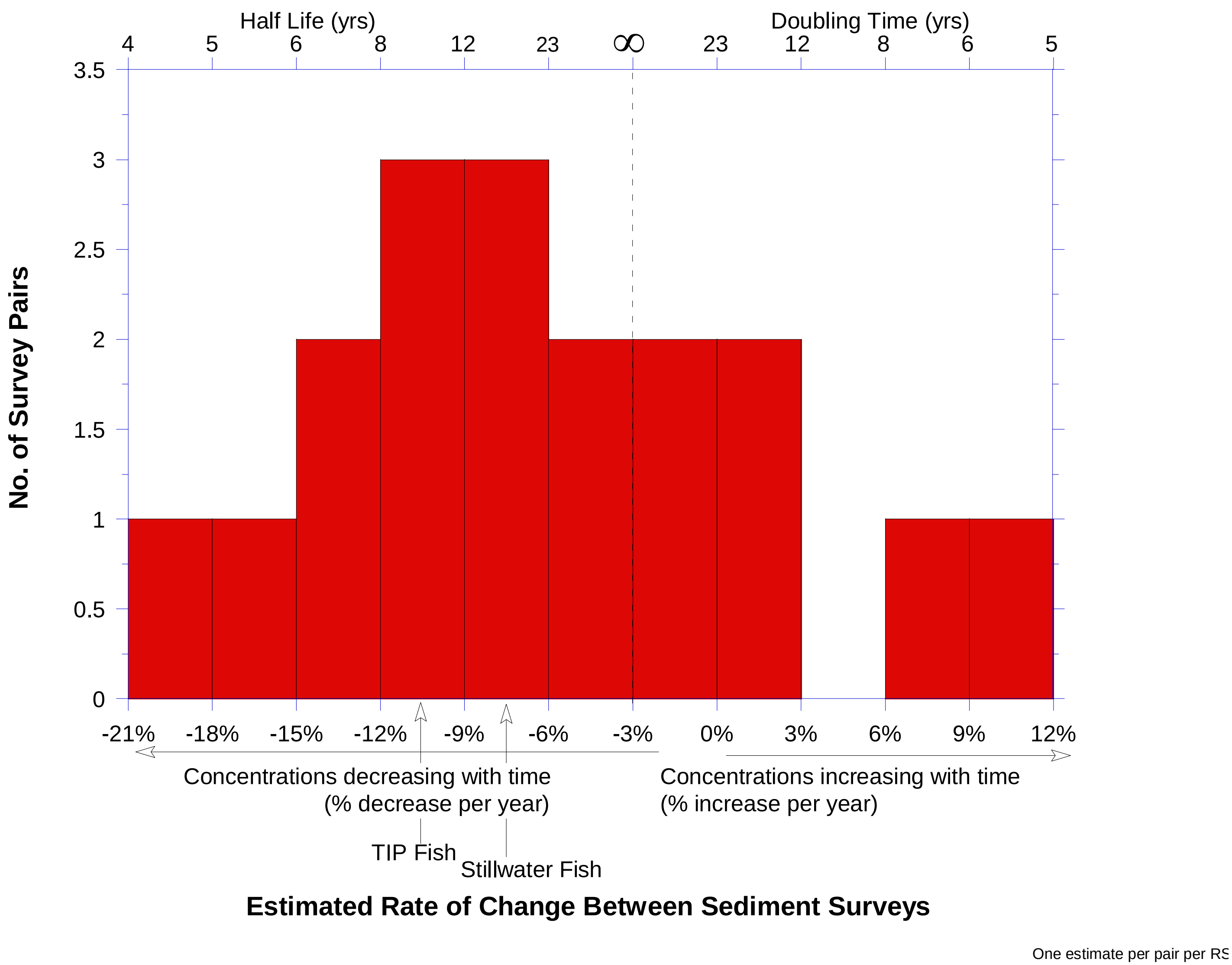
May 2017




| | | |
|---|---|---|
| | Comparison between SSAP and DDS Data<br>River Section 3 Outside Certification Units | Figure A4-9<br>May 2017 |



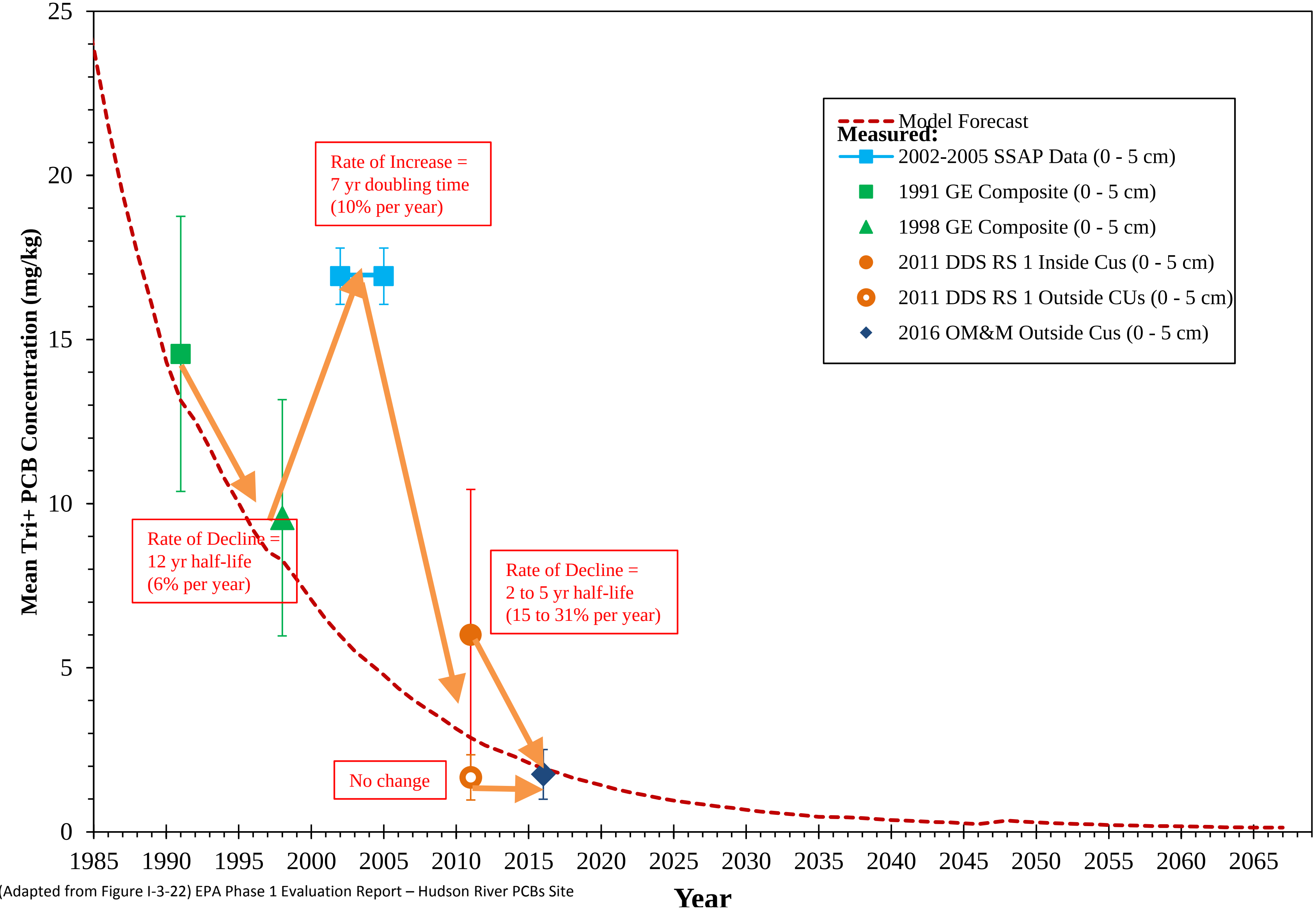

| | | |
|---|---|---|
| | Sediment Half Life Histogram | Figure A4-10 |
| | | May 2017 |




Rate of Sediment Change Histogram

Figure A4-11

May 2017

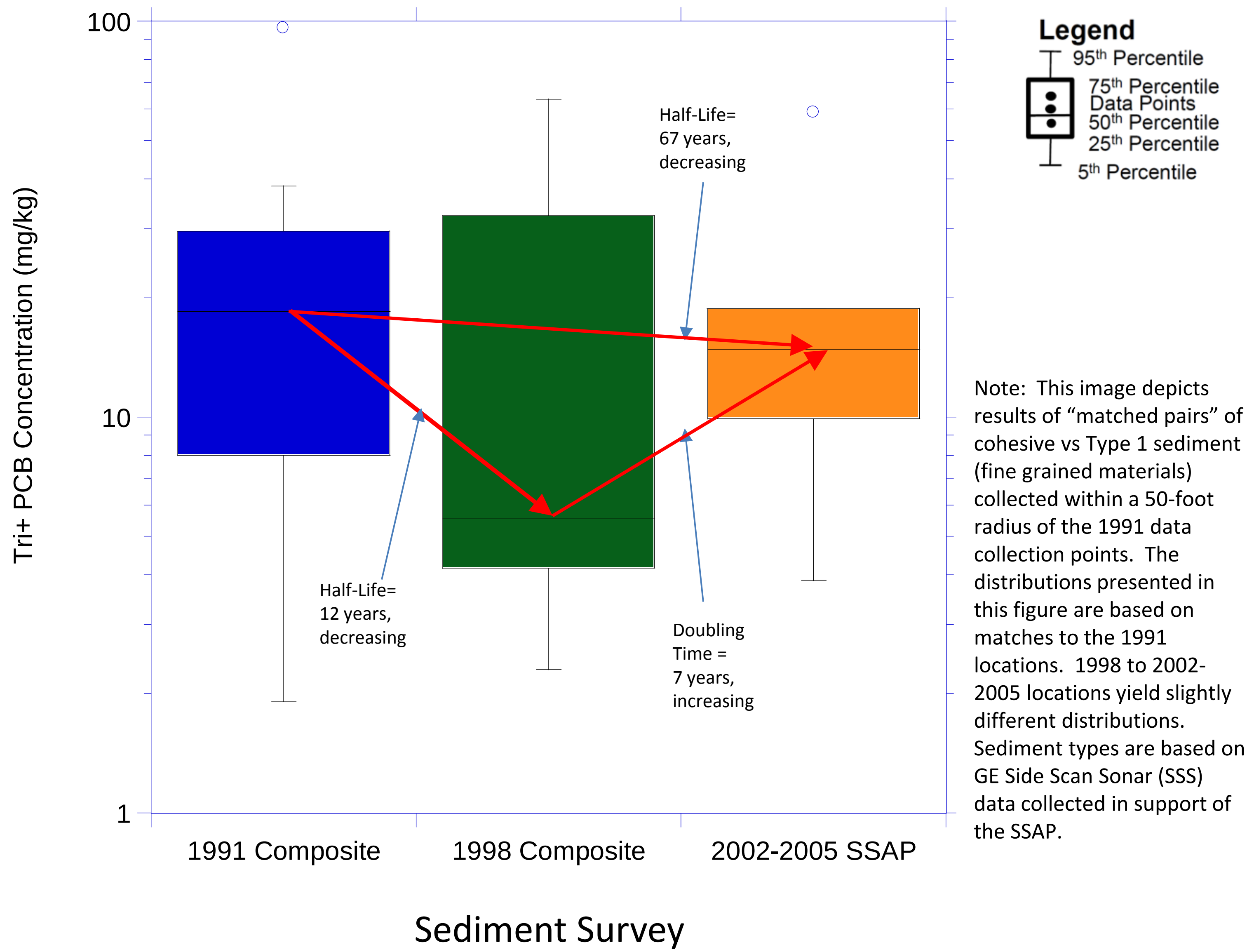



(Adapted from Figure I-3-22) EPA Phase 1 Evaluation Report – Hudson River PCBs Site

HUDTOX Model and Core Data Comparison All Sediment Types
Thompson Island Pool

Figure A4-12

May 2017

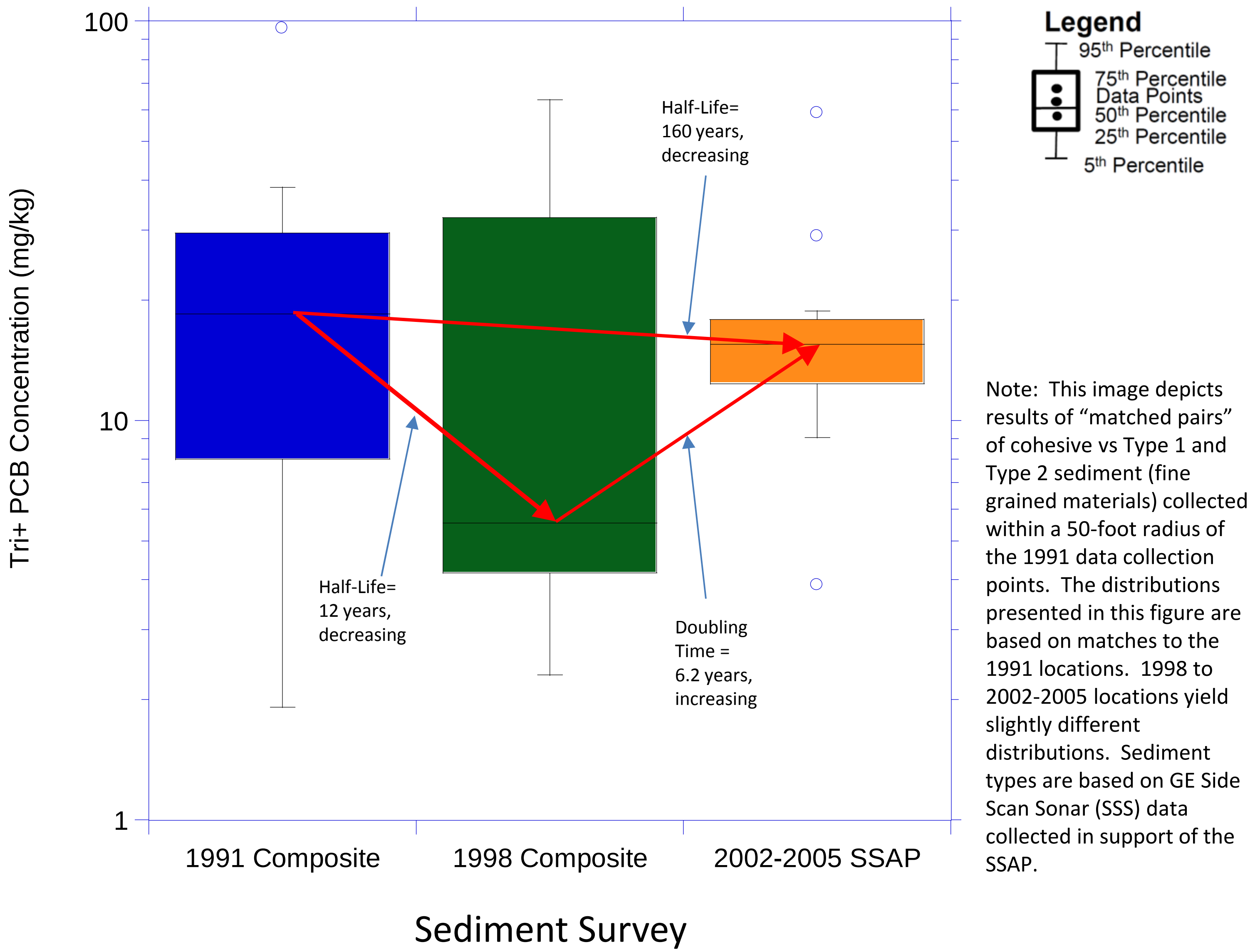



Note: This image depicts results of "matched pairs" of cohesive vs Type 1 sediment (fine grained materials) collected within a 50-foot radius of the 1991 data collection points. The distributions presented in this figure are based on matches to the 1991 locations. 1998 to 2002-2005 locations yield slightly different distributions. Sediment types are based on GE Side Scan Sonar (SSS) data collected in support of the SSAP.

Comparison between 1991 Composite, 1998 Composite and 2002-2005 SSAP Surface Sediment Data (GE SSS Type 1 as Fine Material)

Figure A4-13

May 2017

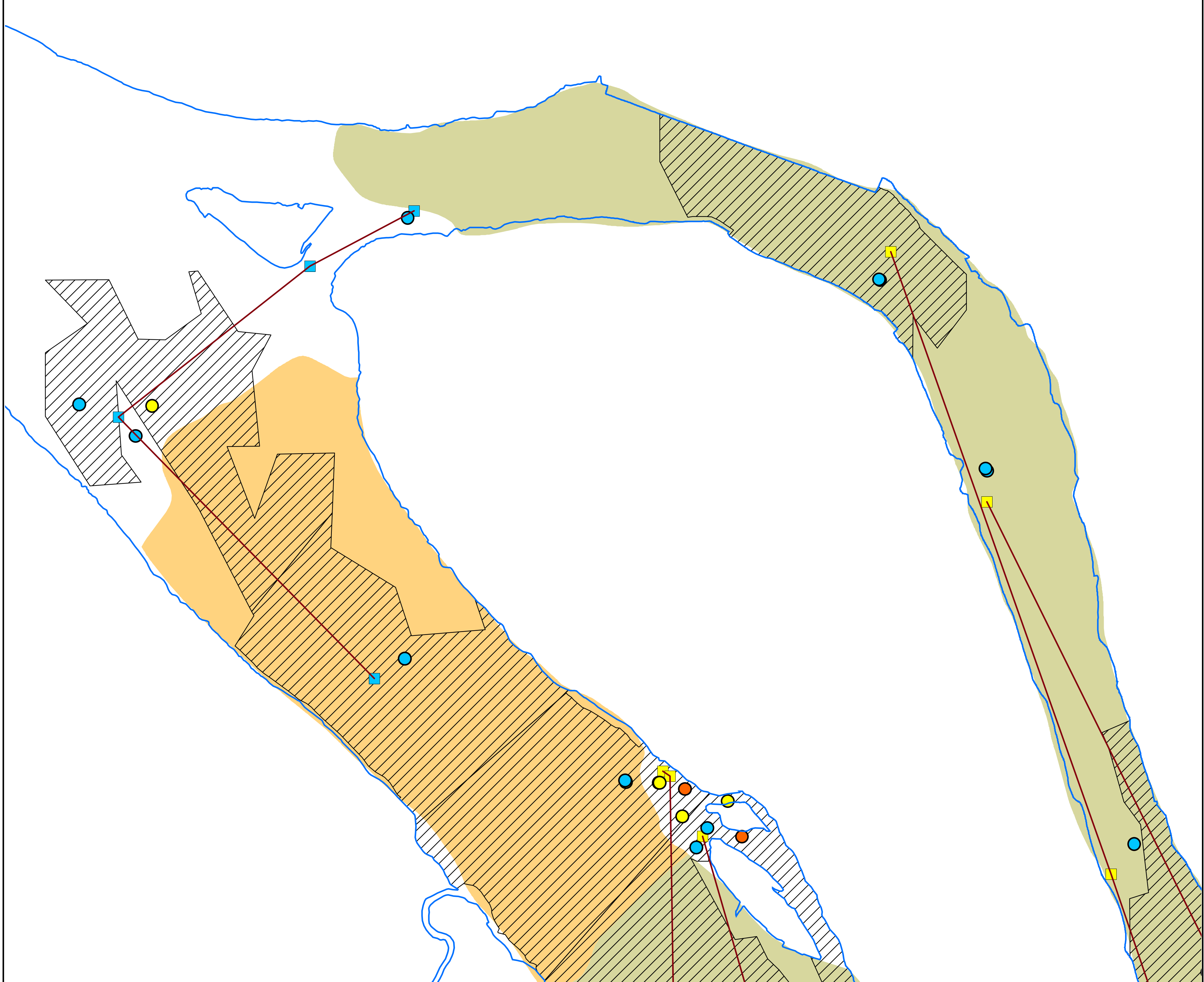



Note: This image depicts results of "matched pairs" of cohesive vs Type 1 and Type 2 sediment (fine grained materials) collected within a 50-foot radius of the 1991 data collection points. The distributions presented in this figure are based on matches to the 1991 locations. 1998 to 2002-2005 locations yield slightly different distributions. Sediment types are based on GE Side Scan Sonar (SSS) data collected in support of the SSAP.

Comparison between 1991 Composite, 1998 Composite and 2002-2005 SSAP Surface Sediment Data (GE SSS Type 1 & 2 as Fine Material)

Figure A4-14

May 2017



**LEGEND**

- Composite Nodes Line
- Shoreline
- Dredge Boundary

**Surface (0-2 inch) Tri+ PCB Conc. (ppm)**

- 0.0-3.0
- 3.1-10.0
- 10.1-30.0
- 30.1-100.0
- >100.0

**SSS Sediment Type**
**type**

- Silt
- Silt and Sand
- Gravel
- Transitional
- Bed Rock

**CLASSIFICATION**

- ● 2002-2005 SSAP Cores
- ■ GE 1991 Composite

N

250 125 0 250 Feet

Hudson River PCBs SUPERFUND SITE

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# 2002 TO 2005 SSAP CORES WITHIN 100 FEET OF 1991 COMPOSITE NODES

Figure A4-15a

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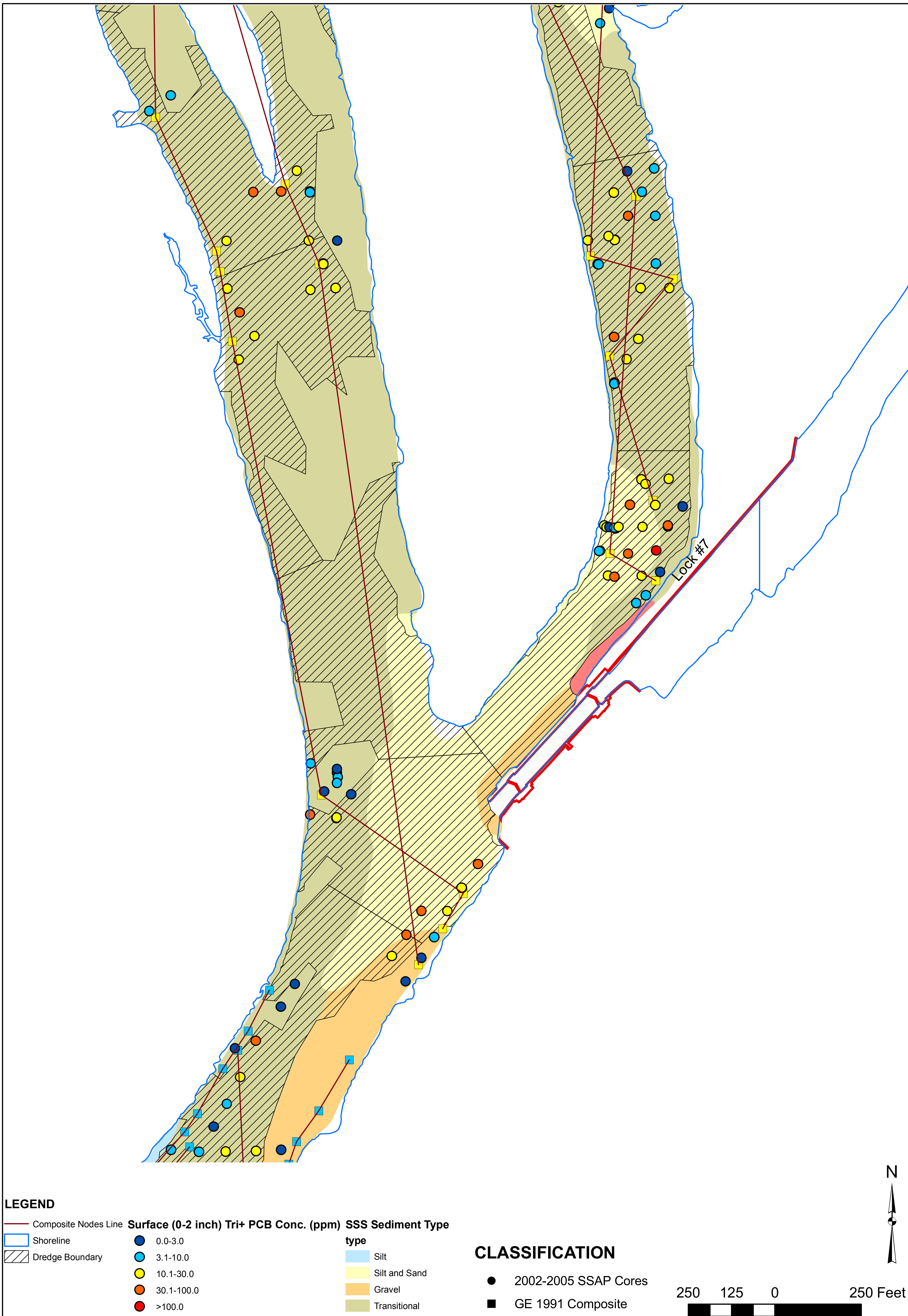


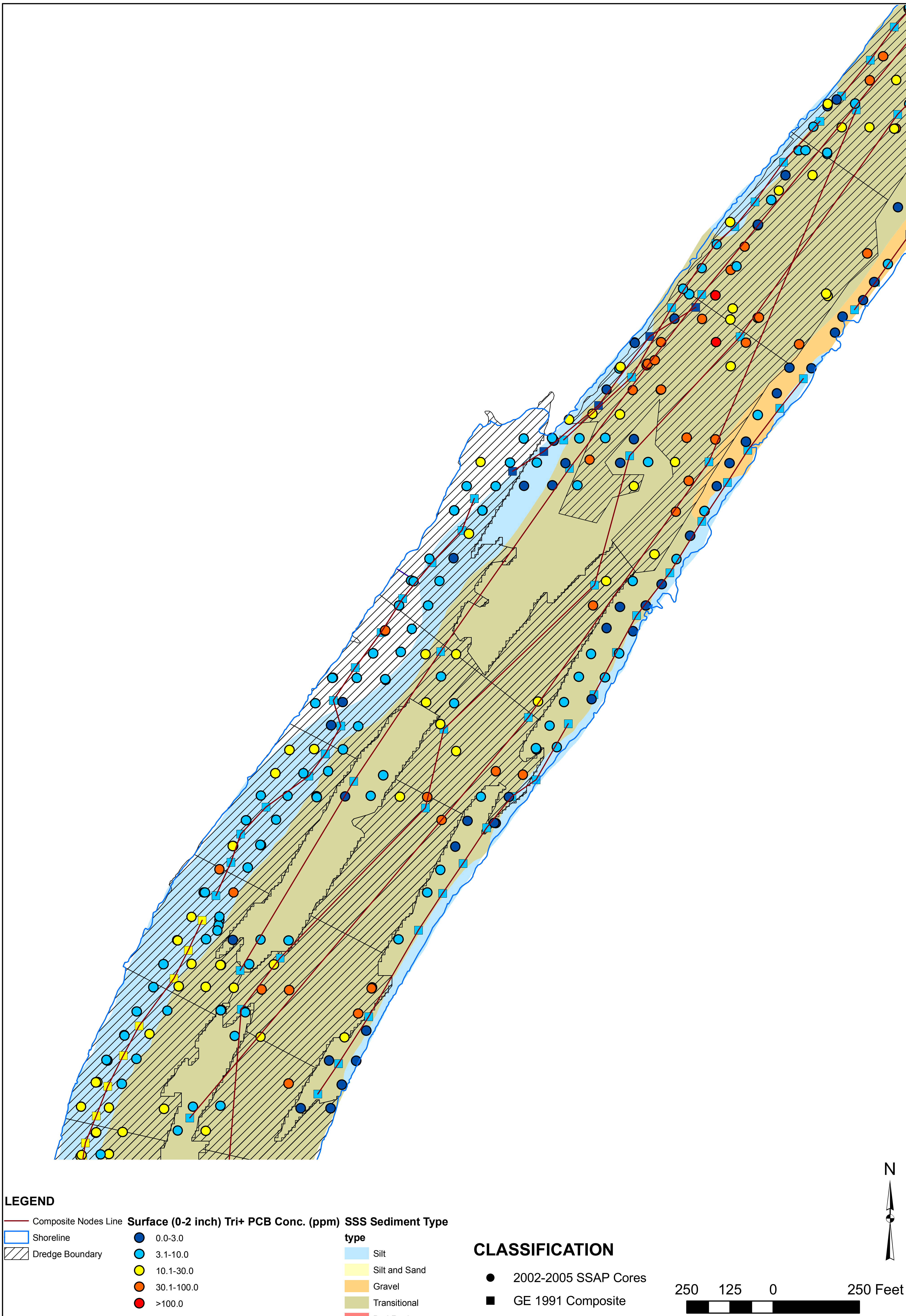





# 2002 TO 2005 SSAP CORES WITHIN 100 FEET OF 1991 COMPOSITE NODES

Figure A4-15b

May 2017




# 2002 TO 2005 SSAP CORES WITHIN 100 FEET OF 1991 COMPOSITE NODES

Figure A4-15c

May 2017

Hudson River PCBs SUPERFUND SITE

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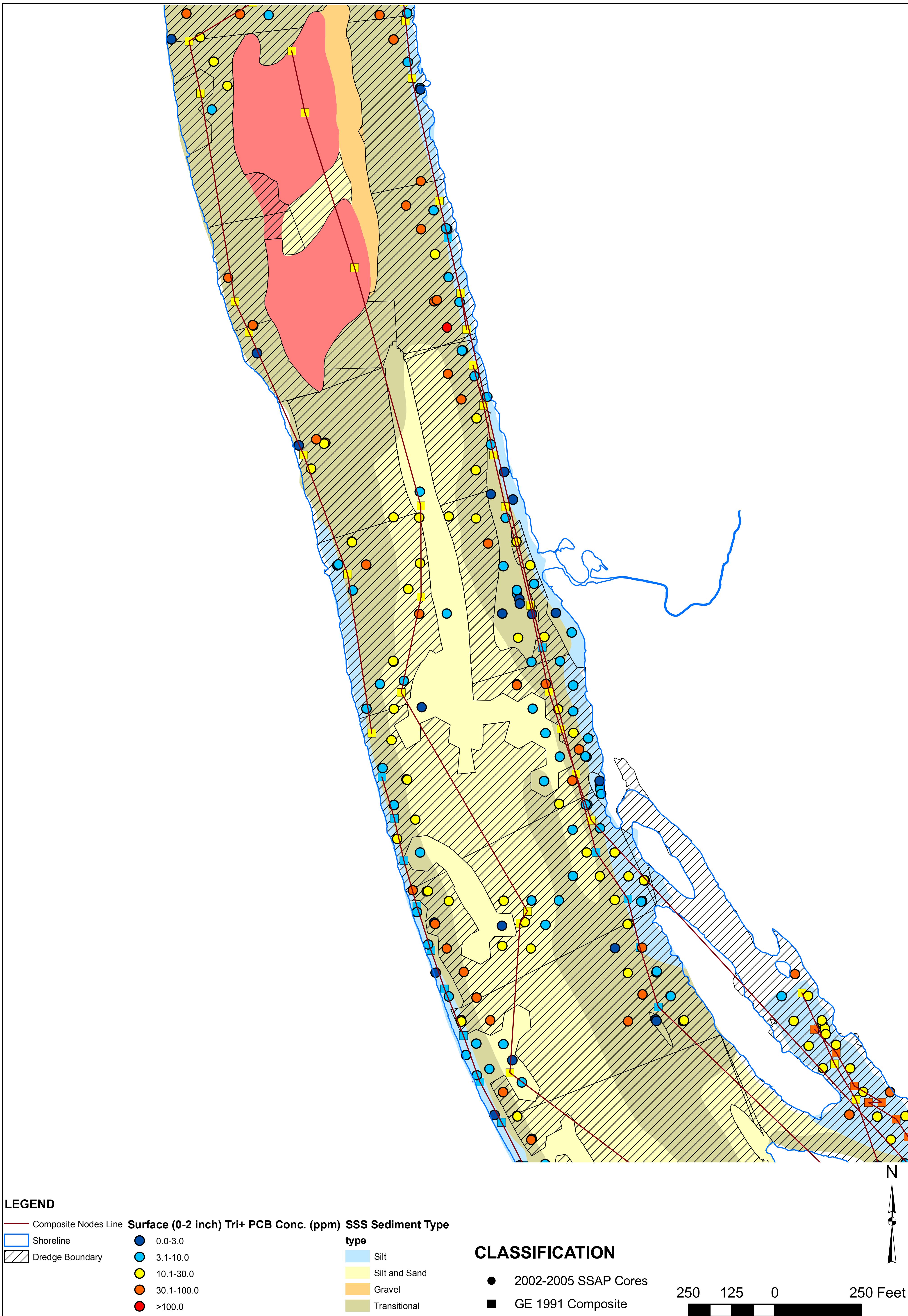
United States Environmental Protection Agency

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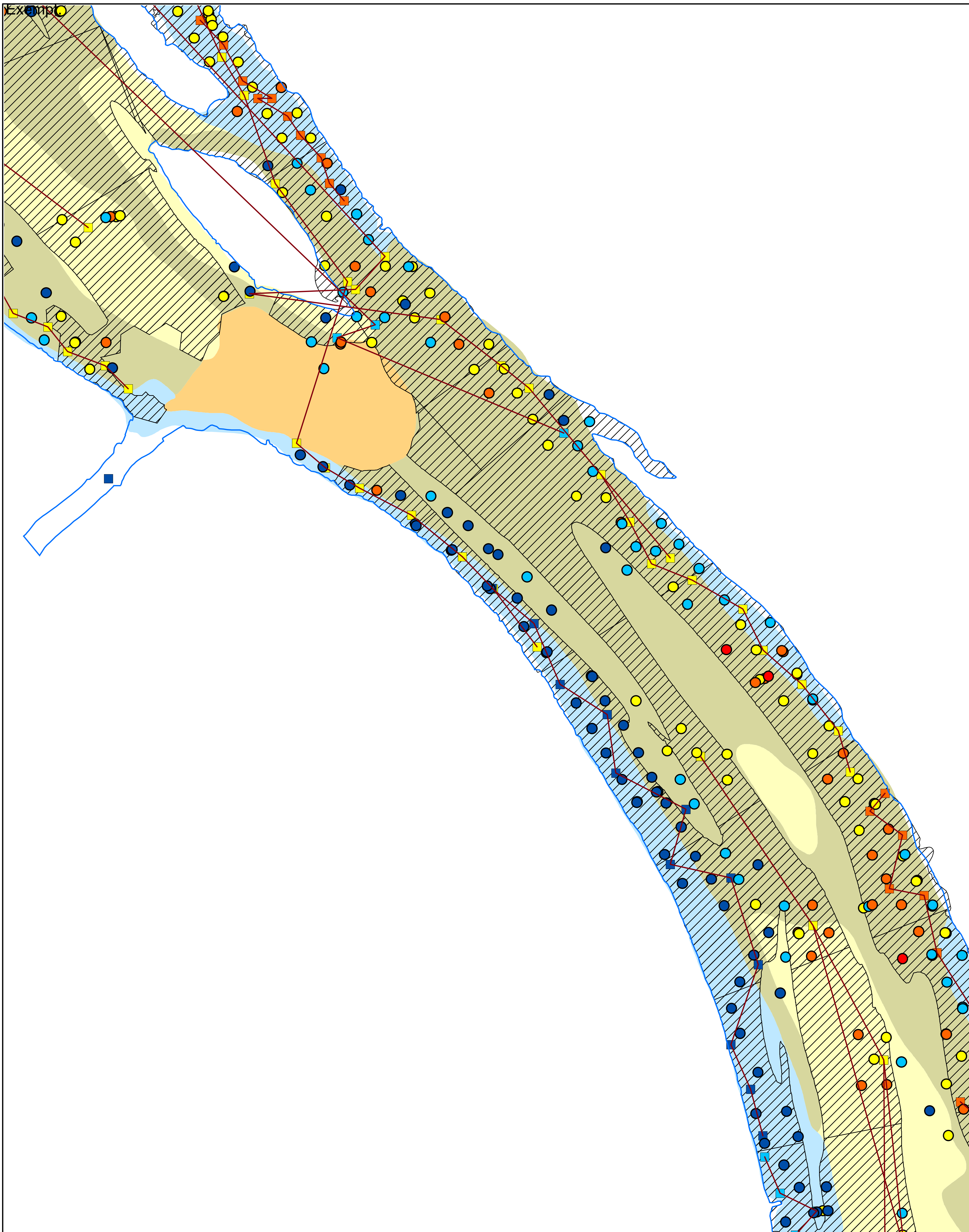
Hudson River PCBs Superfund Site
Region 2: NJ, NY, PR, VI • 290 Broadway, New York, NY 10007

# 2002 TO 2005 SSAP CORES WITHIN 100 FEET OF 1991 COMPOSITE NODES

Figure A4-15d

May 2017




N

**LEGEND**

Composite Nodes Line
Shoreline
Dredge Boundary

**Surface (0-2 inch) Tri+ PCB Conc. (ppm)**
0.0-3.0
3.1-10.0
10.1-30.0
30.1-100.0
>100.0

**SSS Sediment Type**
**type**
Silt
Silt and Sand
Gravel
Transitional
Bed Rock

**CLASSIFICATION**
● 2002-2005 SSAP Cores
■ GE 1991 Composite

250 125 0 250 Feet

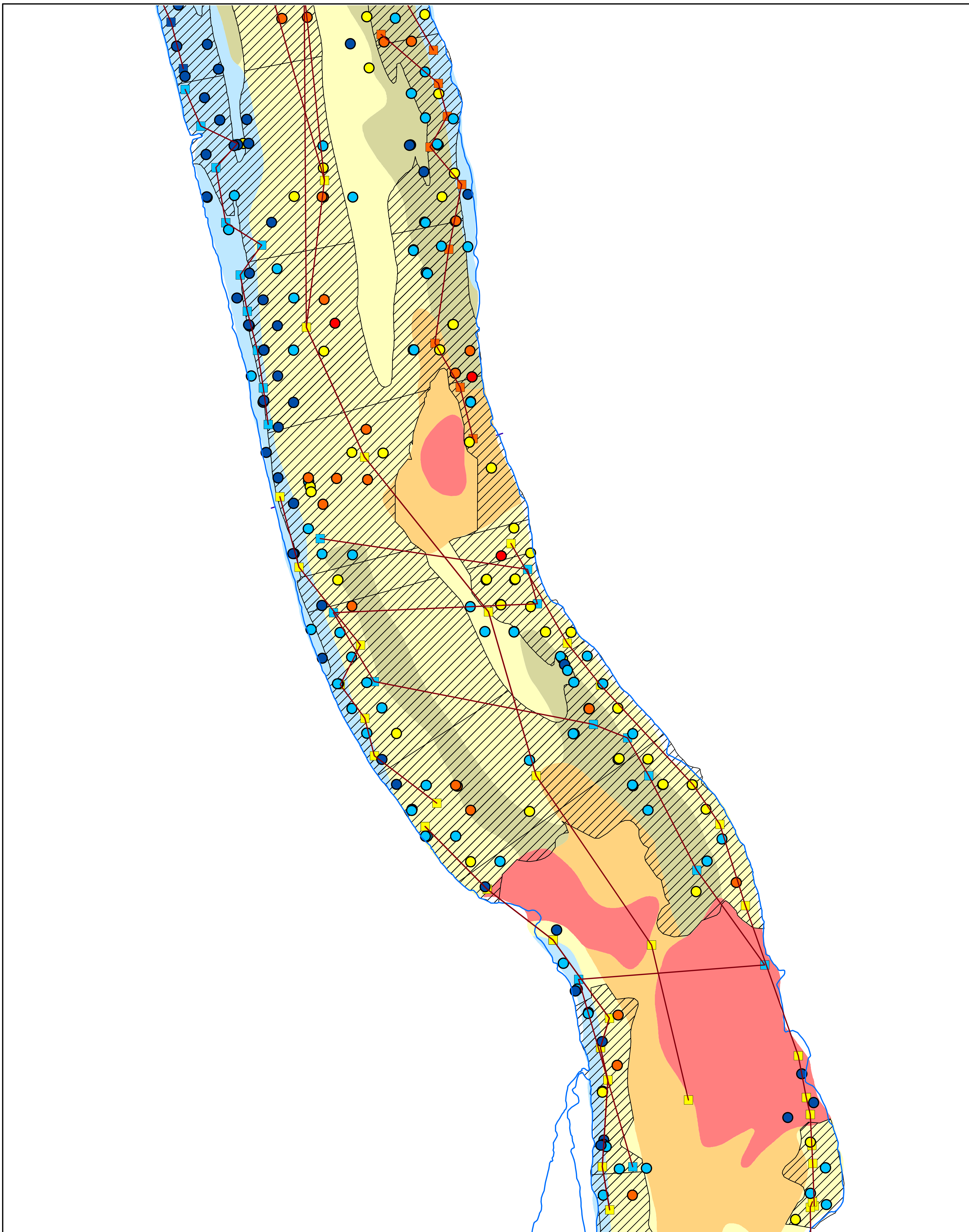
Hudson River PCBs SUPERFUND SITE
Region 2: NJ, NY, PR, VI • 290 Broadway, New York, NY 10007

# 2002 TO 2005 SSAP CORES WITHIN 100 FEET OF 1991 COMPOSITE NODES

Figure A4-15e

May 2017

Map Document: (M:\02859191\GIS\Phase1Evaluation\GE_Composite91_98_SSAPCores.mxd) 8/18/2010 -- 4:50:17 PM



**LEGEND**

- Composite Nodes Line
- Shoreline
- Dredge Boundary

**Surface (0-2 inch) Tri+ PCB Conc. (ppm)**

- 0.0-3.0
- 3.1-10.0
- 10.1-30.0
- 30.1-100.0
- >100.0

**SSS Sediment Type**
**type**

- Silt
- Silt and Sand
- Gravel
- Transitional
- Bed Rock

**CLASSIFICATION**

- ● 2002-2005 SSAP Cores
- ■ GE 1991 Composite

N

250 125 0 250 Feet

Hudson River
PCBs SUPERFUND SITE
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# 2002 TO 2005 SSAP CORES WITHIN 100 FEET OF 1991 COMPOSITE NODES

Figure A4-15f

May 2017

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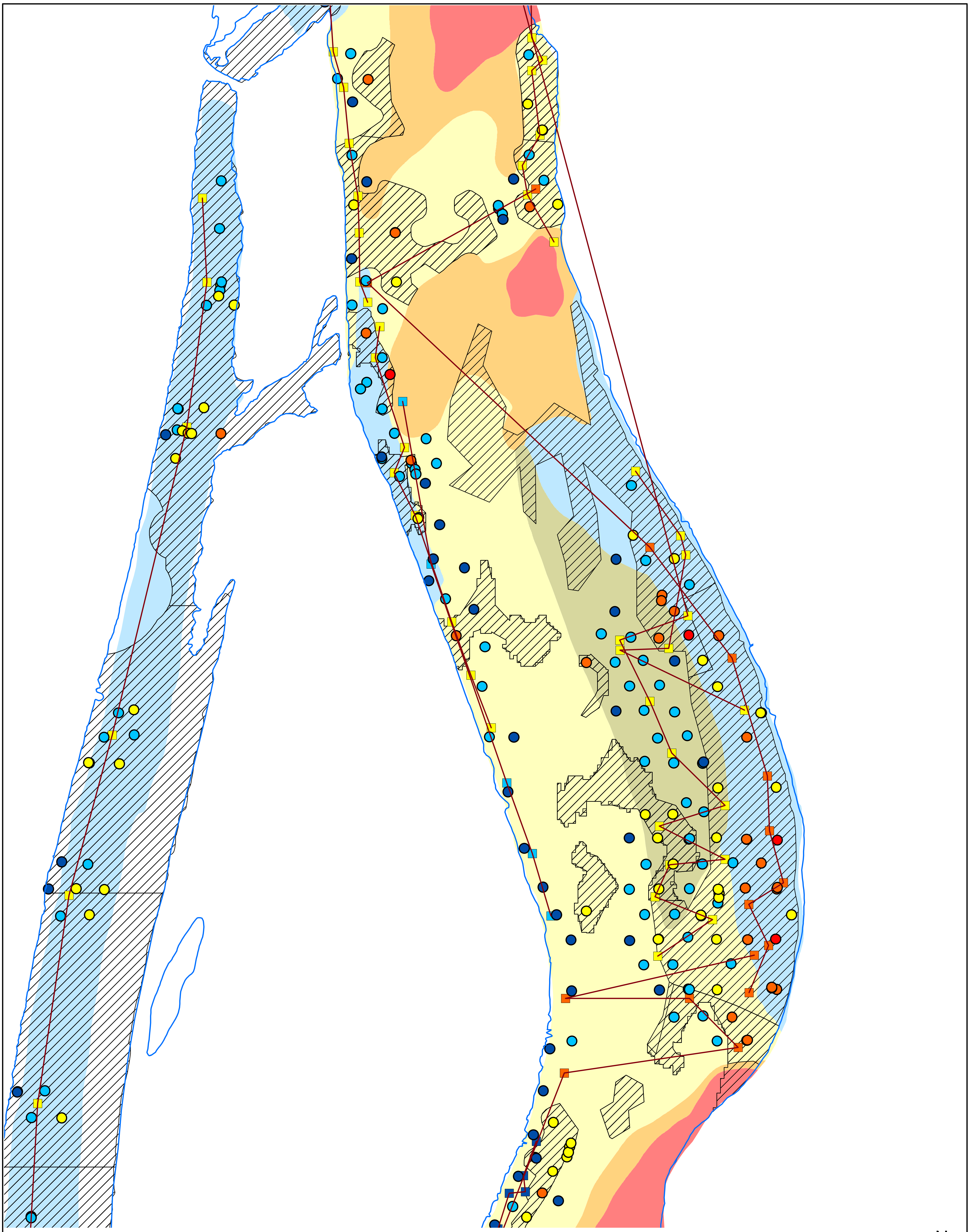



**LEGEND**

Composite Nodes Line

Shoreline

Dredge Boundary

**Surface (0-2 inch) Tri+ PCB Conc. (ppm)**

- 0.0-3.0
- 3.1-10.0
- 10.1-30.0
- 30.1-100.0
- >100.0

**SSS Sediment Type type**

- Silt
- Silt and Sand
- Gravel
- Transitional
- Bed Rock

**CLASSIFICATION**

- 2002-2005 SSAP Cores
- GE 1991 Composite

Hudson River PCBs SUPERFUND SITE

Region 2: NJ, NY, PR, VI • 290 Broadway, New York, NY 10007

# 2002 TO 2005 SSAP CORES WITHIN 100 FEET OF 1991 COMPOSITE NODES

Figure A4-15g

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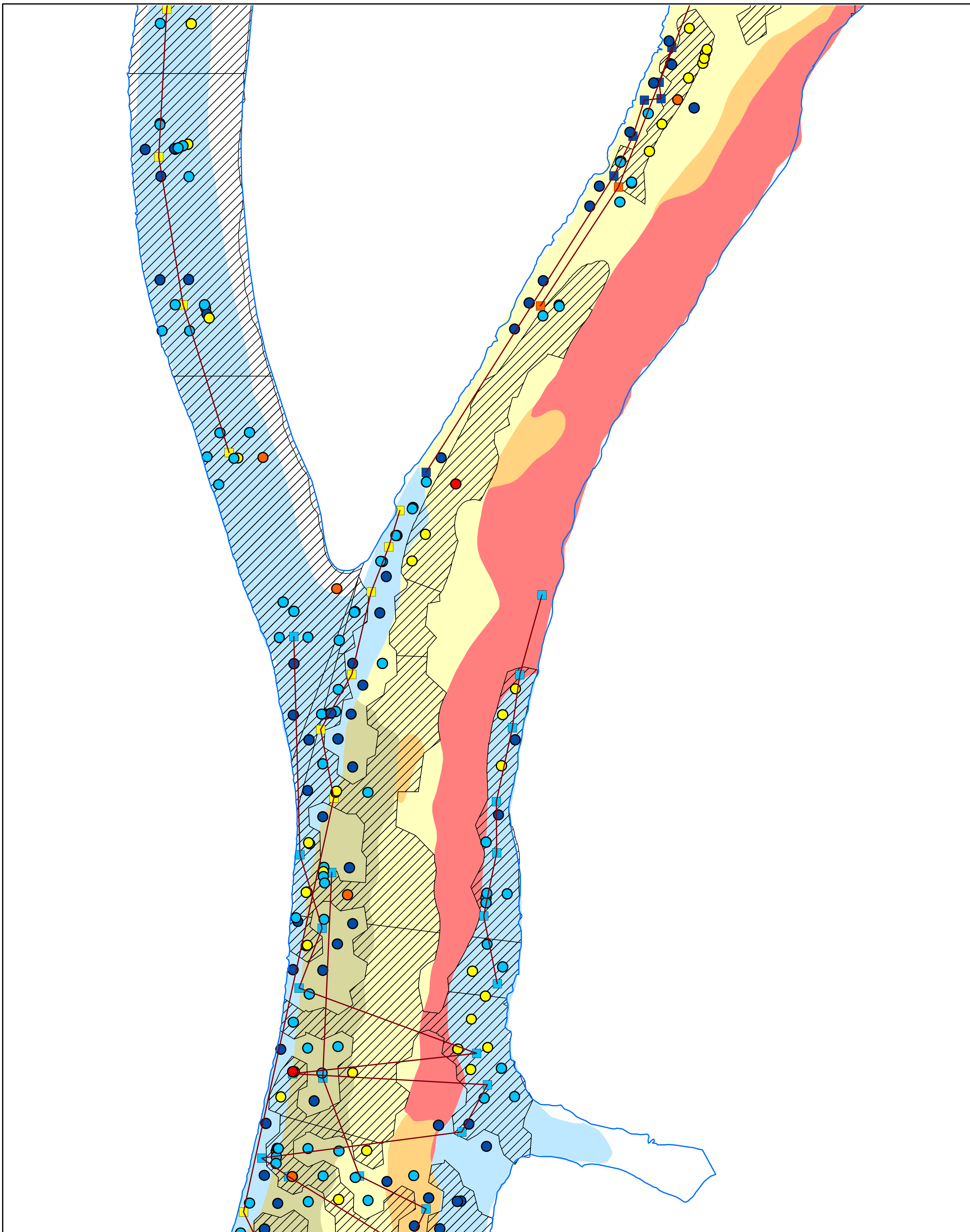
Map Document: (M:\02859191\GIS\Phase1Evaluation\GE_Composite91_98_SSAPCores.mxd) 8/18/2010 -- 4:50:17 PM



**LEGEND**

Composite Nodes Line
Shoreline
Dredge Boundary

**Surface (0-2 inch) Tri+ PCB Conc. (ppm)**
- 0.0-3.0
- 3.1-10.0
- 10.1-30.0
- 30.1-100.0
- >100.0

**SSS Sediment Type type**
- Silt
- Silt and Sand
- Gravel
- Transitional
- Bed Rock

**CLASSIFICATION**
- 2002-2005 SSAP Cores
- GE 1991 Composite

N

250 125 0 250 Feet

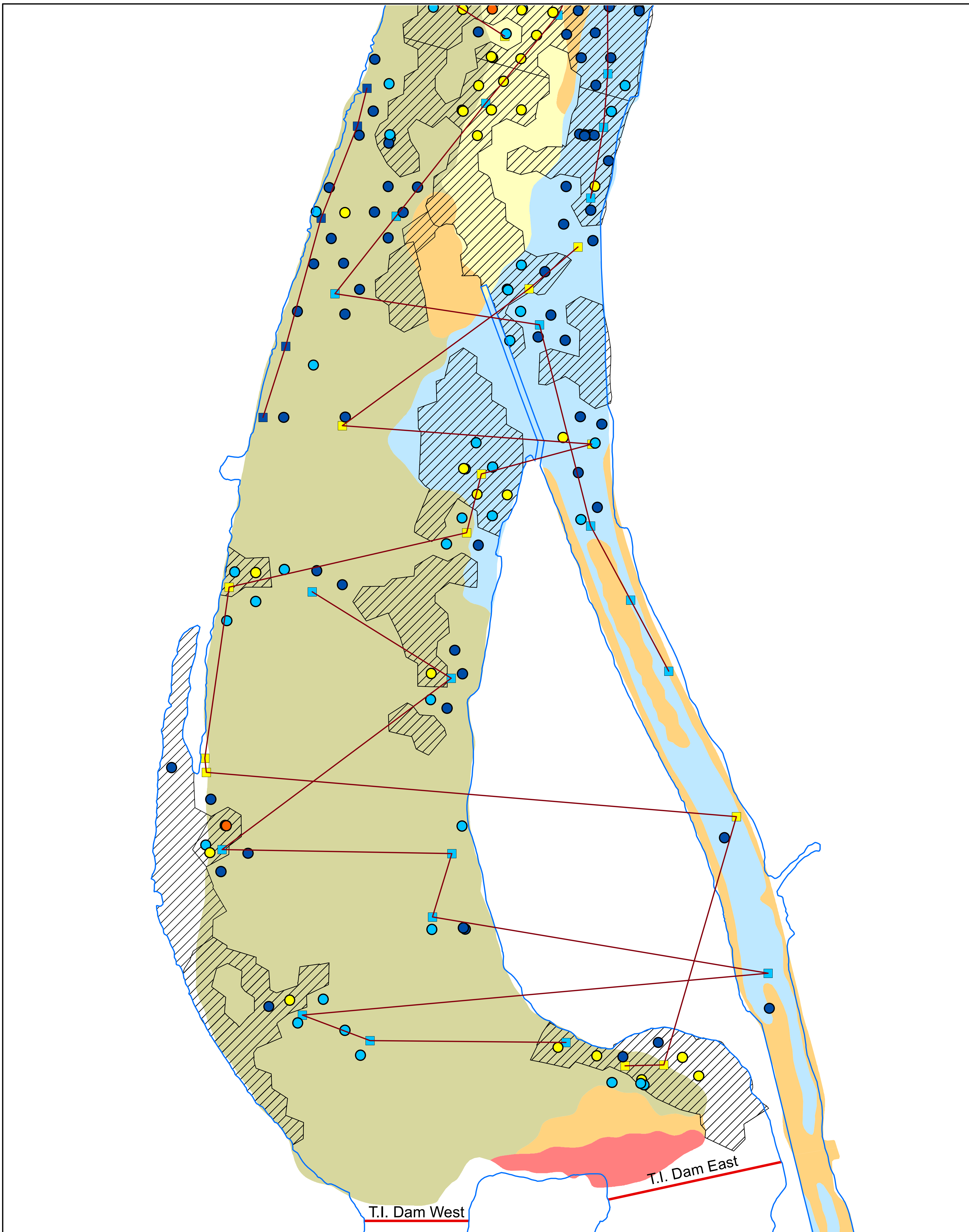
Hudson River PCBs SUPERFUND SITE
Region 2: NJ, NY, PR, VI • 290 Broadway, New York, NY 10007

# 2002 TO 2005 SSAP CORES WITHIN 100 FEET OF 1991 COMPOSITE NODES

Figure A4-15h

May 2017

Map Document: (M:\0285919\GIS\Phase1Evaluation\GE_Composite91_98_SSAPCores.mxd) 8/18/2010 -- 4:50:17 PM




**LEGEND**

- Composite Nodes Line
- Shoreline
- Dredge Boundary

**Surface (0-2 inch) Tri+ PCB Conc. (ppm)**

- 0.0-3.0
- 3.1-10.0
- 10.1-30.0
- 30.1-100.0
- >100.0

**SSS Sediment Type type**

- Silt
- Silt and Sand
- Gravel
- Transitional
- Bed Rock

**CLASSIFICATION**

- 2002-2005 SSAP Cores
- GE 1991 Composite

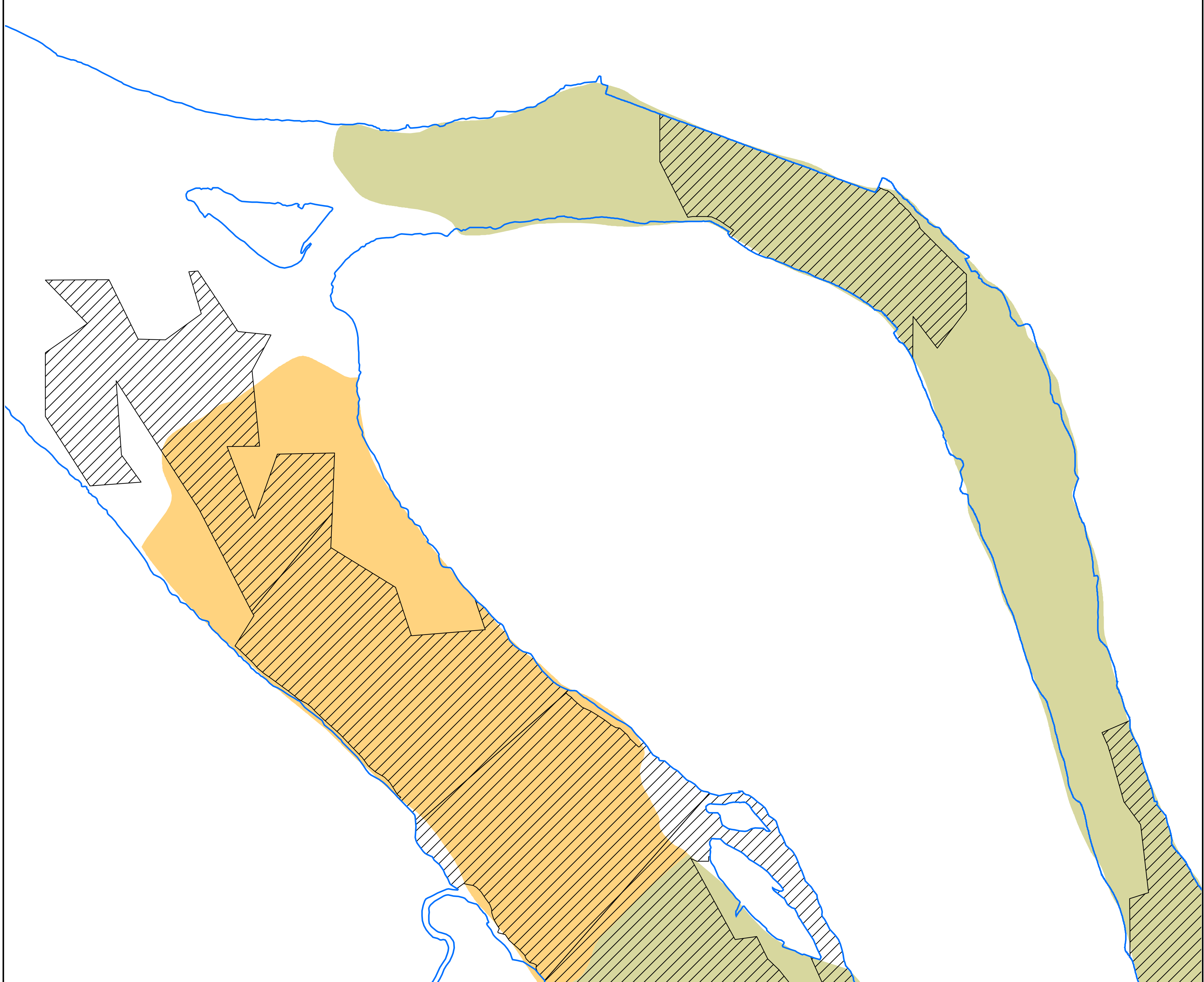
Hudson River PCBs SUPERFUND SITE
Region 2: NJ, NY, PR, VI • 290 Broadway, New York, NY 10007

# 2002 TO 2005 SSAP CORES WITHIN 100 FEET OF 1991 COMPOSITE NODES

Figure A4-15i

May 2017

Map Document: (M:\02859191\GIS\Phase1Evaluation\GE_Composite91_98_SSAPCores.mxd) 8/18/2010 -- 4:50:17 PM



**LEGEND**

- Composite Nodes Line
- Shoreline
- Dredge Boundary

**Surface (0-2 inch) Tri+ PCB Conc. (ppm)**

- 0.0-3.0
- 3.1-10.0
- 10.1-30.0
- 30.1-100.0
- >100.0

**SSS Sediment Type**

**type**

- Silt
- Silt and Sand
- Gravel
- Transitional
- Bed Rock

**CLASSIFICATION**

- 2002-2005 SSAP Cores
- GE 1998 Composite

250 125 0 250 Feet

N

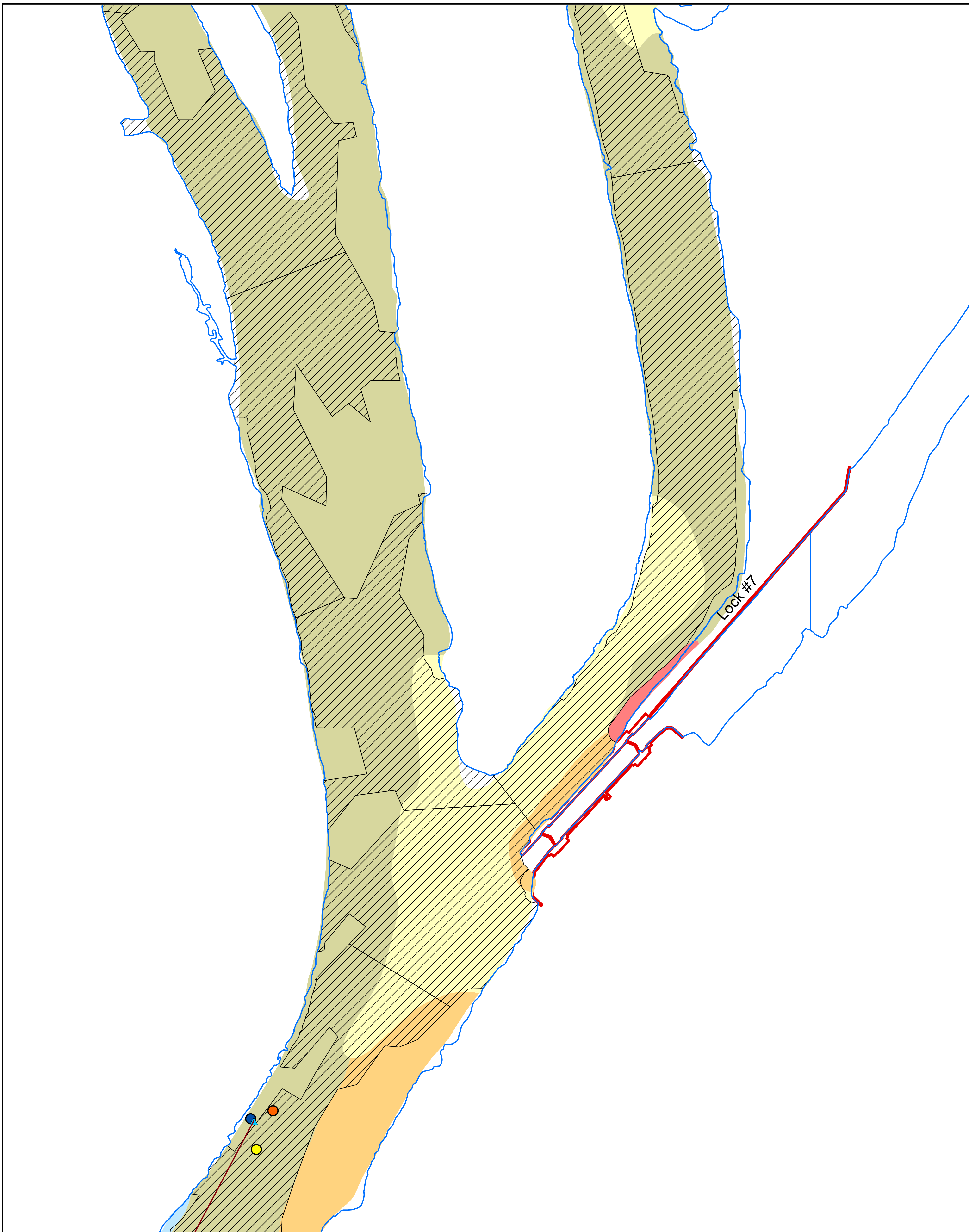
Region 2: NJ, NY, PR, VI • 290 Broadway, New York, NY 10007

# 2002 TO 2005 SSAP CORES WITHIN 100 FEET OF 1998 COMPOSITE NODES

Figure A4-16a

May 2017

Map Document: (M:\02859919\GIS\Phase1Evaluation\GE_Composite91_98_SSAPCores.mxd) 8/18/2010 -- 4:50:17 PM




**LEGEND**

Composite Nodes Line
Shoreline
Dredge Boundary

**Surface (0-2 inch) Tri+ PCB Conc. (ppm)**
- 0.0-3.0
- 3.1-10.0
- 10.1-30.0
- 30.1-100.0
- >100.0

**SSS Sediment Type type**
- Silt
- Silt and Sand
- Gravel
- Transitional
- Bed Rock

**CLASSIFICATION**
- ● 2002-2005 SSAP Cores
- ▲ GE 1998 Composite

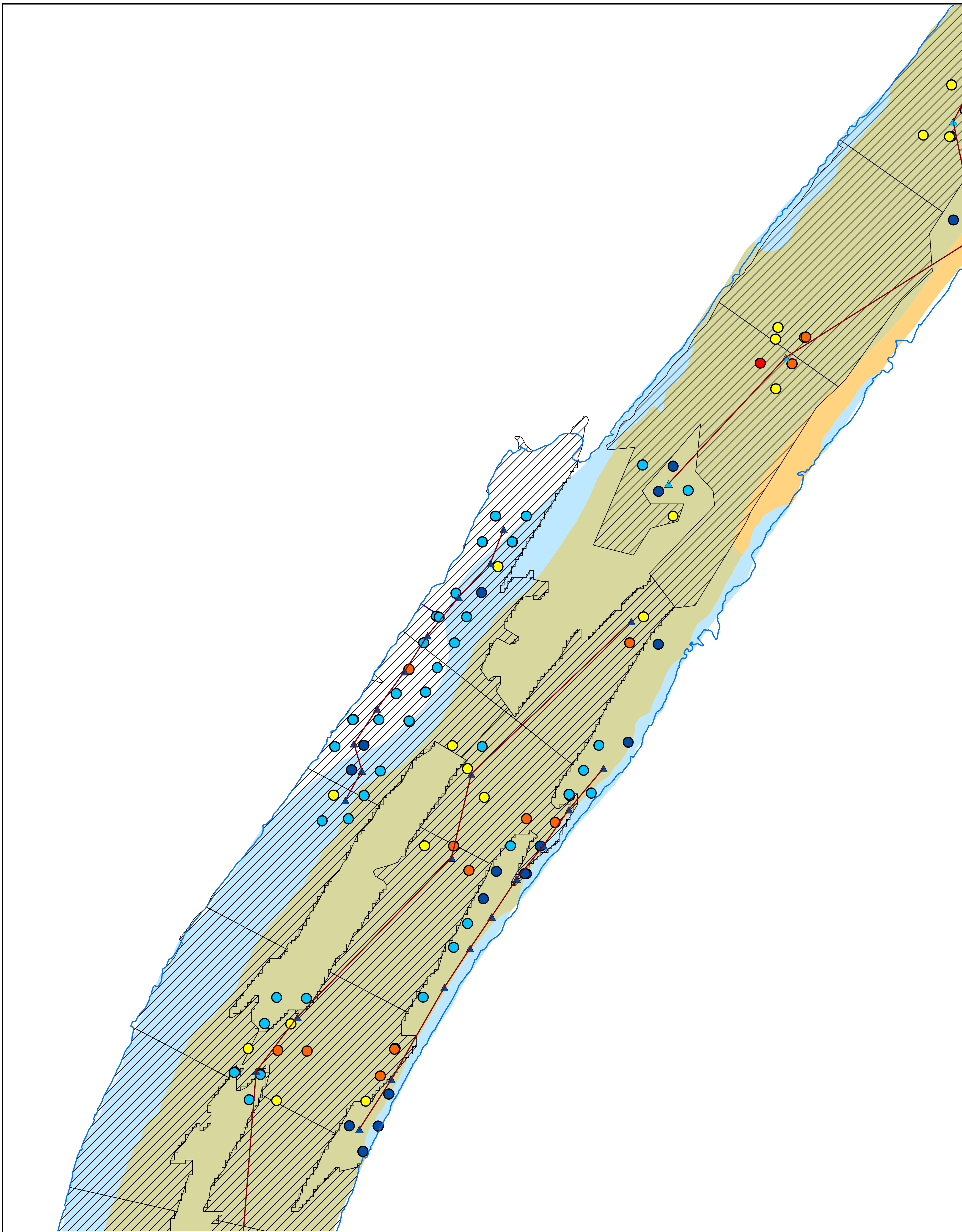
Hudson River PCBs SUPERFUND SITE
Region 2: NJ, NY, PR, VI • 290 Broadway, New York, NY 10007

# 2002 TO 2005 SSAP CORES WITHIN 100 FEET OF 1998 COMPOSITE NODES

Figure A4-16b

May 2017

Map Document: (M:\02859\19\GIS\Phase1Evaluation\GE_Composite91_98_SSAPCores.mxd) 8/18/2010 -- 4:50:17 PM



**LEGEND**

- Composite Nodes Line
- Shoreline
- Dredge Boundary

**Surface (0-2 inch) Tri+ PCB Conc. (ppm)**

- 0.0-3.0
- 3.1-10.0
- 10.1-30.0
- 30.1-100.0
- >100.0

**SSS Sediment Type**

**type**

- Silt
- Silt and Sand
- Gravel
- Transitional
- Bed Rock

**CLASSIFICATION**

- 2002-2005 SSAP Cores
- GE 1998 Composite

N

250 125 0 250 Feet

Hudson River PCBs SUPERFUND SITE

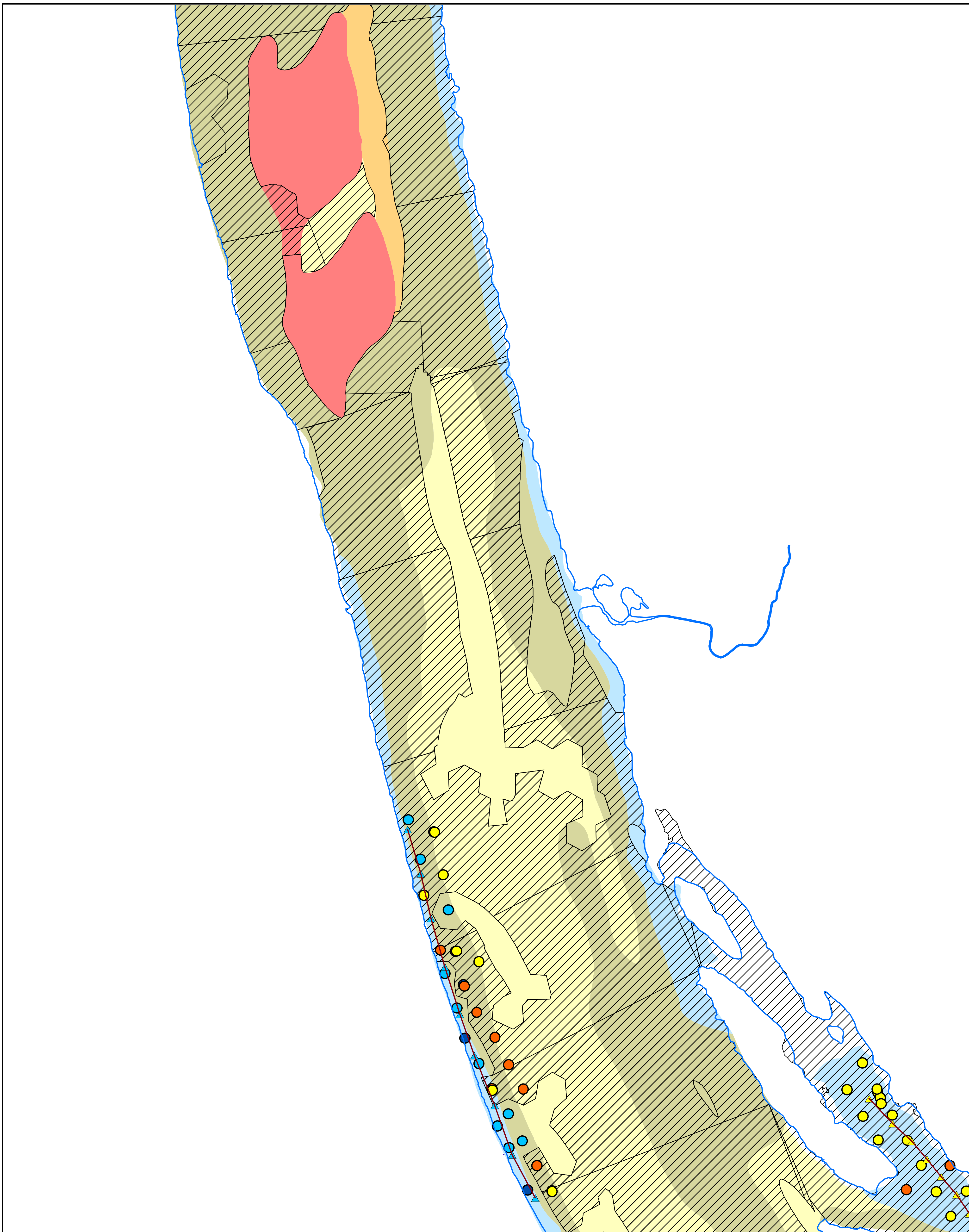
Region 2: NJ, NY, PR, VI • 290 Broadway, New York, NY 10007

# 2002 TO 2005 SSAP CORES WITHIN 100 FEET OF 1998 COMPOSITE NODES

Figure A4-16c

May 2017

Map Document: (M:\02859191\GIS\Phase1Evaluation\GE_Composite91_98_SSAPCores.mxd) 8/18/2010 -- 4:50:17 PM



N

**LEGEND**

Composite Nodes Line
Shoreline
Dredge Boundary

**Surface (0-2 inch) Tri+ PCB Conc. (ppm)**

- 0.0-3.0
- 3.1-10.0
- 10.1-30.0
- 30.1-100.0
- >100.0

**SSS Sediment Type**
**type**

- Silt
- Silt and Sand
- Gravel
- Transitional
- Bed Rock

**CLASSIFICATION**

- ● 2002-2005 SSAP Cores
- ▲ GE 1998 Composite

250 125 0 250 Feet

Hudson River PCBs SUPERFUND SITE

Region 2: NJ, NY, PR, VI • 290 Broadway, New York, NY 10007

# 2002 TO 2005 SSAP CORES WITHIN 100 FEET OF 1998 COMPOSITE NODES

Figure A4-16d

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N

## LEGEND

- Composite Nodes Line
- Shoreline
- Dredge Boundary

**Surface (0-2 inch) Tri+ PCB Conc. (ppm)**

- 0.0-3.0
- 3.1-10.0
- 10.1-30.0
- 30.1-100.0
- >100.0

**SSS Sediment Type**

**type**

- Silt
- Silt and Sand
- Gravel
- Transitional
- Bed Rock

**CLASSIFICATION**

- ● 2002-2005 SSAP Cores
- ▲ GE 1998 Composite

250 125 0 250 Feet

Hudson River PCBs SUPERFUND SITE

Region 2: NJ, NY, PR, VI • 290 Broadway, New York, NY 10007

# 2002 TO 2005 SSAP CORES WITHIN 100 FEET OF 1998 COMPOSITE NODES

Figure A4-16e

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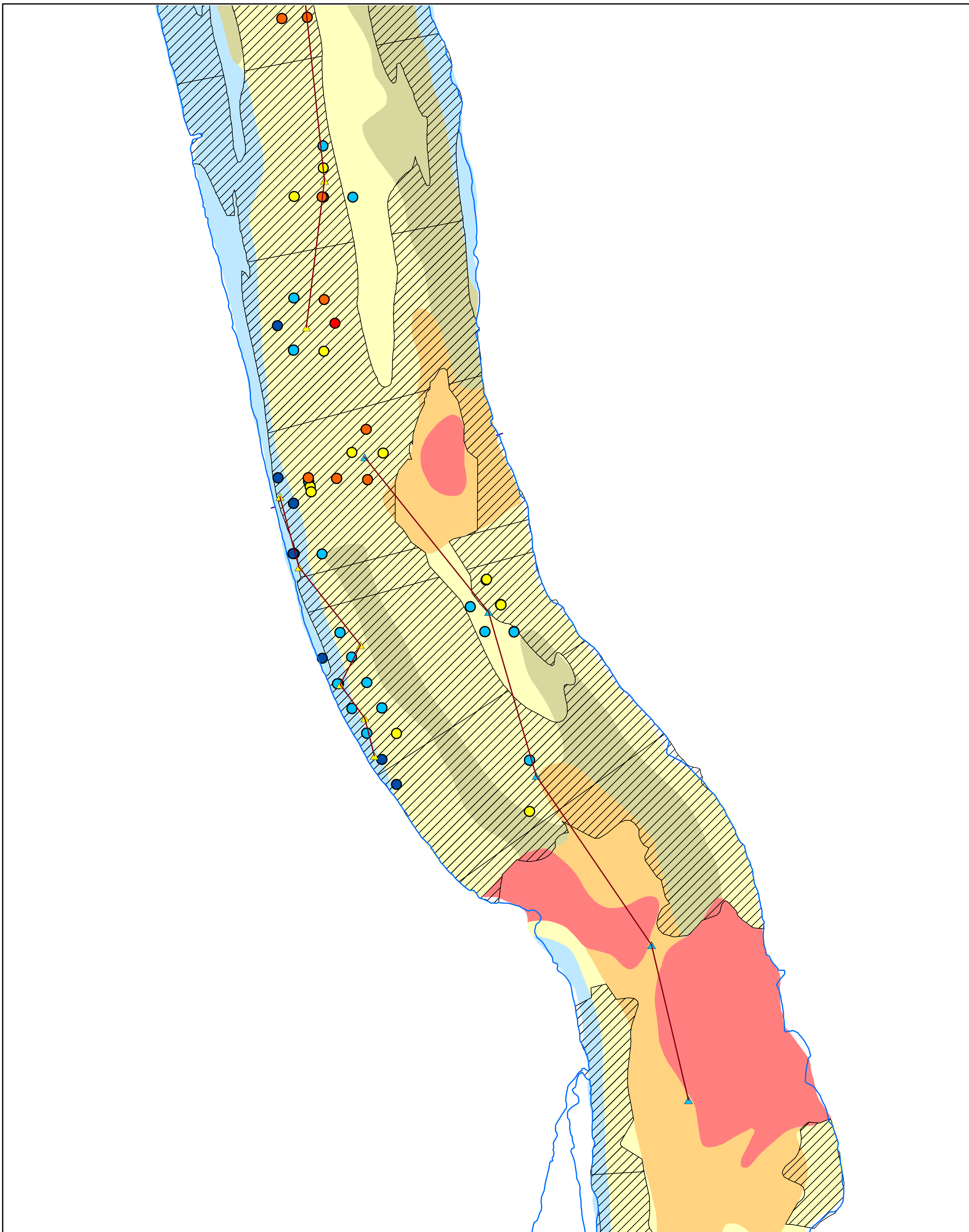
Map Document: (M:\02859191\GIS\Phase1Evaluation\GE_Composite91_98_SSAPCores.mxd) 8/18/2010 -- 4:50:17 PM



**LEGEND**

| | | |
|---|---|---|
| Composite Nodes Line | **Surface (0-2 inch) Tri+ PCB Conc. (ppm)** | **SSS Sediment Type** type |
| Shoreline | 0.0-3.0 | Silt |
| Dredge Boundary | 3.1-10.0 | Silt and Sand |
| | 10.1-30.0 | Gravel |
| | 30.1-100.0 | Transitional |
| | >100.0 | Bed Rock |

**CLASSIFICATION**

- ● 2002-2005 SSAP Cores
- ▲ GE 1998 Composite

N

250 125 0 250 Feet

Hudson River PCBs SUPERFUND SITE

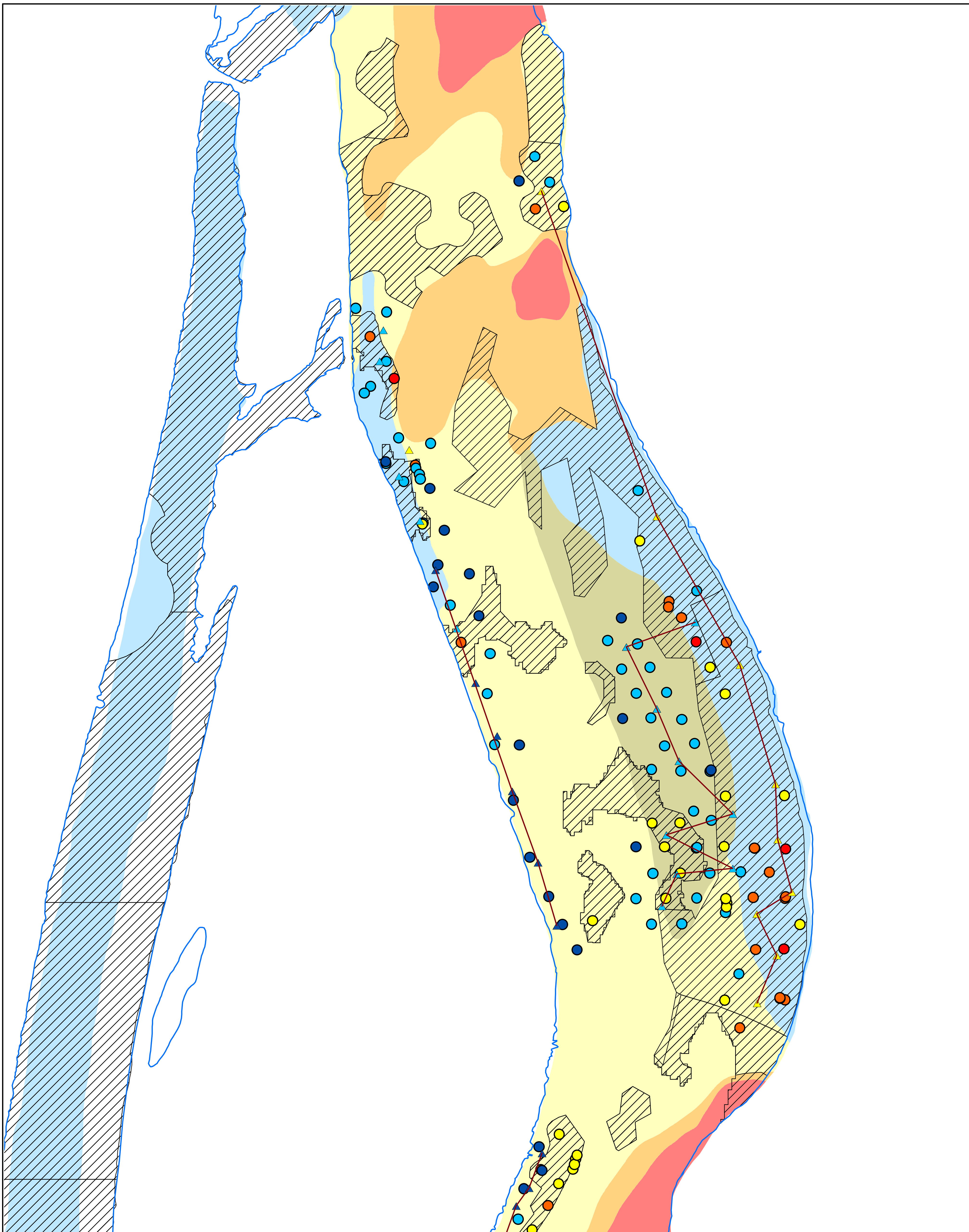
Region 2: NJ, NY, PR, VI • 290 Broadway, New York, NY 10007

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

# 2002 TO 2005 SSAP CORES WITHIN 100 FEET OF 1998 COMPOSITE NODES

Figure A4-16f

May 2017



**LEGEND**

Composite Nodes Line
Shoreline
Dredge Boundary

**Surface (0-2 inch) Tri+ PCB Conc. (ppm)**
0.0-3.0
3.1-10.0
10.1-30.0
30.1-100.0
>100.0

**SSS Sediment Type**
type
Silt
Silt and Sand
Gravel
Transitional
Bed Rock

**CLASSIFICATION**
● 2002-2005 SSAP Cores
▲ GE 1998 Composite

250 125 0 250 Feet

N

Hudson River PCBs Superfund Site
Region 2: NJ, NY, PR, VI • 290 Broadway, New York, NY 10007

2002 TO 2005 SSAP CORES
WITHIN 100 FEET OF 1998 COMPOSITE NODES

Figure A4-16g

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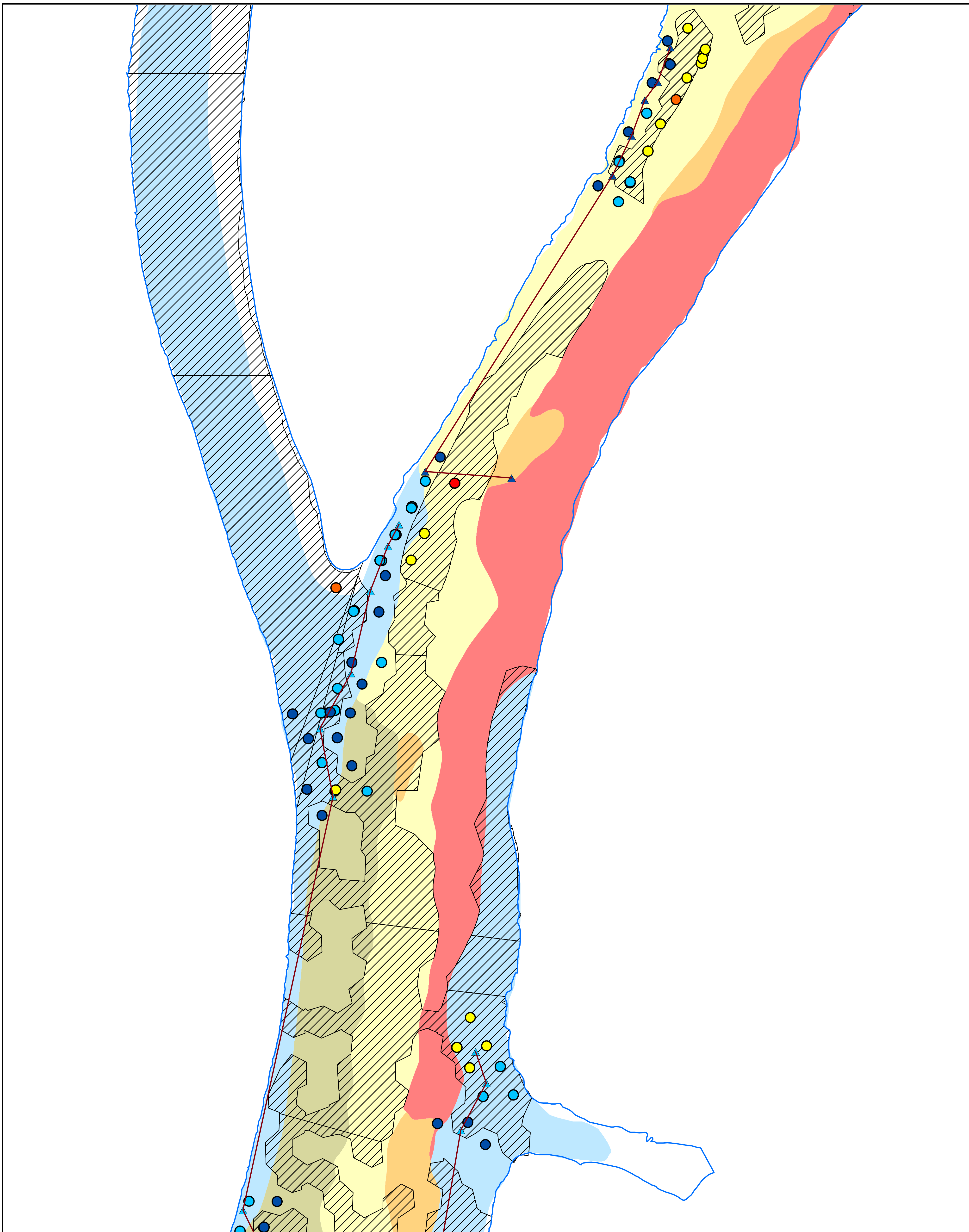
Map Document: (M:\02859191\GIS\Phase1Evaluation\GE_Composite91_98_SSAPCores.mxd) 8/18/2010 -- 4:50:17 PM



**LEGEND**

- Composite Nodes Line
- Shoreline
- Dredge Boundary

**Surface (0-2 inch) Tri+ PCB Conc. (ppm)**

- 0.0-3.0
- 3.1-10.0
- 10.1-30.0
- 30.1-100.0
- >100.0

**SSS Sediment Type**
**type**

- Silt
- Silt and Sand
- Gravel
- Transitional
- Bed Rock

**CLASSIFICATION**

- ● 2002-2005 SSAP Cores
- ▲ GE 1998 Composite

N

250 125 0 250 Feet

Hudson River PCBs SUPERFUND SITE

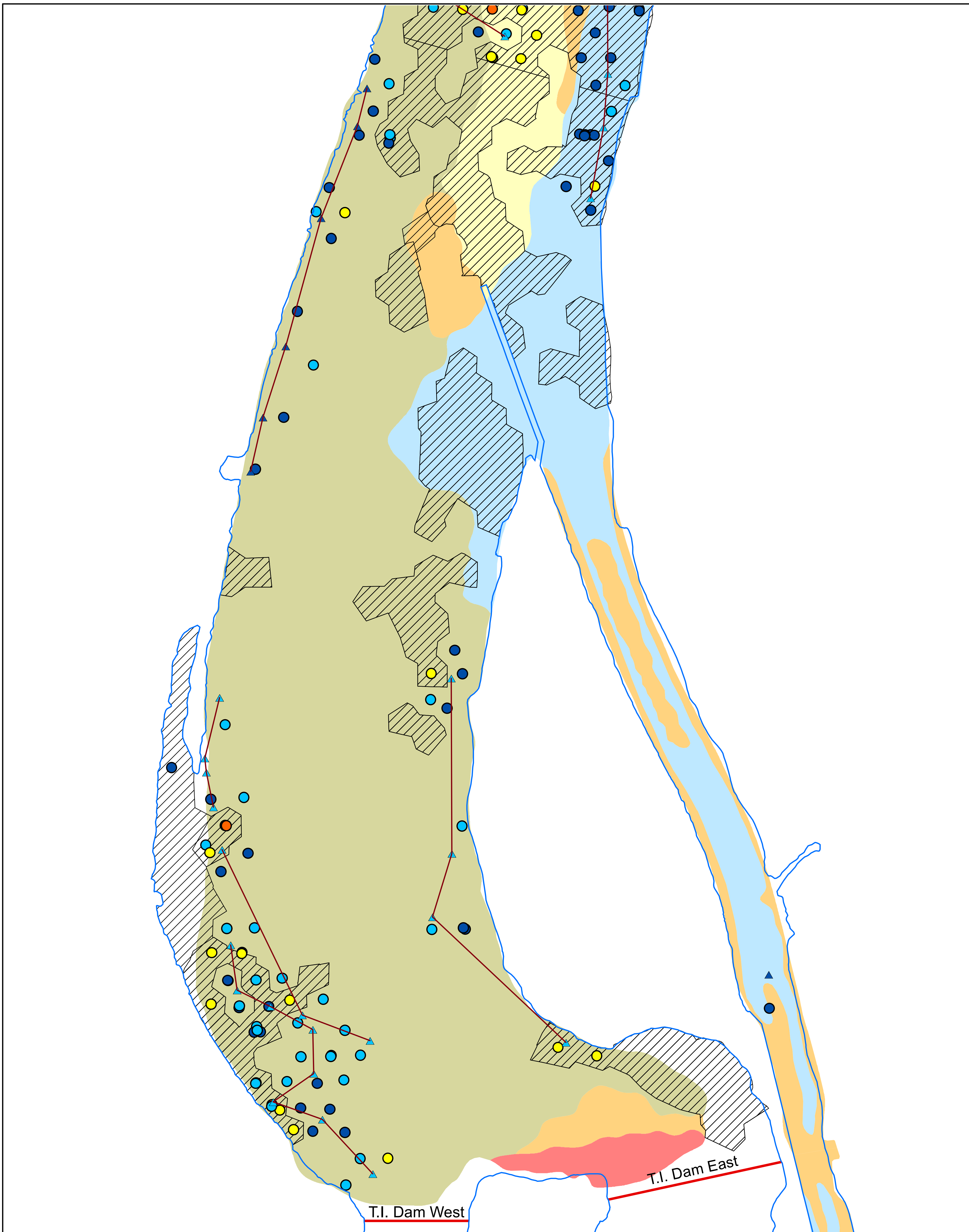
Region 2: NJ, NY, PR, VI • 290 Broadway, New York, NY 10007

# 2002 TO 2005 SSAP CORES WITHIN 100 FEET OF 1998 COMPOSITE NODES

Figure A4-16h

May 2017

Map Document: (M:\02859919\GIS\Phase1Evaluation\GE_Composite91_98_SSAPCores.mxd) 8/18/2010 -- 4:50:17 PM




**LEGEND**

Composite Nodes Line
Shoreline
Dredge Boundary

**Surface (0-2 inch) Tri+ PCB Conc. (ppm)**
0.0-3.0
3.1-10.0
10.1-30.0
30.1-100.0
>100.0

**SSS Sediment Type**
**type**
Silt
Silt and Sand
Gravel
Transitional
Bed Rock

**CLASSIFICATION**
● 2002-2005 SSAP Cores
▲ GE 1998 Composite

250 125 0 250 Feet

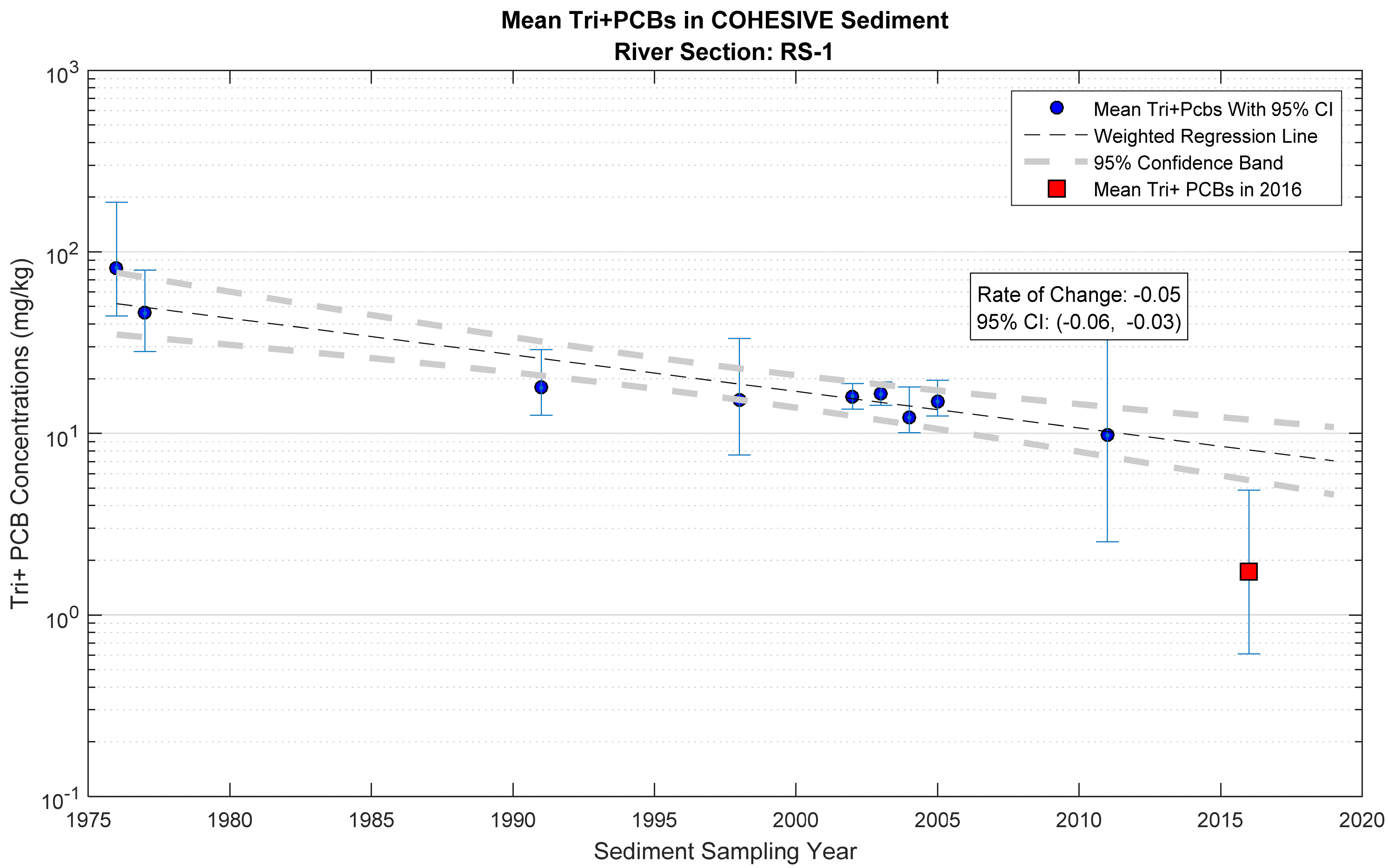
Hudson River PCBs SUPERFUND SITE
Region 2: NJ, NY, PR, VI • 290 Broadway, New York, NY 10007

# 2002 TO 2005 SSAP CORES WITHIN 100 FEET OF 1998 COMPOSITE NODES

Figure A4-16i

May 2017

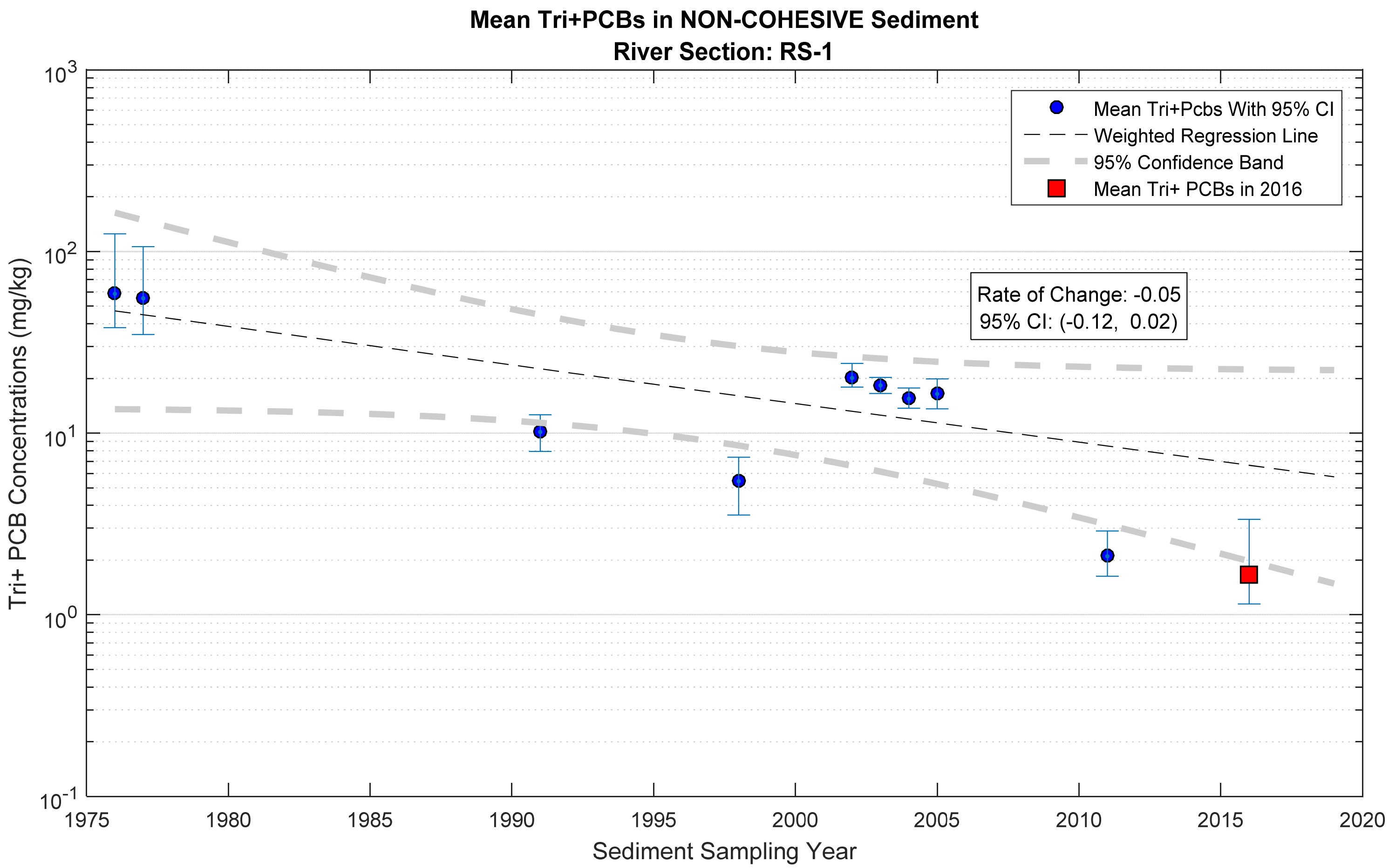
Map Document: (M:\02859191\GIS\Phase1Evaluation\GE_Composite91_98_SSAPCores.mxd) 8/18/2010 -- 4:50:17 PM




Temporal Trend Models Fit to Tri+ PCB Means in Cohesive and Non-Cohesive Sediments

Figure A4-17a

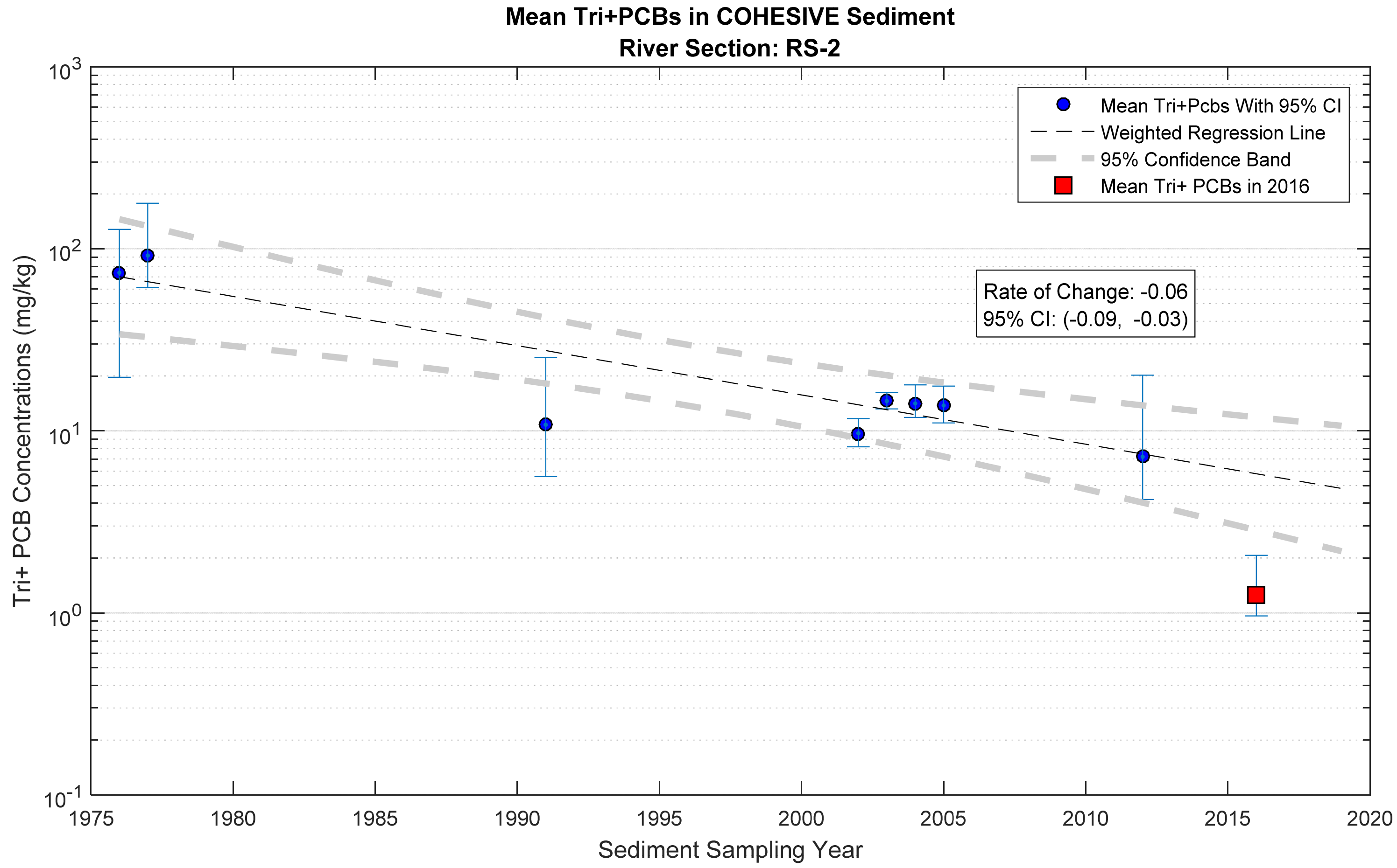
May 2017




Temporal Trend Models Fit to Tri+ PCB Means in Cohesive and Non-Cohesive Sediments

Figure A4-17b

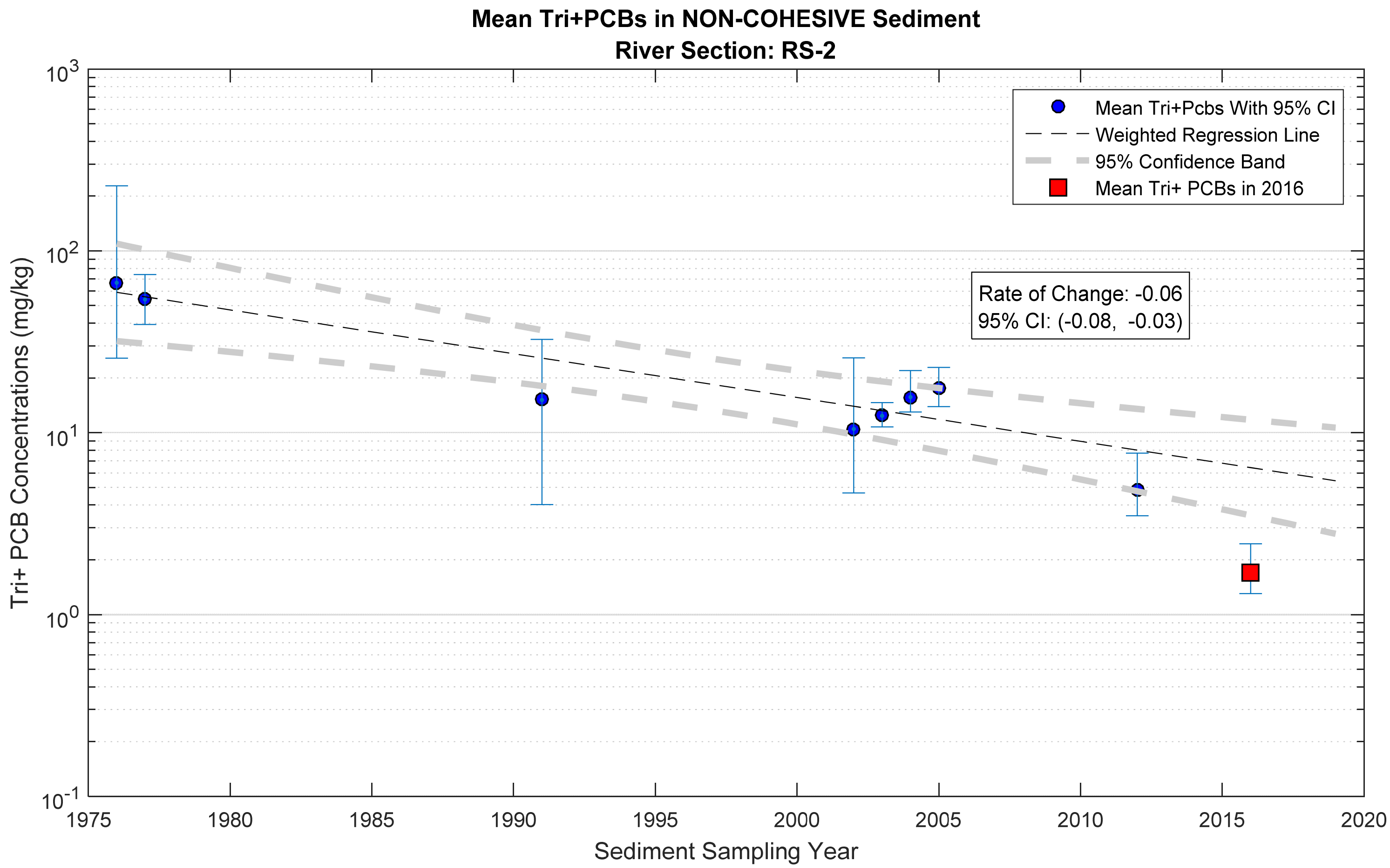
May 2017




Temporal Trend Models Fit to Tri+ PCB Means in Cohesive and Non-Cohesive Sediments

Figure A4-17c

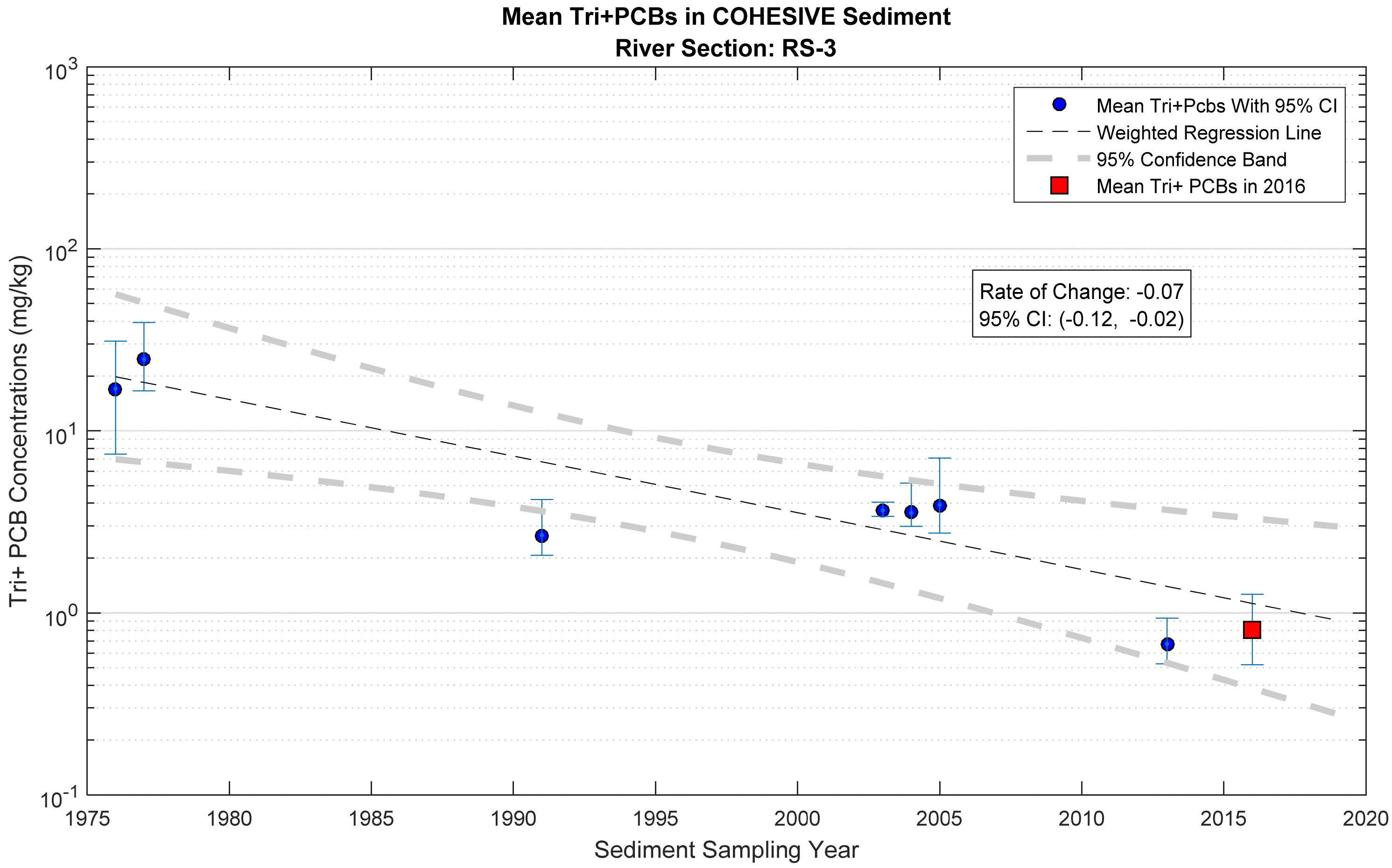
May 2017




Temporal Trend Models Fit to Tri+ PCB Means in Cohesive and Non-Cohesive Sediments

Figure A4-17d

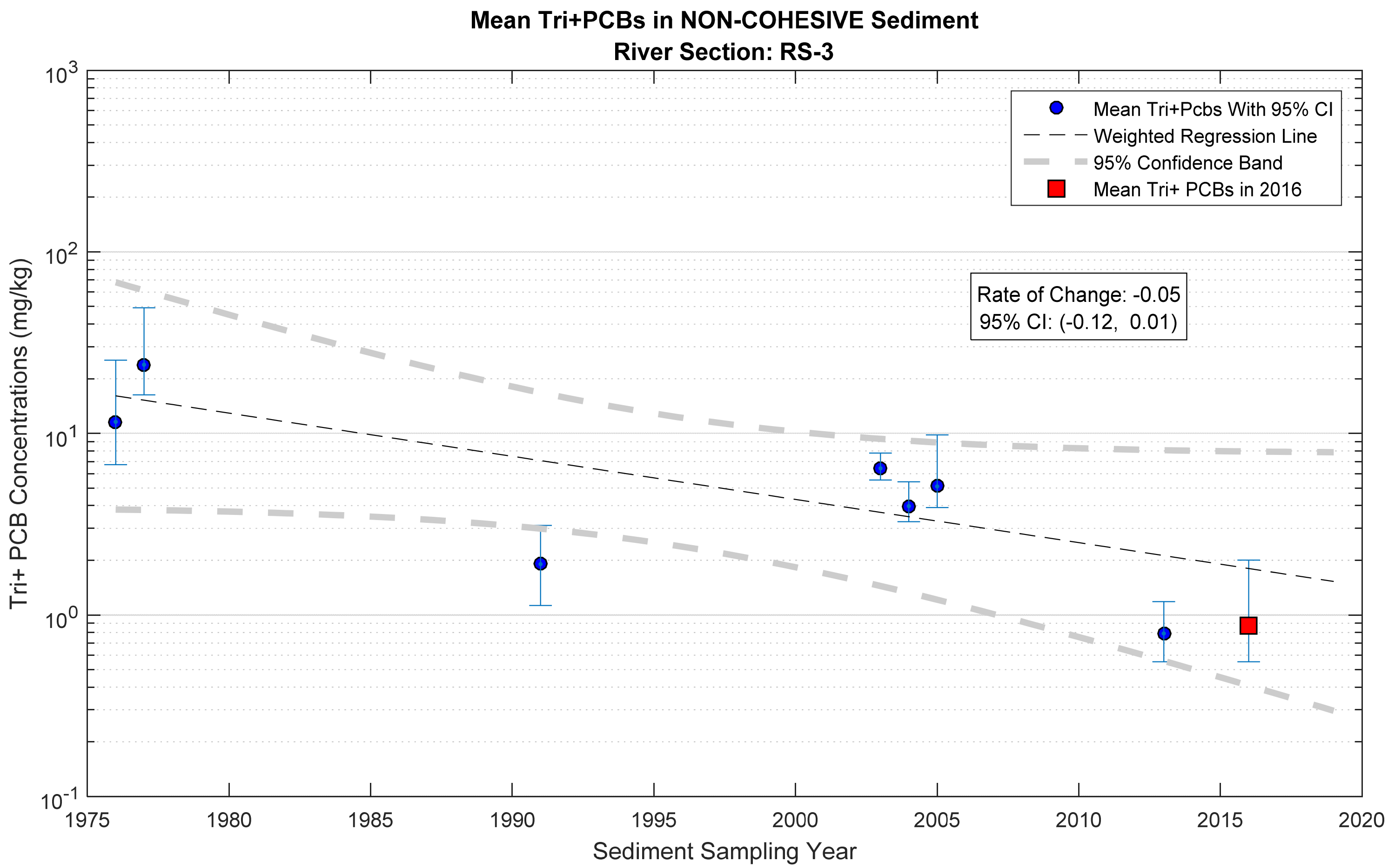
May 2017




Temporal Trend Models Fit to Tri+ PCB Means in Cohesive and Non-Cohesive Sediments

Figure A4-17e

May 2017




Temporal Trend Models Fit to Tri+ PCB Means in Cohesive and Non-Cohesive Sediments

Figure A4-17f

May 2017