U. S. Environmental Protection Agency
Region 2

Hudson River PCB Superfund Site
New York

White Paper:
Responses to NOAA Manuscript Entitled: “Re-Visiting Projections of PCBs in Lower Hudson River Fish Using Model Emulation” (Field, Kern, Rosman, 2015)

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1. Executive Summary

This White Paper presents the U.S. Environmental Protection Agency's (EPA's) response to the National Oceanic and Atmospheric Administration's (NOAA's) manuscript entitled: "Re-Visiting Projections of PCBs in Lower Hudson River Fish Using Model Emulation." Specifically, this paper addresses NOAA's contention that the remedy selected by EPA in the 2002 Record of Decision (ROD) and implemented by General Electric Company (GE) was insufficient to meet the remedial goals for reduction of PCB concentrations in fish tissue in the Lower Hudson River[1]. EPA Region 2 believes that NOAA's claim that fish tissue concentrations will not meet remedial goals until many decades after the years anticipated by model forecasts contained in the ROD is based on analyses that did not reflect the breadth of project sediment data or the variety of fish species data across sampling stations in the Upper and Lower Hudson River, and therefore is not supported by the available evidence.

EPA Region 2 notes that NOAA focused on only a small fraction of the available measurements of PCB levels in fish tissue data, primarily examining a single station in the Lower Hudson at river mile (RM) 152 (Albany/Troy) for two species. A comprehensive and more appropriate analysis of the river's status and projected recovery would have considered the entirety of the Hudson River fish data sets, which contain tissue levels in many more species covering much of the Upper and Lower Hudson River. NOAA also did not focus their analysis on the period of monitored natural attenuation (MNA) prior to the onset of dredging (*i.e.*, 1995 to 2008), during which time natural recovery alone occurred in the river, and which would have been a more appropriate time frame to test its assertions regarding the rate of sediment recovery.[2]

EPA also noted in its evaluation of NOAA's model emulation that it does not appear that NOAA properly took into consideration the step of recalibrating or validating the model emulation to actual fish and water data. EPA considers this an important step when a new set of values (*e.g.*, the SSAP results) are introduced over the initial conditions used to develop the mechanistic model . This issue further raises concern about the accuracy of the NOAA fish tissue recovery predictions.

Overall, when assessing the rates of recovery in a complex river system such as the Hudson, it is important first to evaluate the suitability of the data available for this purpose. Specifically, for of the data sets available across media (sediment, water and fish tissue), only the latter two data sets were designed and obtained specifically to document changes in PCB concentration in these media through time. The sediment data, which NOAA uses as its main line of evidence, were not collected for this purpose. In general, the sediment data were obtained to characterize various

[1] EPA is responding to the manuscript provided by NOAA on March 11, 2015.
[2] NOAA focused their analysis largely on the 1991-2005 period, based on sediment data, then looked at the 1997-2014 period for fish. Neither analysis focused on the only available MNA period, when true internal recovery rates (largely free of external or upstream loads) would be observable. This period begins sometime between 1995 and 1998, and ends in 2009 when the dredging begins.

select aspects of the river's condition needed for use in remedy selection and design, but were not designed or collected in a manner well suited for monitoring long term trends in PCB concentration. Notably, the rates of decay obtained from both Upper Hudson water column monitoring and from fish in the Upper Hudson and at RM 152 in the Lower Hudson are internally consistent and do not agree with the sediment recovery rate obtained by NOAA.

The inadequacy of the sediment data to independently provide a reliable recovery rate can be readily demonstrated by comparing the results of the various sediment surveys available. Depending upon the surveys compared, it is possible to identify rapidly declining trends, slowly declining trends and even periods of increasing surface sediment concentrations. NOAA used sediment data sets from 1991 and 2002-2005 to draw conclusions about sediment, water, and fish recovery. This comparison generated an average rate of sediment recovery of only 1.3 percent per year (equivalent to a 53 year half-life). Those data sets are now over a decade old. More recent data collected in 2011 to 2013 were not included in NOAA's interpretation. Notably, when these more recent data are compared to the 2002-2005 data, EPA obtains rates of sediment PCB concentration decay as rapid as 22 percent per year, comparable to or faster than those observed for fish and water. The inconsistency among the sediment survey data is illustrated in Figure ES-1, which compares the surface sediment concentration estimates from the four sediment surveys available with the original model forecasts for the Thompson Island Pool.

These observations notwithstanding, it is EPA's assertion that because the sediment data were not collected for the purpose of documenting changes through time, the sediment data do not provide a reliable basis to independently estimate sediment PCB rates of decay. In this regard, they are clearly inferior to the water column and fish data that were explicitly collected for this purpose, each of which provides internally consistent rates throughout the Hudson River to RM 152. The average rates of decay in PCB levels obtained by interpretation of the water and fish data are approximately 8 to 14 percent per year (equivalent to half-lives in the range of 8 to 5 years, respectively).[3] NOAA's choice of sediment surveys creates an extreme case that is inconsistent with these direct measures of the rates of decay of PCB levels in water and fish.

In addition to the inconsistent use of sediment data to estimate rates of decay in PCB levels in fish; the fish data selected by NOAA as a surrogate for the Lower Hudson (white perch and largemouth bass), are not representative of the average decays rates for Lower Hudson fish at RM 152, resulting in a underestimate of the rate of decay in fish tissue PCB levels. In contrast to NOAA's analysis, EPA has examined PCB concentrations for the larger set of long-term fish records available for the Lower Hudson, including those that comprise the species-weighted average described in the ROD (largemouth bass, brown bullhead, and yellow perch) using

[3] The reader should note that the rate of decay and the half-life are two ways of expressing the rate of decrease in PCB concentrations through time in this paper. In particular, the rate of decay and the half-life are inversely proportional, such that slower rates of decrease are expressed as smaller percent changes per year and as longer half-lives.

observed data (not a model forecast). This analysis showed that data are not available for all fish species at all stations, and that recovery rates can vary across species and stations. EPA's examination of the larger fish data set indicates that the average rate of recovery for Lower Hudson fish at RM 152 is 8 percent per year (equivalent to a 9 year half-life,), including an average decay rate for black bass at this station of 7 percent per year. These rates are notably different from an approximate 5 percent per year decay rate (15 year half-life) for the white perch that EPA obtains at this station or the 3 percent decay rate suggested by NOAA.[4]

Demonstrating the trends for various fish in addition to white perch and black bass is an important consideration because exposure to Lower Hudson fish is based on a species-weighted average that reflects more than a single fish species. White perch concentrations constitute only approximately 7-9 percent of the of the species-weighted average concentration used by EPA (HHRA, EPA 1999a), and not all species exhibit similar half-lives and decay rates at all locations across the Lower Hudson. In addition, data from the Lower Hudson Ecological Risk Assessment (EPA, 1999b) and Responsiveness Summary (EPA, 2000a) show that the modeling analysis for white perch was not as accurate in projecting body burden targets as it was for the other fish studied.

EPA also examined decay rates for fish tissue concentrations at three additional Lower Hudson stations, RM 113 (Catskill), RM 90 (Kingston/Poughkeepsie) and RM 50 (South Newburgh), which are downstream of the Upper Hudson River area of remediation. Decay rates at these stations are slower than those observed upstream, and decrease with increasing distance from the Upper Hudson. This trend is expected since the influence of PCB load to the lower river would be most significant closer to the Upper River. In the Lower River PCBs are distributed over a large area at low concentration which influences decay rates. Additionally decay rates are influenced by local factors (included other potential PCB sources) unrelated to the Upper Hudson River. Further since fish tissue concentrations are substantially lower than in the Upper Hudson River it is more difficult to ascertain key factors that would hasten further declines.

EPA expects that the rates of decay in Tri+ PCB concentrations in water column and fish tissue reflect a parallel rate of decay in surface sediment concentrations, based on standard geochemical and biochemical theory. The observation that some sediment survey comparisons do not support this correlation is likely due to the fact that the sediment surveys were not collected with the objective to track surface conditions through time, as noted above.

Contrary to NOAA's assertions regarding slow rates of decay in surface sediments and fish tissue, it is clear that PCB concentrations were declining prior to the implementation of the remedy consistent with the forecasts made by EPA's models. This is not to say the agreement

[4] Note that NOAA did not fit the white perch and largmouth bass data directly to obtain a decay rate estimate for these species. Rather, in their Figures 10 and S-4, they compare the fish data to a 3 percent decay rate curve (23 year half-life) that they obtained by their other analyses. As discussed later in this paper, EPA infers that NOAA's presentations of largemouth bass data actually represent all black bass at this station.

between model forecast and observed decline was exact. Rather, the data show that the rates of decay (or recovery) estimated by EPA's models for the Upper Hudson and at RM 152 were similar to those observed. EPA intends to continue its examination of the model forecast and fish and water data to obtain further insights in this regard.

Furthermore, it is not unusual for a large complex project such as the Hudson River remedy to encounter challenges to its implementation relative to the operational assumptions outlined in the ROD, and for adjustments to be made during the project to respond to those challenges. It is also possible for those adjustments to affect the rate of recovery originally projected in the ROD. For example, Upper Hudson fish-tissue concentrations (congener homologue lipid-normalized) for pre-dredging (2004-06) and near-term post-dredging (2014) periods are similar (Arcolor data also reflect this trend). The lack of a decline in PCB levels during the intervening period is not unexpected, however, because the dredging was not performed upstream-to-downstream as envisioned in the ROD, but rather included periods of simultaneous dredging at several locations along the entire course of the project area. Additionally, the fact that the dredging started later than anticipated in the ROD correspondingly delayed the expected recovery in the river as compared to the model estimates. It is expected that recovery has continued during the remediation itself in localized areas less affected by the implementation. The yearling fish collected in the fall of each year will continue to provide a good indicator of future recovery in localized areas. EPA will continue to review this approach to remedy evaluation as part of the next five year review.

As described in the document, data cited by NOAA is over a decade old. EPA is not discounting these data and in fact these data were evaluated as part of a 2010 peer review and the 2012 Five Year Review of the project. EPA has more recent data from 2011-2013 that paints a different picture. It is EPA's opinion that NOAA's retrospective analysis has limitations and does not support the need for additional dredging at this time. EPA also contends that the analysis as presented to the public by NOAA and without the benefit of considering the additional available data, may be misleading. It should be noted that higher than anticipated surface concentrations and the fact that dredging removed twice the anticipated mass are two distinct concepts that need to be considered carefully. The higher than anticipated surface concentrations is related to shallower core results outside of targeted dredge areas. The concept regarding twice the anticipated mass removed is related primarily to PCBs found deeper in debris areas dredged. Further, EPA does not have any evidence at this time to suggest anything other than that the project is a success. The project has significantly and effectively reduced the volume of PCBs in the river to which the fish are exposed. PCBs have been removed from the portions of the river bottom with the highest PCB concentrations.

The Hudson River dredging project was one of the largest and most technically complex environmental dredging projects conducted in the United States and EPA expects that the project will help restore the environmental health of the Hudson River. EPA will continue to cooperate and engage with New York State, NOAA and the other Federal Trustees, as well as the Site's Community Advisory Group, as it designs its Second Five-Year Review and determines the best way to collect data to inform that review.

2. Introduction

EPA Region 2 has prepared this White Paper (paper) in response to the manuscript prepared by NOAA personnel and others entitled "Re-Visiting Projections of PCBs in Lower Hudson River Fish Using Model Emulation" (See: footnote #1, page 1). The NOAA manuscript presents several analyses to support its ultimate contention that the remedy selected by Region 2 and implemented by GE was insufficient to meet the remedial goals for reduction of PCB concentrations in fish tissue in the Lower Hudson River. In particular, NOAA asserts that fish tissue concentrations in Lower Hudson River will not meet remedial goals until many decades after the year anticipated by model forecasts contained in the ROD. Region 2 does not agree with NOAA's conclusions in this regard and disputes the assertions underlying several of the technical arguments presented in the NOAA manuscript. While Region 2 agrees that there is uncertainty concerning the actual year in which the remedial goals will be attained for the Lower Hudson, the Region does not believe there is sufficient evidence to indicate that the original forecasts are off by many decades. On the contrary, the evidence available at this time is more consistent with EPA's original forecasts. In addition to the issues raised in the discussion below, it is Region 2's position that the remedy as implemented must be studied and monitored for several years after dredging (*i.e.,* beginning in 2016) before it will be possible to discern post-remedial action trends in fish tissue concentrations that are not influenced by disruptions caused by implementation of the remedy. These trends will provide the best basis to assess the timing of attainment of the EPA's fish tissue goals.

EPA agrees that there is uncertainty concerning the actual year in which the remedial goals will be attained for the Lower Hudson. There is a degree of uncertainty in both the peer reviewed EPA detailed mechanistic modeling and NOAA model emulations. EPA has previously acknowledged the uncertainties associated with the mechanistic model.[5] The emulation approach taken by NOAA may be potentially useful for some purposes when supplied with sediment inputs that are consistent with those used in the original EPA mechanistic model calibration. However, the emulation outputs, relative to the mechanistic model, would be less reliable when sediment initial conditions are modified without recalibration of the model. The processes in the EPA model that represent transfer from sediment to water and fish tissue were calibrated based on 1991 and 1998 sediment data. Compared to these data the 2002-2005 data are inconsistently high. Therefore, application of the EPA model, or an emulated version of it, using the 2002-2005 sediment data as the input values will predict water column and fish tissue concentrations that are biased high. This appears to be the case with the NOAA model emulation, as shown

[5] See for example, the Phase 3 Feasibility Study, Section 8.1.5.4, (EPA, 2000c).

below, and this bias would propagate to fish tissue predictions as well. In this regard, there is no substitute for an evaluation of all available data and the NOAA analysis does not provide a replacement for the original model output and forecasts. Rather, if it can be concluded that a new set of values (*e.g.,* the SSAP results) is more appropriate for use in the model, it is necessary to recalibrate other mechanistic terms in the model with available data (such as water and fish concentrations). NOAA's emulation did not include such recalibration. EPA believes there is insufficient data currently available to make judgements about the accuracy of the original fish tissue forecasts; and EPA believes that, contrary to NOAA's assertions, the fish tissue and water column data currently available are generally consistent with the original forecasts. Future data will be collected as part of the operation, maintenance and monitoring (OM&M) program and assessed as part of EPA's five year review process.

In the discussion to follow, Region 2 identifies significant technical concerns with the NOAA analyses that undermine NOAA's assertions regarding the effectiveness of the remedy, and provides evidence in support of its conclusions. The concerns identified can be separated into two groups: 1) concerns regarding the use of only a subset of the available data thus rendering the NOAA analysis as less than comprehensive; and 2) concerns regarding the application of NOAA's statistical representation (model emulations) of EPA's HUDTOX and FISHRAND models. [6]

3. Background

The issues raised by NOAA are largely based on a subset of the observations obtained since the ROD was issued in 2002. In particular, NOAA focused on the sediment data collected for the Sediment Sampling and Analysis Program (SSAP) conducted by GE during the period 2002-2005, as well as white perch and largemouth bass data obtained at RM 152 by the New York State Department of Environmental Conservation (NYSDEC) and GE, from 1997 to 2014. EPA notes that at RM 152 (and adjacent Lower Hudson reaches), data for largemouth bass (*Micropterus salmoides*) are largely available only through approximately 1999. In contrast, smallmouth bass (*Micropterus dolomieu*) is a separate species with a slightly different life history and ecological niche than largemouth bass. Data for smallmouth bass are consistently available at RM 152 and adjacent Lower Hudson reaches from 1990 to the present. In this paper, EPA refers to the data combining the results for both species at RM 152 as "black bass" data. Due to very limited data for largemouth bass post 1999 (only 2 additional samples), EPA determined it was not appropriate to estimate a decay rate for this species alone during the period of natural recovery (1995-2008). EPA is uncertain how NOAA assembled the largemouth bass data shown in NOAA Figure S-4 but it appears that the figure combines the data for both smallmouth and largemouth bass (*i.e.,* black bass) for this station. In the discussion below, EPA

[6] These models were originally developed as part of the remedial investigation in support of the 2002 ROD.

will assume this is the basis for NOAA Figure S-4 and refer to the data as black bass data. EPA is not awere of any other largemouth bass data post 1999 for this station.

In its analysis, NOAA compared the SSAP data with an earlier survey of surface sediment PCB concentrations obtained by GE in 1991 as a basis for its assertions concerning the rate of recovery for surface sediment concentrations. Similarly, NOAA used the white perch and black bass data from the Lower Hudson at RM 152 to support its conclusions regarding the rate of recovery. Using these analyses, NOAA concluded that the model forecasts used as a line of evidence for the ROD were incorrect and overly optimistic. Furthermore, NOAA concluded that the recovery of Lower Hudson fish tissue concentrations post Upper Hudson remediation will require decades more time than forecast by the EPA models.

However, NOAA's analyses did not involve several other large data sets whose data and temporal trends must be considered before drawing any conclusions regarding the rates of recovery for fish and sediment. The type of information available from these data sets, their usefulness in describing temporal trends in PCB levels, as well as the sources of these data are described briefly below. See the sections immediately below, and Sections 4.1 and 4.2 (and Figures 2 through 7) for EPA analyses of sediment, water column, and fish tissue data.

3.1. Sediment Data Sets

Sediment data are inherently spatially limited, and are typically obtained from 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 concentrations in sediments, even over short distances (less than 2 meters), a statistically appropriate number of samples and an appropriate sample design is needed to accurately represent the mean concentration in an area. Thus any program to monitor changes in surface sediments must be designed with this purpose in mind and samples need to be collected repeatedly over time in a consistent way. As discussed below, none of the sediment sampling programs to date were designed specifically with this objective (*i.e.,* to represent changes in sediment PCB concentrations over time). As a result their use can present limitations when attempting to conduct such an analysis. The four available data sets and their limitations have been carefully evaluated by EPA and are well understood. With this understanding, EPA cautions that sediment data must be viewed as inherently highly uncertain if used in attempting to estimate sediment PCB trends over time,

The sediment data described below were all quantified by GE's laboratory primarily using Aroclor-based methods. The 1991 and 1998 data were reported as congener (peaks) only, based on Aroclor standards. The primary basis of analysis for the SSAP was PCBs as Aroclors. A subset of the SSAP (2002-2005) data were also analyzed for PCBs as congeners. The Downstream Deposition Study (DDS) data were exclusively quantified for PCBs as Aroclors. Samples with matched analyses by Aroclor and congener methods results were used to develop estimates of Tri+PCB concentrations for all samples that were not directly analyzed for PCB congeners. These data were used for the sediment data evaluations in this paper.

The first two data sets (1991 and 1998) were previously provided to NOAA by EPA and have been used by NOAA in analyses for over a decade (these data are part of the dataset that accompanied the Feasibility Study, EPA, 2000b). The 2002 to 2005 SSAP and 2011 to 2013 DDS data were provided to NOAA through the distribution of documents and other information as required by the Consent Decree (EPA 2005, EPA 2010b). Furthermore, the DDS data sets were described in the 2010 Statement of Work for Phase 2 (EPA 2010b) and discussed in the 2011 Five Year Review (EPA, 2012a).

3.1.1. GE 1991 Sediment Survey

This data set is comprised of sediment core samples sectioned into 0-2 inch and deeper segments (EPA, 2000b). This program was intended to characterize average PCB concentrations in surface and deeper sediments across entire Upper Hudson River (River Sections –RS1, RS2 and RS3). However, sample site selection was not statistically-based and was subjective. 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 maintained 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). The NOAA analyses were based on these data and the 2002-2005 SSAP data (see below).

3.1.2. GE 1998 Sediment Survey

This data set is comprised of sediment core samples sectioned into 0-1 inch segments and deeper segments (EPA, 2000b; EPA, 2000c, Book 2). Like the 1991 survey, the objective was to characterize the average sediment concentrations of PCBs across entire river sections and sample site selection was subjective (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 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, sample composites generally did not combine sediments from both sides of the river into a single composite. Composites were restricted to eastern shoal, western shoal, and center channel. 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). The 1998 survey also does not include composites that cross the river and potentially blend depositional locations (inside of turns) with erosional ones (outside of turns). NOAA declined to include these data in its analyses.

3.1.3. GE 2002-2005 SSAP

The GE Sediment SSAP was designed under EPA direction to characterize both surface and deeper sediment contamination throughout the Upper Hudson as part of the Remedial Design (GE, 2005; GE, 2007a). Specifically, its purpose was to identify and delineate areas whose sediment concentrations or inventories of PCBs exceeded the ROD-specified thresholds. 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. These grids were centered on areas of suspected contamination and were extended to areas where contamination fell below the ROD removal thresholds. In this manner, measurements in contaminated areas represented an unbiased data set. However areas of low contamination, frequently in RS2 and RS3, were not sampled in an unbiased fashion. Because of the extent of contamination in the TIP, the coverage required in the TIP was quite extensive, such that the entire TIP was fairly densely sampled, providing a basis to estimate sediment concentrations across the entire river section. Because this sampling program was implemented tosupport dredge design, sampling density declined moving downstream. This pattern reflected the higher removal thresholds and smaller areas of contamination relative to the thresholds in RS2 and RS3. The NOAA analyses were based these data and data from the GE 1991 Sediment Survey (described above).

3.1.4. GE DDS

GE's DDS program was designed under EPA direction to address the monitoring goals of the Engineering Performance Standards (EPS) for resuspension of dredged sediments to non-dredge areas located downstream of dredge areas (AQEA, 2011; EPA, 2012, Appendix B). This special study was performed to identify the spatial extent, concentration, and mass of PCBs that were deposited in areas downstream from dredging. The primary data quality objective (DQO) for this study was to determine the pattern and magnitude of PCB re-deposition downstream of dredging. The secondary purpose of the sampling effort was to use the data (to the extent possible) to further evaluate sediment concentrations over time. 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 following is the general procedure used by EPA in establishing DDS sample locations.

- Step 1 - Potential locations for sampling were established on cross-section-based transects. The transects were sited from upstream to downstream through RS 1, 2, and 3. Transects in RS1 were spaced approximately 500 ft apart starting in the west channel of Rogers Island and extending downstream approximately 1 mile to certification unit 4 (CU4). South of CU4 in RS 1, the transects were spaced approximately 1500 ft apart. Transects in RS2 were spaced approximately 1000 ft apart, and transects in RS3 were spaced 2000 ft apart. At locations where samples were taken for use in composites, the composited locations were within the same sediment type and either located exclusively inside dredge areas or exclusively outside dredge 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-dredge 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 dredge 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 Type 1, 2, and 4 (the sands and fined-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, sample preference was given to siting locations to be co-located with SSAP sample locations.

Although the sampling for this study was not done on an unbiased grid, consideration was given to collecting representative samples throughout the 40 miles of the Upper Hudson River, so that downstream deposition could be evaluated, and the data could be considered in relation to changes in surface sediment concentrations. Changes in surface sediment concentrations were of particular interest to EPA given the major flood events of 2011.[7] See Section 5 for a more detailed discussion of this event. See Section 9 and Figures 12 through 20 and Figure 23 for a discussion of DDS data and a comparison of DDS samples with SSAP results. NOAA did not focus on these data in its analyses.

3.2. Water Column Monitoring

Water column monitoring has been conducted in the Upper Hudson for the primary purpose of tracking PCB concentrations and loads over time. Thus, the water column data are focused on temporal change and are far better suited than the sediment data for tracking improvements in the Upper Hudson through time. Both the U.S. Geological Survey (USGS) and GE have collected water column data in the Upper Hudson. In both instances, water sampling techniques and analytical methods are standardized, and stations are revisited

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

yearly (to the extent possible) to maintain year-to-year comparability in the data. In preparing the Remedial Investigation/Feasibility Study (RI/FS) (EPA, 2000c) and Responsiveness Summary for the ROD (EPA 2002a), EPA completed a detailed analysis of available water column data and which demonstrated that the data were comparable through time both within and across the two data sets.

It is important to note that water column samples, unlike sediment samples, integrate across much larger effective areas. For example, a water column sample collected from the middle of the river at Schuylerville effectively integrates the PCB release and redeposition processes in the entire river upstream of that location. Thus, improvements upstream, such as the decline in PCB concentrations, will be reflected at that station.

There is an important link between sediment and water column conditions that applies to the period after direct releases to the river associated with the Allen Mill event above Rogers Island were largely eliminated by GE, circa 1996. A detailed discussion of sources and releases during this period is found in Section 6.2.2.2 of the ROD (EPA, 2002a). In the post-1996 period, water column concentrations and loads of PCBs in the Upper Hudson are produced almost entirely as the result of interactions between the water column and the sediment, and in particular the surface sediments, which directly contact the passing water. Thus, for water column concentrations to decline, the releases from the sediments to the water must also decline. By inference, for the release of PCBs from the sediments to decline, the PCB concentration in those surface sediments must decline, thereby reducing the gradient between sediment and water that drives the various release processes. For the most part, exchange processes between sediments and water are linearly related to the concentration gradients between sediments and water. Therefore a 10 percent decline in surface water concentrations and loads is the result of a similar percent decline in average PCB concentrations in surface sediments.

3.2.1. USGS Water Column Monitoring

The USGS conducted long-term water column monitoring at a number of Upper Hudson locations beginning in 1978 and extended to 2002 for the Waterford and Stillwater stations. Water column samples were analyzed by Aroclor-based PCB methods for the entire period of record. In the RI/FS, EPA documented that these results could be treated as a measure of the sum of trichloro- and higher PCB congeners (Tri+ PCBs) (EPA 2000c). NOAA used these data by digitizing (*e.g.*, copying or transcribing map or other images into Geographic Information Systems or manually entering data into databases) EPA model results.

3.2.2. GE Water Column Monitoring

GE water column monitoring data began in 1990 with the completion of the remnant deposit remediation above Fort Edward. GE generated long-term records of water column PCB concentrations at the TI Dam and Schuylerville, which continued well into the 2000s. The Schuylerville record is the longest of all, beginning in 1991 and extending to the present. Although there were some alterations to the stations over time, GE also obtained parallel measurements of water column conditions under the old and new station configurations for limited periods after the changes to facilitate maintenance of the long term trends. In 2004, GE also began monitoring regularly at Waterford, extending the USGS record there to the present time. GE's water column monitoring was almost exclusively done by GE's in-house congener-based method, which provides a consistent basis to estimate Tri+PCB concentrations in the water column at these stations through time. NOAA used these data by digitizing EPA model results.

3.3. Fish Tissue Data Sets

In some respects, the fish themselves are well suited for capturing long term changes in PCB conditions in the river. Fish are continuously exposed as they live and feed in the river, integrating water and sediment conditions across their habitat as well as through the time of their exposure. Thus, long-term fish records are essential in evaluating the success of the remedy and the long-term recovery of PCB levels in fish (EPA, 2008). To a large degree, fish body burdens are linearly related to the PCB concentrations in the media to which they are exposed (Burkhard, 2009, Burkhard *et al*., 2013). Thus, if fish tissue concentrations decline over time, then the concentrations of PCBs in their exposure media must decline as well. As a corollary, it is highly unlikely for fish tissue concentrations to decline in the absence of declines in PCB levels in water and sediment.

For both the NYSDEC and the GE data, the majority of the fish data are reported on Aroclor-based methods. However, measures of the Total PCB mass by a congener- or homologue-based method are available for these databases to enable the conversion of all fish data to a consistent Tri+ PCB basis. EPA developed conversion bases as part of the RI/FS (Butcher *et al.,* 1997; EPA 2000c) and they are used for this paper.

In its analyses, NOAA focused on only a small fraction of the available measurements of PCB levels in fish tissue data. Specifically NOAA used only the fish data at a single station in the Lower Hudson (RM 152) for two fish (white perch and black bass). However, The NYSDEC and GE data sets contain tissue PCB levels for multiple species covering much of the Upper and Lower Hudson that should also be considered in any comprehensive analysis of the river's status and projected recovery. These results are described below. It should be further noted that these fish surveys, like the water column monitoring and unlike the sediment surveys, were explicitly intended to track changes in fish tissue concentrations of PCBs through time. Thus, the design and implementation of these collection programs (*i.e.,* the sampling techniques, analytical methods, processing techniques, and sampling locations) were repeated as consistently as possible through time to best capture the temporal changes in PCB concentrations in fish tissue.

A special note is warranted concerning the young-of-the year (YOY) pumpkinseed. These samples are intended to generally represent fish born and sampled in the same year. They are ideally suited for tracking short term (*e.g.,* year-to-year) changes through time since their body burdens of PCB are generally the result of exposure to river water and sediment during the prior 6 to 9 months. The YOY pumpkinseed data do not represent longer term body-burden averaging, as might be expected from larger and older fish.

3.3.1. NYSDEC Fish Monitoring

The NYSDEC began routine monitoring of PCB concentrations in fish tissue in 1977, starting with a limited number of stations and expanding to include multiple species and stations throughout the Upper and Lower Hudson. In some years, the number of stations or samples may have been reduced due to budgetary limitations or catch success, but the NYSDEC nevertheless strove to create a long term record of fish tissue levels in the Hudson, as well as in other watersheds within the state. As a result, there are nearly continuous, long term records of PCB levels in fish tissue at three stations in the Upper Hudson (*i.e.,* TIP at RM 189, Coveville at RM 172, and Stillwater at RM 168). There are also numerous NYSDEC long term stations in the Lower Hudson River. These Lower Hudson data have been reported in NYSDEC reports and databases (NYSDEC 2002; NYSDEC 2005) and were organized into 40-mile "reaches" (*i.e.,* Troy at RM 152, RM 113, RM 90, and RM 50) for analyses in support of the various project Baseline Ecological Risk Assessments (BERAs). At each of these stations, there are long term records of individual species, including largemouth bass, smallmouth bass, brown bullhead, YOY pumpkinseed, yellow perch, white perch, striped bass, and carp. Not every species is available at every station, but long term records exist for multiple species at each of the stations listed above. There are also shorter-term records available for other species at these stations as well as for these and other species at other stations. Considering just the species examined in the risk assessments developed for the ROD, there are more than 20 species-station time trends available.

3.3.2. GE Fish Monitoring

As part of the monitoring program requirements under the ROD, GE began monitoring fish tissue concentrations in the Upper Hudson in 2004, at a series of monitoring stations located within each of the three river sections of the Upper Hudson (GE 2007b, EPA 2009; EPA 2012b). Three of these stations (RM 189, RM 172, and RM 168) are coincident with the long term Upper Hudson monitoring stations maintained by the NYSDEC. Lower Hudson monitoring stations include Albany/Troy (~ RM 152), Catskill (~RM 113) and Nyack/Tappan Zee (RM 35). GE's techniques mimic those performed by the NYSDEC, including sample collection, processing, and PCB analytical techniques.[8] Species collected by GE in the Upper Hudson locations include largemouth bass, smallmouth bass, brown bullhead, yellow perch, YOY pumpkinseed,and forage species in the Upper Hudson. Lower Hudson species include largemouth and small mouth bass, brown and yellow bullhead, white and yellow perch, and striped bass. While this record is not as extensive as the NYSDEC program, it has provided the project with fish data since 2004.

4. Assessment of NOAA's Use of the Available Data

EPA has identified a number of significant concerns with NOAA's use of the large set of available data for the Hudson. Most importantly, NOAA chose to disregard several data sets that would contradict many of their conclusions regarding fish recovery rates. Specifically, there are multiple data sets that indicate rates of decay for PCBs in fish tissue in both the Upper and at RM 152 in the Lower Hudson in the range of 6 to 14 percent per year (equivalent to 5 to 13 year half lives). These rates stand in sharp contrast to the apparent decline of 1.3 percent per year (53 year half-life) that NOAA reported for sediments and for the 3 percent per year (23 year half-life) curve NOAA includes on its white perch and black bass data presentations for RM 152. Similarly, water column trends in the Upper Hudson also yield rates of decay of 5 to 14 percent per year (equivalent to 5 to 14 year half lives). The fish and water data sets were specifically designed to assess changes over time in their respective media, unlike the sediment surveys. However NOAA focused on only one sediment trend and did not present other lines of evidence relevant to its fish tissue concentration projections. While EPA does not dispute a slow rate of recovery for white perch at RM 152 (although EPA obtained a decay rate of 5 percent for this species at this station), the assertion that this species represents decay rate trends in other fish species is not supported by a review of other fish at this station as well as other lines of evidence. Notably, black bass at this station have a decay rate of about 8 percent per year. NOAA's conclusions appear to be based on a limited portion of the available fish data. These conclusions are not supported by the larger data set. As will be discussed below, EPA's review of the current data set shows continued decline of Upper Hudson and RM 152 fish tissue concentrations throughout the post-ROD period up to the start of dredging, consistent with EPA's model forecasts. The only evidence for slower rates of decay are observed in the Lower Hudson stations far from the Upper Hudson (RM 113 to RM 50), stations that were not examined in the NOAA manuscript.

[8] There is an outstanding issue concerning GE's replication of the NYSDEC's standard fillet processing. The issue and its impacts on GE's long term trend record is currently being investigated by the EPA, NYSDEC, and GE. Based on information provided by NYS, EPA's current understanding is that the fillets were processed with the ribs out for the period of 2007 to 2013. Based on EPA's evaluation of a special study, and that data are available for periods before and after the change in fillet processing, EPA has concluded that the lipid normalized data from this period are comparable for evaluation of long term trends.

In addition to NOAA's focus on only two fish from among many in the long-term fish records, they also examined only two of the four sediment surveys to estimate rates of decay in surface sediment PCB concentrations. Like the selection of the white perch and black bass, NOAA's focus on these sediment surveys leads to conclusions that are inconsistent with the estimated effective decay rates given by examination of other sediment survey pairings.

It is EPA's expectation, based on standard geochemical and biochemical theory, that the rates of decay in Tri+ PCB concentrations in water column and fish tissue should parallel the rate of decay in surface sediment concentrations. Sediment survey comparisons that do not support this correlation are suspect, and are likely due to the fact that the sediment surveys were not collected with the objective to track surface conditions over time. In the discussion below, the evidence to support these conclusions is presented in detail.

4.1. Issues Regarding the Use of the 2002-2005 SSAP Data as a Basis to Estimate the Rate of Decay in Tri+ PCB Surface Sediment Concentrations.

Arguably, the most important source of disagreement between Region 2 and NOAA lies in the interpretation of the 2002-2005 SSAP surface sediment data obtained by GE as part of the remedial design investigation. The SSAP data set contains more than 9100 measurements of surface sediment concentrations. For approximately 8600 of the locations, (94 percent of the entire SSAP sampling locations), the surface sample consisted of the 0-2 inch depth interval. An additional 600 SSAP locations were characterized by sampling a 0-6 inch interval. The SSAP locations provide a very dense coverage of conditions in the TIP. As discussed above (Section 3.1.3) the amount of river bottom represented by SSAP locations declines moving downstream through RS2 and RS3. In addition, the samples were focused primarily on cohesive/fine grained sediments. Nonetheless, these areas were sampled at the same density as those in the TIP.

NOAA based a large part of its assertion regarding the need for further dredging on a comparison between the 2002-2005 SSAP data and the 1991 surface sediment study completed by GE. In their comparison, NOAA noted a minimal rate of decay in Tri+ PCB surface sediment concentrations of approximately 1.3 percent per year (equivalent to a 53 year half-life). The uncertainty in the estimate ranges from an increasing trend with time to a decline rate of approximately 2.6 percent per year (equivalent to a 27 year half-life). This information is presented in Table 1 of NOAA's manuscript (Field *et al,* 2015). EPA noted a similar apparent lack of decline between the studies for the TIP in the Phase 1 Evaluation Report (Figure I-3-22, *EPA, 2010b*, reproduced here as Figure 1). Indeed, in the Phase 1 Evaluation Report, EPA notes that the mean concentration of the 2002-2005 data are equal to or higher than the 1991 average. Additionally, the Phase 1 Evaluation Report notes that the 2002-2005 mean surface concentration for the TIP is substantially higher than the 1998 surface sediment results, indicating that surface concentrations appear to be increasing with time since 1998. This apparent increase is also noted in an earlier report by NOAA (Field *et al.,* 2009).

In preparing their calculations of the decline in surface sediment concentrations for their 2015 report, however, NOAA did not consider the 1998 study. An examination of the results of all three studies intended to characterize surface sediments shows a major inconsistency among the studies (see Figure 1) and points out EPA's concerns with NOAA's approach. Based on the 1991 and 1998 surveys, surface sediment concentrations for the entire TIP decline at a rate of about 8 percent per year (equivalent to a 9-year half-life). The trend between the 1998 and 2002 to 2005 data would indicate an increase in the surface concentration over this period, equivalent to 14 percent per year rate of <u>increase</u> (5 year doubling time) if expressed as an exponential function.

EPA has explored this relationship among the various studies, examining in particular the TIP, where data from all three 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 2 and 3 which compare the surveys on the basis of matched sample locations, while accounting for two different fine sediment definitions.)

Based on these comparisons, EPA and NOAA are faced with several questions that cannot be discerned from the sediment data alone, specifically:

- Are surface sediments subject to such large swings in PCB concentration over such short time periods?
- Is one or more of the surveys incorrect?
- Which trend among the studies represents the correct relationship?

No comparison among the studies provides a satisfactory answer to these questions. Both the 1991 and 2002-2005 surveys measured surface sediments at 0-2 inches. However, the 1991 survey generated composite samples across locations, while the 2002-2005 samples were all discrete locations with no compositing. The 1998 survey examined a shallower surface segment (0-1 inch), but also composited samples across locations. It is EPA's assertion that no combination using two of the three surveys provides a defensible selection over the other possible combinations. However, it is also EPA's opinion that the SSAP program, which had extensive oversight by the agency, including the use of performance evaluation samples to track the analytical accuracy of GE's contract laboratory throughout the program, represents the most accurate estimate of the actual Tri+ PCB surface concentrations in the Upper Hudson. Ultimately, any attempt to couple the 2002-2005 surveys with either of the prior surveys leads to the following quandaries, which cannot be resolved in a satisfactory manner, specifically:

- What is the basis to dismiss one set of composite survey results over the other? Both were collected by GE and its scientists and are presumably of comparable quality.
- The 1991 survey covers more of the TIP than the 1998 survey. However, the fraction of the TIP left unexamined by the 1998 survey is not so large that it should have resulted in

significantly overestimated rates of decay. Compare Figures 4a through 4i (1991 survey) with Figures 5a through 5i (1998 survey), which show the coverage of each GE survey compared to the nearby SSAP locations.[9] Note that while the 1998 survey is somewhat smaller in coverage, its nodes are more consistent regarding sediment type because 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). Notably, the best-matched composite sample pairs between the 1991 and 1998 surveys still yield a significant decline in Tri+ PCB concentrations.

- If both composite-based data sets are deemed representative, then what mechanism can be cited to explain the more than two-fold increase in mean surface concentrations from 1998 to 2002-2005? Notably, no parallel rise is observed in PCB concentrations in fish or water during this time period.
- If the 1998 survey is dismissed, as was done by NOAA, how can the lack of decline in surface sediments be reconciled with the observed declines in fish tissue and water column concentrations over the period 1991 to 2002-2005? These declines are evident even if the samples impacted by the 1991 Allen Mill release are excluded. This lack of parallel declines for fish tissue would imply a temporal change in the effective bioaccumulation factor, which is inconsistent with the current understanding of contaminant uptake by biota (Burkhard, 2009; Burkhard *et al.*, 2013). These observations are discussed in the next section.

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 are comprised of 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, sediment compositing itself may be a questionable technique due to the difficulties of achieving true homogeneity among discrete portions when concentrations can vary by orders of magnitude, and sediment textures can vary significantly in percent coarse *vs.* percent fines. It is EPA's opinion that 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. While the effective rate of decay in sediment concentrations used in the EPA model was approximately 8 percent per year and based on a 1991-1998 comparison, this rate is similar to those observed for water and many fish species, supporting its selection.

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[9] Note that these figures contrast the 1991 and 1998 surveys with the nearest SSAP locations based on a 100-ft radius around each composite sample node. The presentations made in Figures 2 and 3 are based on nearest neighbors within 50 feet of the composite sample nodes. However, the observations concerning the rates of change between surveys are approximately the same, regardless of the radius used.

Nonetheless, NOAA claimed the emulated models with updated sediment information showed that the EPA mechanistic model projections greatly overestimated recovery time in the Lower Hudson River fish. There is inherent uncertainty with any model estimates that impose limitations regarding how the information should be used. It should also be noted that with any modeling there is more uncertainty with predication over longer periods of time and when concentrations are lower. However, steps can be taken to identify and minimize the uncertainty but those uncertainties cannot be eliminated. EPA's mechanistic model prediction of 8 percent recovery and NOAA's emulated model prediction of less than 3 percent recovery face similar challenges regarding uncertainty. NOAA's prediction should certainly not be viewed with higher confidence. On the contrary, the availability of other lines of evidence that tend to be consistent with EPA's original predictions suggests that EPA's mechanistic model predictions should be viewed with higher confidence than NOAA's emulated model prediction. In any event, the degree of model uncertainty in this case is not sufficient to cause EPA to abandon its model projections at this time. As additional data on surface water, surface sediment and fish are collected under a long-term monitoring program, EPA will continue to consider the overall project predictions and protectiveness of the remedy consistent with the five year review process for Superfund sites.

4.2. NOAA's Estimate of the Rate of Decay of Tri+ PCB Concentrations in Sediments did not Consider the Rates of Decay in Fish and Water.

As stated above, NOAA placed much emphasis on its estimate of the rate of decay in surface sediments based on the comparison of the 1991 and 2002-2005 surface sediment surveys. However, its analysis did not examine the rates of decay in the matrices that are directly impacted by surface sediment PCB concentrations, namely the surface water and fish. As will be shown below, these matrices declined during the sediment monitoring period used by NOAA (1990-2005), as well as in the 11 years after completion of the modeling and prior to the onset of dredging (1998-2008). This latter period is effectively a period of Monitored Natural Attenuation (MNA) and provides a useful validation check on the model forecasts that were calibrated on prior years' data. Note that since the ROD and other project documents were written, the term "MNA" has been replaced with the phrase "Monitored Natural Recovery" (MNR) on most sites where active remediation has been completed and whose recovery is now being monitored by EPA. For consistency with project documents, we use MNA throughout this paper.

To ensure an estimate of fish tissue recovery rates that was unaffected by releases above Rogers Island or by dredging-related releases, EPA estimated rates of decay in fish tissue PCB concentrations for the period 1995 to 2008 (Figures 6a -6b and 7a-7d).[10] This time span was

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[10] Note that all fish tissue presentations in this paper are based on estimates of Tri+ PCBs, the sum of PCB homologue concentrations, as was done for all fish-related calculations in the ROD and supporting documents. Estimates of Tri+ PCBs are obtained by a linear conversion of the Aroclor-based concentrations reported by the NYSDEC and GE. An extensive discussion of the conversion calculation was provided in the BERA (EPA, 1999b) and by Butcher *et al.*, 1997. The calculations to convert Aroclor to Tri+PCB concentrations for the post-ROD data

important to focus upon because it represents the most recent time during which natural recovery alone occurred in the river. For some species at some stations, fish data are limited and span only a portion of this period. These were excluded from the long-term trend analysis and are not shown here. As discussed previously, the fish and water column data sets derived from sampling programs that were specifically desiged and conducted to monitor change over time and are thus superior to any sediment-based estimates of the decline in PCBs. For the Upper Hudson, both water and fish data are available for multiple locations to support long term estimates of recovery. The long term Upper Hudson fish data are shown in Figures 6a and 6b. Fish data for the four Lower Hudson stations are shown in Figures 7a to7d. Figure 7e compares the trends for smallmouth bass and all black bass at RM 152. For the MNA period, the rates of decline for these two data sets are approximately 10 percent and 8 percent, respectively. NOAA presents their data for black bass at RM 152 in Figure S-4 of its manuscript. This figure does not reflect the MNA period and instead applies a 3 percent decay curve over the entire period of record, including the period of dredging when fish tissue levels were impacted by the short-term dredging-related releases.

To further highlight the difference between white perch and other species in the Hudson, EPA developed a separate figure, Figure 7f, which represents white perch decay rate relative to other species tissue data (including smallmouth bass) and the observed changes in these species from upstream to downstream within the Lower Hudson. Upper Hudson water column data are shown in Figures 8 to 10. For the Lower Hudson, fish tissue represents the only matrix available to examine long term trends.

NOAA's use of fish data is presented in Figures 10 and S-4 of its manuscript. All of the earlier figures presented in their manuscript regarding fish tissue involved comparisons of EPA's mechanistic model results with those obtained by NOAA's regression model. No actual measured data were presented for these comparisons. These comparisons largely confirmed the ability of the NOAA model to replicate the EPA model output, and EPA does not have an argument with this replication at this time. However, NOAA did not take the next step, which would have been to examine how the extensive set of fish data across species and Hudson River fish sampling locations vary with time. EPA's review of the NOAA emulation is ongoing. NOAA chose to examine only two species at a single station. As EPA shows below, white perch not representative of the general trends observed across most species, and over the period of MNA, black bass decline at a rate between 8 and 10 percent per year. That is, most Upper Hudson fish and Lower Hudson River fish at RM 152 decline at rates and to concentrations consistent with those predicted by the models used by EPA. Notably, there are a few species that parallel the rates of decay observed in white perch (15 year half-life; Table 2 and Figure 7a).

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utilize the available PCB homologue results performed on a subset of the fish samples obtained since 1998, similar to what was done previously. Although the presentations here are based on Tri+homologue values, which represent the best estimates of the actual PCB concentrations in fish tissue, similar temporal trends are obtained if the analyses are repeated using the original Aroclor-based values.

However these rates of decay clearly are not characteristic of fish recovery in the areas most directly impacted by PCBs originating in the Upper Hudson and remediated under the ROD. As noted previously, this choice by NOAA to examine a limited portion of the available fish data, and not to focus on the period of MNA undermines its conclusions regarding the efficacy of the remedy.

4.2.1. Upper Hudson Fish Tissue Concentrations Decline at Rates Comparable to the Rate for Surface Sediment PCB Concentrations Given by the 1991 to 1998 Surveys.

EPA examined the available fish tissue records for many species with long-term records in the Upper Hudson. These data were found at two long-term monitoring stations, TIP (RM 189) and Stillwater (RM 168). The trends for species with long term records are shown in Figure 6a for the TIP and Figure 6b for Stillwater. To be selected for this calculation, the fish records had to constitute more than 20 samples and span more than 5 years. These considerations minimized uncertainties associated with estimating long-term decay rates based on very limited data or short monitoring periods. The decay rates and half-lives from this analysis are summarized in Table 1 of this paper. In each instance, the rate of decay for the lipid-normalized concentration in fish tissue was examined for the period 1995 to 2008 to obtain the longest trend under MNA conditions. In each instance, the trend in the data was estimated by an exponential decay curve, yielding an annual rate of decay expressed in percent per year as well as a half-life estimate.[11] As is evident in both the figures and table, the half-lives for fish tissue in the Upper Hudson corresponding to the MNA monitoring period range from 5 to 21 years (equivalent to 14 percent to 3 percent decline rates, respectively), with an average half-life of 7 years (equivalent to a 10 percent per year decline). The observed fish tissue half-lives compare favorably to the surface sediment Tri+ PCB concentration half-life obtained by comparing the 1991 and 1998 surveys for the TIP (8 years). More importantly, the rates of Upper Hudson fish tissue decline are much faster than the average decay rate estimated by NOAA for the Upper Hudson sediments (1.3 percent per year, equivalent to a 53 year half-life).

[11] Note that for both the fish and water column trend analysis, the period of time corresponding to the failure of the Allen Mill structure (aka the Allen Mill event) was excluded from the regression analysis. While this event was probably not large enough to change the surface sediment concentrations, it did change water column concentrations and appeared to impact fish tissue concentrations. By excluding the period of the event from the regression analysis, the calculated rates of decay reflect the sediment-driven water column and fish tissue concentration trends.

4.2.2. Lower Hudson Fish Tissue Concentrations Decline at Rates Comparable to the Rate for Surface Sediment PCB Concentrations Given by the 1991 to 1998 Surveys. White Perch do not Reflect Lower Hudson Fish Trends at RM 152.

EPA examined the available fish for the Lower Hudson as well. At RM 152, PCB concentrations in fish exhibit a range in the rates of decay, with an average decay rate of 8 percent, equivalent to a 9 year half-life. Table 2 summarizes the long term trends for eight species with long-term records at RM 152. These trends are shown in Figure 7a. In each instance, the available fish data between 1995 and 2008 are used as a basis for the rate of decay calculation. Like the Upper Hudson fish, the decay rate for Lower Hudson fish at RM 152 are also consistent with the rate of sediment decline used in EPA's mechanistic model.

The rate of decay for white perch at RM 152 is also presented in Table 2 of this paper. EPA obtains a rate of 5 percent per year for the 1995 to 2008 period, slower than all other fish at this stations except for channel catfish, but significantly faster than NOAA's sediment-based estimates of 1.3 percent per year (average) and 3 percent per year (upper bound). The EPA rate was determined for the most representative period, the MNA period (1995-2008), to estimate the decay rates in the post-remedy period,. As noted in their manuscript, NOAA used the period 1997-2014, which included the 6-year period of short-term impacts due to Upper Hudson dredging, thus yielding an underestimate of the likely rate of decay for fish tissue concentrations at RM 152.

Regardless of which value is used, however, it is also evident from the Table 2 that the NOAA-generated rates of decay are not typical of most fish at this station. In fact, even the EPA generated 5 percent decay rate is low relative to othe species at this station. Further downstream, at RM 113 (where consistent largemouth bass data can be obtained), fish decay rates are slower than those observed in the Upper Hudson and at RM 152. Even so, white perch does not reflect average decay rates for fish at this station (in contast to largemouth bass, which reflect the average decay rate for this station). Only at the farthest downstream stations does the decay rate of PCBs in white perch become representative of other species. It should be noted that the success of this project is not based on reducing fish consumption advisory for the slowest recovering fish species but overall recovery species by species and area by area over time.

The sum of these observations identify NOAA's selection of white perch as a surrogate for Lower Hudson fish to be poorly representative at RM 152, not supportable by the larger set of data, and resulting in an underestimated rate of decay that is not borne out by the period of observation (1995 to 2008) available for several other fish species at this station. Their selection of black bass at RM152, when examined for the period of MNA (1995 to 2008) is actually consistent with EPA's estimated rate of decay for fish tissue concentrations at this station.

In addition, NOAA's reliance on white perch data does not recognize that white perch is a small contributor (less than 8 percent) to the anglers' creel data (and thus the species weighted average) in the Lower Hudson. Most of the main contributors to the anglers' creel at RM 152 in the Lower Hudson exhibit half-lives (based on the data) of less than 10 years, matching the trend EPA estimated for Upper Hudson sediments as well as the general rate of decay for fish tissue forecast by EPA models. EPA notes that largemouth bass constituted 15 percent of the anglers' creel data for the Lower Hudson.

As part of this analysis, EPA also examined the long-term fish records available for the period 1995-2008 at Lower Hudson River locations RM 113, RM 90 and RM 50. These records are shown in Figures 7b, 7c and 7d, respectively and are also summarized in Table 2. It is evident from this presentation that decay rates decrease (*i.e.*, slow down) in the Lower Hudson, with the slowest decay rates found farthest from the Upper Hudson contamination. Also evident is the lack of increase in fish tissue concentrations at these stations in response to increased loads to the Lower Hudson during dredging, ulike at RM 152.

The decrease in decay rates at these stations is further illustrated by the two diagrams in Figure 7f. The left diagram shows all decay rate estimates for Upper and Lower Hudson fish plotted as a function of river mile, with the average decay rate per station for the given species also noted. The decay rates decrease from average rates of 8 to 11 percent per year in the Upper Hudson and at RM 152 to rates that approach zero change at RM 90. At RM 50, based on the Tri+PCB homologue estimates, lipid normalized concentrations actually appear to be increasing (*i.e.*, the decay rate becomes positive). The right side of Figure 7f shows the decay rates for the same fish species and stations based on the original reported sum of Aroclors in fish tissue. A similar decrease with distance downstream is seen in the decay rates although the average decay rate does not become positive (i.e,. indicative of an increasing trend) at RM 50.

The EPA draws two important conclusions from these results. First, that NOAA's analysis of white perch and black bass at RM 152 does not reflect fish tissue concentration trends for other species at RM152, which are declining at rates comparable to those observed in the Upper Hudson (on the order of 8 to 11 percent per year). These rates are consistent with those forecast by the EPA's models. Thus NOAA's forecasts of fish tissue decline for black bass and white perch do not accurately represent the community of fish tissue concentrations at RM 152. Second, that Lower Hudson fish tissue concentrations at and below RM 113 are less likely to be strongly linked to conditions in the Upper Hudson, given that the concentrations do not decline at rates comparable to those observed upstream. Additionally, fish tissue concentrations at these stations did not increase during the dredging period when loads from the Upper Hudson increased temporarily. This lack of response is distinctly different from the responses exhibited by most fish in the Upper Hudson stations and at RM 152. These observations suggest that Lower Hudson fish tissue levels may be additionally influenced by local factors that are unrelated to current Upper Hudson conditions, such as local sources and historical inventory. It is noted that fish tissue concentrations in the Lower Hudson are substantially lower than those in the Upper Hudson. This may offset the decreased rates of decay in achieving the remedial goals for fish in the Lower Hudson, but makes it ever more difficult to ascertain key factors that would hasten further declines. Resolution of this issue will require further monitoring by EPA.

4.2.3. Water Column Concentrations Decline at Rates Comparable to the Surface Sediment PCB Concentration Decline Rate Given by the 1991 to 1998 Surveys.

EPA examined the water column concentrations of Tri+ PCBs over two periods: one corresponding to the sediment monitoring period (1990-2005) used by NOAA and the other covering the 11 years after completion of the EPA modeling effort, up to the start of dredging (1998-2008). Water column monitoring data examined by EPA are restricted to the Upper Hudson. In particular, EPA examined the records at TI Dam (1997-2008), [12] Schuylerville (1991-2008),[13] and Waterford (1990-2008). These periods combine available data from the USGS and from GE.

The time trends for Tri+ PCB concentrations at these stations are shown in Figures 8 to 10. Table 3 presents the half-life and rate of decay estimates based on the available data. Water column concentrations at nearly all stations decline with half-lives on the order of 5 to 10 years for the two periods examined.[14] Like the fish tissue data, these results are consistent with the half-life suggested by the 1991-1998 sediment survey comparison but not with the half-life developed by NOAA. These empirically-based observations of water column and fish tissue data continue to give EPA an added degree of comfort regarding the use of the sediment PCB decline parameter value within the mechanistic model of 8 percent per year. While the uncertainty in this value is discussed above, EPA also maintains that it was (and remains) adequate for its intended use in the EPA modeling that supported the ROD.

4.3. The Data Used to Calibrate the EPA Models Show a Consistent Rate of Decay.

The various lines of evidence described above all indicate similar rates of decay in Tri+ PCB concentrations in the data used to calibrate the EPA models. Specifically, the trends apparent from the fish tissue, water column, and 1991-1998 sediment survey data all yield similar,

[12] The TI Dam station is limited to data collected at TID PRW2 and the TID transect stations collected downstream of the dam, which are considered representative of mean water column concentrations at the TID..

[13] The Schuylerville trend is based on the use of two closely located stations; the Rt. 29 Bridge (used by both GE and the USGS) and the GE transect station.

[14] The rate of decline for 1990-2005 at Waterford yields a 14 year half-life with a high degree of uncertainty, reflecting relatively sparse data for this time interval. However, the overall rate of decline for the period 1990 to 2008 yields an 11 year half-life, consistent with the other water column and fish records.

consistent rates of decay with half-lives on the order of 5 to 10 years. These data sets represent an internally consistent calibration data set that was used to develop the HUDTOX and FISHRAND models. While it is likely that the composite sampling surveys may not have accurately captured the true surface sediment Tri+ PCB concentrations, it would appear by correlation to both the fish and the water column concentrations that the composite sampling captured the rate of decay quite accurately. With the control of PCB releases above Ft. Edward completed over the 1989-1996 period, the sediments become the main reservoir and essentially the driving source of contamination to the water column and fish of the Upper Hudson. Thus, it is expected that the rates of decay in Tri+ PCB concentrations in water column and fish tissue should parallel the rate of decay in surface sediment concentrations (Burkhard, 2009, Burkhard et al., 2013).

While it remains unclear how the change in concentrations between composite surveys could yield an underestimate of the actual surface concentrations while also yielding a rate of decay which parallels that of the fish and water columnrate of decay, the evidence would suggest that this is the most comprehensive way to interpret the available data. Indeed, the observed parallel behaviors of the sediment, water column, and fish tissue PCB concentrations are what is expected from geochemical and biochemical theory. More importantly, these parallel behaviors of Tri+ PCB concentrations in the three matrices indicate that the rate of recovery estimated by the EPA models is not implausibly optimistic, but rather is consistent with the available observations. At a minimum, the uncertainty in the analysis of the available data does not support the need to immediately expand the scope of the remediation as suggested by NOAA. Rather, this uncertainty supports the original plan laid out in the ROD: to monitor the sediment, fish, and water over the next several years and further into the future and to assess the recovery of Tri+ PCB concentrations. The technical points and suggestion made by NOAA will be evaluated further in the upcoming five year review.

It should also be noted that the Hudson River Dredging Project has specific criteria that would need to be met before any additional remdial work could be required. EPA has been clear that these criteria have *not* been met at the present time.

5. NOAA's Assertions on Surface Sediment Trends Did not Consider Major Sediment Transport Events Within the Last Decade.

NOAA used data sets from 1991 and 2003 to draw conclusion about sediment, water, and fish recovery. Those data sets are now over a decade old. More recent data collected from 2011 to 2013 (*i.e.,* the DDS program) was not included in NOAA's analyses. NOAA also made no mention the potential impacts from three major storm/flood events that occurred in the Hudson River in recent years. Although the effects of these events on surface sediments in the Hudson River are not yet well understood or quantified, it is reasonable to expect that some changes have occurred. The likely result of these events is the reduction of sediment concentrations due to physical processes such as sediment redistribution and the introduction of cleaner sediment from upland areas into the system. The potential impacts of these floods require further evaluation and are a consideration for EPA in the upcoming five year review. In addition, during the remedial action GE placed large quantities of clean backfill over dredged areas in the Upper Hudson. The following is a brief description of the flood events and considerations related to placement of backfill during the remediation.

<u>Spring 2011: Upper Portion of the Upper Hudson River – 100 year flow event.</u> This event was significant in the upper portion of the Upper Hudson River (from Fort Edward extending about 30 miles downstream). USGS gage data at Fort Edward indicated a flow of about 50,000 cubic feet per second, which is 10 times mean flow in this part of the river (an approximate 100 year flood). This event was caused by a rain event and significant snow melt. Aerial photography was collected by GE (at EPA's request) and indicated vast areas of flooding. Bathymetry surveys taken after the event were compared to pre-event surveys. Overall the river bottom did not change significantly, but some areas were identified as having some measureable sediment loss. It is reasonable to anticipate that some near-surface sediment changes occurred during this event. Upper River tributaries such as the Snook Kill, Batten Kill, and the Hoosic River discharged substantial quantities of upland sediment into the Hudson River during the event.

EPA, in close cooperation with NYSDEC, conducts an annual floodplain deposition study in the UHR that began in 2010. Prior to 2010 flood deposition sediment samples were collected by NYSDEC. EPA refers to this sampling as "flood mud sampling." The purpose of the flood mud sampling program is to monitor and evaluate the potential deposition of PCBs from within the Hudson River to its floodplain following significant flooding events. As previously discussed, there was a significant flood event in the UHR in the spring 2011 which deposited flood mud outside the banks of the river and within the UHR floodplain. Immediately following the flood event EPA, NYSDEC and GE mobilized to conduct a flood mud sampling event that was larger and more comprehensive than the regular annual sampling. The 2011 sampling event included collection of 191 samples (including appropriate QA/QC samples) for PCB analysis. The average PCB concentration for the post flood 2011 sampling event was 0.63 ppm, the highest concentration was in RS 1 (4.8 ppm), 39 samples were slightly greater than 1 ppm, 14 samples were reported as not detected and the remainder were less than 1 ppm (GE, 2012; EPA, 2013). These flood mud results are consistent with the low level surface sediment concentrations measured during the DDS program and are generally representative of sediment redistribution. and the introduction of cleaner sediment from upland areas into the river system associated with this flood event.

<u>Fall 2011: Lower Portion of the Upper Hudson River – Storms Irene and Lee - August – September 2011.</u> Hurricane Irene and Tropical Storm Lee in 2011 produced intense precipitation and flooding in the Hudson River watershed (primarily RS 3 and the Lower Hudson River). Sediment input to the Hudson River was reported to be several times the long-term annual average. In particular, the Mohawk River delivered substantial sediment loads just above the

Federal dam at Troy, and therefore to the Lower Hudson River during both storms. Additionally, significant flooding occurred in the area of the Hudson River around Waterford and Albany largely due to the combination of Mohawk and Upper Hudson flows. Farther downriver, storm activity from Irene suspended sediment, which covered submerged aquatic vegetation. Significant vegetation losses were reported. In addition, Irene scoured the bottom of the Hudson in some areas, washing away submerged aquatic vegetation. While Irene did push storm surge up the Hudson, the flooding associated with the storm came mostly from heavy rains and the resulting runoff. Superstorm Sandy had a stronger storm surge pushing up the Hudson River.

Fall 2012: Lower Hudson River – Superstorm Sandy - October 2012.The effects of Sandy in comparison to Irene were short lived. Sandy swelled the Lower Hudson with tidewaters, increasing salinity and turbidity, but these effects ended as the tide retreated, rather than lasting for weeks, as was the case with Irene. Storm surge from Sandy was more than 11 feet at Albany. The USGS's gage at Poughkeepsie recorded its highest water level ever during Sandy. Sandy also played a role in lower river submerged aquatic vegetation losses due to burial by sediment.

Clean Backfill Placement 2009-2015. In addition to the natural events impacting surface sediment conditions, NOAA also did not consider the fact that the placement of backfill into CUs after dredging introduced large quantities of clean sediment into the Upper Hudson River system. It was unavoidable that some backfill was distributed by resuspension in the water column or as a result of increased flow along the river bottom prior to its consolidation. The degree of effect stemming from these processes in reducing surface sediment in areas outside of the CU boundaries is not known, but it is expected that some benefit to surface sediment PCB reduction occurred. The potential reduction of surface sediment concentrations outside of dredge areas due to placement of approximately 2.75 million tons of clean backfill into the Upper Hudson River was not mentioned or considered in the NOAA analysis.

6. NOAA's Discussion Focuses on the Absolute Change in Tri+ PCB Concentrations when the Main Goal of the Remedy is a Relative Reduction in Tri+ PCB Concentrations.

The parallel declines of sediment, water, and fish tissue concentrations described above reflect standard geochemical and biochemical theory that relates the behavior of persistent organic compounds such as PCBs in nature. That theory holds that relationships among these media are governed by linear relationships, such that a partition coefficient (K_{oc}) or biota-sediment accumulation factor (BSAF) can be used to estimate water or fish tissue concentrations given sediment concentrations (EPA, 2002; Burkhard, 2009; Burkhard *et al.,* 2013). These relationships can be derived from thermodynamic considerations, if equilibrium among the media is assumed. Based on these linear relationships, if a tenfold reduction in fish tissue body burden is desired, then a tenfold reduction in the media causing this body burden (*i.e.,* sediment and water) must be achieved. The corollary to this is that fish tissue will only decline when there is a reduction in the exposure media. Thus, the parallel declines of fish and water described above (and sediment if the 1991-1998 data are used), are expected given this theory.

This fundamental theory also recognizes that differences in sediment type, organic carbon, and ecological setting can affect these coefficients (e.g., K_{oc}, BSAF), so while the relationship among PCB concentrations in these media may be linear, the coefficients themselves are subject to change and reflect local conditions.

One of the goals of the remedy is to reduce surface sediment PCB concentrations and the sediment PCB inventory so as to cause a reduction in fish tissue concentrations. Because PCB concentrations in fish tissue proportionately reflect their environmental exposure to PCBs, the goal of the remedy is produce a reduction in surface sediment Tri+ PCB concentrations proportional to the targeted reduction of Tri+ PCB concentrations in fish tissue. Thus, NOAA's concern that PCB concentrations in sediment were shown to be much higher than expected is not a significant issue for the river sections where the degree of reduction achieved by dredging is comparable to that anticipated by the ROD. For RS 1 and RS 3, the percent reductions in surface sediment PCB concentrations achieved by dredging are comparable to those expected by the ROD. Only in RS 2 did the dredging result in a smaller proportionate reduction than expected (67 percent *vs.* 85 percent, meaning that proportionately, the post-remedy average concentration is about twice as great as targeted; see Appendix A of EPA, 2012).[15] Given that both RS 1 and RS 3 achieve reductions proportionate to or greater than those anticipated by the ROD, and that RS 2 achieved only half of the anticipated reduction, it is EPA's opinion that NOAA's retrospective analysis has limitations and does not support the need for additional dredging at this time. EPA will be reviewing all the available data including the analysis prepared by NOAA during the next FYR.

7. NOAA's Analysis Did Not Examine the Available Temporal Trends during the Period of MNA 1995 to 2008 to Test its Assertions Regarding the Rate of Sediment Recovery.

There is only one period of time in the site history where the impacts of natural recovery alone can be estimated, specifically the period beginning around 1995 and ending at the close of 2008, just prior to the start of dredging. The period prior to 1995 is more difficult to use due to the influence from upstream sources at the GE Fort Edward Plant, the GE Hudson Falls Plant and the remnant sites. It is generally accepted by NYSDEC and EPA that by the 1995 to 1998 time frame, sources that would substantially influence water and fish were generally brought under control. Similarly, though perhaps to a more limited degree, it is also difficult to assess natural recovery in fish and water between 2009 and 2015 due to PCB exposures in the vicinity of dredging areas; thus related to disturbances from implementation of the remedy. These periods of natural recovery and disturbance apply equally to assessments of both the Upper Hudson River and the Lower Hudson River. When evaluating relative rates of recovery in a river system such

[15] Since Tri+ PCB surface concentrations in RS 2 are about twice as high as expected, it is anticipated that this river section will achieve the desired reduction approximately one half-life later than originally estimated. Given that half-lives for Upper Hudson matrices are on the order of 5 to 10 years, this river section is expected to achieve its desired reduction about 5 to 10 years later than originally estimated.

as the Hudson, the best indicators of recovery are the fish and water. Recovery rates in sediment are more difficult to measure and the relationship between sediment and fish concentration are more difficult to determine. Note that for the Hudson project reducing restrictions on the consumption of fish is a key project goal. In New York State, the Department of Health (NYSDOH) administers and reviews fish consumption advisories annually.

8. NOAA's Statistical Emulation of the Output of the EPA Models was an Appropriate Approach to Test Variations in Post-Calibration Conditions. It was not an Appropriate Approach to Test Changes in the Model's Initial Conditions.

It was evident from the manuscript that NOAA spent considerable effort and resources to emulate the mechanistic fate and transport models and the probabilistic bio-uptake models developed by EPA. NOAA used straightforward regression analysis to generate statistical models capable of replicating many of the complex relationships among flow, location, sediment concentration, water column concentration, and fish tissue concentration. To accomplish this, NOAA included both linear and non-linear relationships among the variables. EPA agrees that in general this was an acceptable approach, given that the expected linear or non-linear relationships among variables are already established by the mechanistic model. That is, the regression should use the same set of variables in the same form (x, x^2, $1/x$, $x^{1/2}$, *etc.*) as are used in the mechanistic model.

EPA further notes that the regression model results do not exactly match the mechanistic model output (see NOAA manuscript Figure 4. These differences between the regression model and the mechanistic model outputs are incorporated in NOAA's estimates of the confidence limits around the mechanistic model forecasts. That is, the true uncertainty in the mechanistic model may be smaller than the estimate generated by NOAA's regression model shown in Figure 12 of the NOAA manuscript.

In addition to developing a regression to emulate the EPA model, NOAA also used its regression model to run other scenarios not examined by EPA. EPA has major concerns with NOAA's application of its regression model as discussed below.

8.1. NOAA's Incorporation of the 2002-2005 Data Set Effectively Changed the Initial Conditions of the Model and Cannot Be Supported.

NOAA used its regression model to create a new scenario for the Upper Hudson, incorporating both their upper bound estimate of the decay rate for surface sediment concentrations of Tri+ PCB (3 percent per year, a 23 year half-life) as well as the Tri+ PCB surface sediment concentrations obtained by the 2002-2005 investigations. Both of these adjustments are questionable given the basis for NOAA's regression model. The regression model developed by NOAA effectively incorporated the various calibration settings that were used to match the observed decline rates in sediment, water, and fish. This includes terms like sediment mixing, sediment-water exchange, bio-uptake factors, etc. These terms represent mechanisms that are interrelated and whose coefficients were optimized with respect to one another during the mechanistic model calibration. By emulating the EPA model, NOAA built the net result of these processes into the terms of their emulation model. It is not appropriate to modify one mechanism (*e.g.,* the rate of sediment mixing by way of limiting surface sediment concentration decline) without recalibrating the other mechanistic terms in the model for the purpose of generating a revised model forecast, as was done by NOAA. That is, it is not appropriate to set the surface sediment concentrations to meet the 2002-2005 conditions and then compare the emulation results to current conditions or use the emulation output as a basis to predict downstream impacts. This is because the internal mechanisms in the NOAA model have not been recalibrated to balance the revised sediment conditions with the concurrent measurements of PCB concentrations in fish tissue and the water column.

Use of the 2002-2005 data in this fashion is effectively changing the initial conditions of the EPA model, a process that requires recalibration of the EPA model and, therefore, NOAA's emulation of that model. This need is further illustrated by examining the model formulation developed by NOAA in Appendix A of the manuscript. The formula describing Upper Hudson PCB loads (L_i) is given as equation A1 (Field *et al.,* 2015):

$$
\begin{aligned}
L_i = \; & L_{i-1} \times (1 - g_i \times \delta_i) \\
& + \{\gamma_i \times (c_{si} \times \;) \times (1 - g_i \times đ_i) \\
& + \beta_i \times (R_i \times c_{si} \times A_i)\} \times Q_i
\end{aligned}
$$

A detailed discussion of this equation is provided at Field *et al.*, 2015, Appendix A. In this equation, the coefficients δ_i and γ_i were developed as empirical coefficients relating surface sediment and water exchanges of PCBs. These coefficients were optimized to match the mechanistic model output, which in turn was based on the data from the initial conditions and calibration period. These coefficients balance the processes, so that the model accurately predicted the water column concentrations and the fish tissue concentrations of the calibration period as well as the surface sediment concentrations originally used to calibrate the EPA model. However, if substantially higher surface sediment concentrations from the 2002-2005 data are inserted into the EPA model, then the EPA model will no longer accurately predict the surface water and fish tissue concentrations used in the calibration without re-optimization of the EPA coefficients. Since the NOAA regression model is intrinsically tied to the EPA calibration, the NOAA regression model would require the same re-optimization.

This can be seen from a HUDTOX model sensitivity analysis that was done as part of the Phase 1 Evaluation (LTI 2010), presented in Figure 11. In this analysis, the HUTOX model was run while forcing the surface sediment to match the 2002-2005 conditions. The figure shows the impact on Tri+ PCB load estimated by the model. For the entire period examined 1998-2008, the revised model scenario (pink symbols) overestimates the load to the Lower Hudson. The scenario that uses the original calibration but the actual flows for the period (red symbols) most closely tracks the empirical estimates of load based on the data (green symbols). This sensitivity analysis demonstrates that the exchange coefficients developed for the original calibration will not work if the actual surface concentrations are much greater than originally thought. To use the new information on surface sediment concentrations, the model must be recalibrated, including optimizing the exchange coefficients so that it accurately predicts the measured PCB levels in the other two matrices, water and fish, which were also measured in 2002-2005.

For these reasons, the NOAA analysis using the 2002-2005 data is not supportable. Forcing the model to comply with the 3 percent decay rate is effectively changing mechanisms internal to the model, while failing to recalibrate the other related mechanisms. Similarly, NOAA's use of the 2002-2005 data is effectively changing one matrix, without using the available data on other matrices to properly recalibrate the exchange coefficients with these matrices. This scenario may be an interesting numerical experiment, but it cannot be used as a basis to conclude that the model is over-predicting the rate of recovery. An assessment of the model concerning the accuracy of its fish forecasts can only be determined by a recalibration of the model to all of the available data, or by monitoring the post-remedy conditions to determine if the actual rate of recovery is adequately similar to that originally estimated by the model.

On a related note, as mentioned above, EPA conducted a sensitivity analysis of the HUDTOX model results using the 2002-2005 data set and showed that the model no longer matched water column loads. However, this analysis did show the need to use the measured flow information during the period of comparison (1998-2008), rather than the original forecasted flow estimates made in 1998. The actual flow data provided a better fit. It is not clear to EPA whether NOAA used the revised flows in attempting to match the 1998 to 2008 data.

8.2. NOAA's Estimate of the Impact of Additional Dredging is Not Supportable

NOAA used the model scenario with the modified recovery rate (3 percent per year) and revised sediment concentrations (2002-2005) to test the impact of dredging an additional area in RS 2. This exercise is effectively just another numerical experiment because the internal factors to the fate and transport model as well as the exchange coefficients to sediment and water were set by the original initial conditions and calibration period. While it is not surprising that fish tissue would be predicted to respond to an increase of the dredging footprint by nearly 40 percent, it is not clear what the rate of recovery would be or what the time to achieve a fish advisory level would be after the dredging was completed, for all the reasons discussed above. That is, the exchange coefficients originally developed for the model would not apply to the post-remedy period because they were based on different initial conditions. NOAA's calculation of the post-remedy rate of recovery is inherently linked to exchange coefficients that were not properly calibrated. The calculations therefore are not representative of the system that they seek to emulate.

9. Analysis of Temporal Trends in Surface Sediments from other Sediment Survey Pairs Yields a Wide Range of Decline Rates, although the Most Recent Sediment Survey Pairs Yield Half-Lives on the Scale of 5 to 10 years.

In the discussions below, the surface sediment PCB concentrations from the most recent sediment survey, the DDS program conducted between 2011 and 2013, are contrasted with the 2002-2005 SSAP results. In addition, estimates of the rates of decay between all possible pairings of the various surface sediment surveys are compiled. The results of this compilation show that decline rate estimates can vary widely, but that the most frequent estimates are consistent with the rates of decay observed in the fish tissue and water column during the period 1998-2008 as described in Section 4.

9.1. Analysis of Temporal Trends in Surface Sediments from 2002-2005 *vs.* 2011 to 2013 is Consistent with the Rate of Decay Observed in Fish Tissue and Water Column Concentrations.

The analysis of sediment trend completed by NOAA focused on a single pair of surveys: the 1991 GE composite survey and the 2002 to 2005 SSAP. However, there are a total of four surveys which can be examined to assess the rate of decay in surface sediments. In this section, the results of the most recent study completed by GE under EPA's direction (DSS) are compared with the SSAP data to examine the most recent rates of change. The DDS program was completed between 2011 and 2013, and examined surface sediment in all three river sections. The study was done sequentially, with RS 1 completed in 2011, RS 2 completed in 2012, and RS 3 completed in 2013.

The goals of the DDS program are described in more detail in Section 3 of this paper and are summarized here:

- Establish a basis for long-term monitoring of the river post remedy.
- Examine whether surface sediment concentrations change due to dredging-related resuspension and re-deposition.

Similar to the SSAP program, the DDS program was not designed as a basis to examine changes in river bottom PCB concentrations since the prior study. Thus, its use here, like the previous comparisons made between the SSAP and earlier programs made by both EPA and NOAA, must recognize the uncertainty derived from comparing studies with differing investigative objectives.

The DDS program involved the use of sediment grab samplers to obtain surface sediments between 0 and 2 inches, mostly by a Van Veen sampler equipped with a lander to aid in obtaining reproducible sampling depths. This technique differs from the SSAP program, which obtained surface sample segments (0-2 inches) via sediment vibracoring.

The DDS program varied in its sample handling by river section. In RS 1, individual sampling locations were treated as discrete samples, yielding approximately 60 samples representing 60 locations. In RS 2 and RS 3, samples were composited so that one sample result would represent two to four locations. Approximately 25 samples represented 75 locations in RS 2, and 30 samples represented 90 locations in RS 3. 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 RS 1 and RS 2. Thus, discrete samples were obtained in RS 1 in June of 2011, prior to the start of dredging and in November 2011, after dredging was completed. The sampling in RS 2 followed the same regimen in 2012. In creating composites in RS 2, 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 RS 3 was conducted in August 2013, and did not examine pre- and post-dredging impacts in that river section. Note that in RS 1 and RS 2, 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.

While not presented here, one of the important observations from the DDS program came from the matched samples collected before and after dredging. For both RS 1 and RS 2 and for locations inside and outside of the CUs, there was no discernable change in the average Total 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 agreed on average, 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 May of 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 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. When compared to the SSAP program, the results of the DDS sampling suggest this was not the case. This is further discussed below.

9.1.1. Comparison of the DDS Results to the SSAP Program Yields Declines in PCB concentrations for both Targeted Pairs and when the Entire Data Sets are Considered.

Similar to the previous 1991, 1998, and 2002-2005 surveys, the DDS program attempted to represent surface sediment concentrations. Like the other surveys, it was not intended to characterize long-term trends across the entire Upper Hudson. However, with some care, the DDS and SSAP results can be matched to yield an estimate of the rate of decay of surface sediment PCB levels. The results of the DDS and SAP program are discussed below and compared in Figures 12, 13 and 14, corresponding to RS 1, RS2 and RS 3, respectively. The results are also summarized in Table 4 of this paper. As mentioned above, the goals of the DDS program were focused on long term post-dredging monitoring and the impacts of dredging on areas outside the CUs. As such, the locations selected for DDS sampling were largely SSAP locations that met the criteria described in Section 3.1.4. That is, these SSAP locations were selected and then re-occupied (or targeted for a new measurement) under the DDS program to assess how much the PCB concentrations had changed at the SSAP locations. However, the SSAP locations were not selected to assess how the entire river section had changed, but rather how areas close to the dredging had changed. If assessing changes in conditions for the entire river section were the DQO, then care would have been taken to ensure that the distribution of the PCB concentrations targeted by the DDS program would have been a representative subset of the SSAP program.

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. While EPA recognizes that this analysis is another exercise in comparing sediment surveys for purposes other than what was originally intended, the analysis is presented here to further emphasize that sediment comparisons can yield a wide range of rates of decay.

Recognizing that the DDS locations were not selected in a statistical fashion, it is important for this comparison to assess how the median of the re-occupied (*i.e.,* targeted) SSAP sites (locations chosen to be resampled by the DDS program) compared to the overall SSAP distribution in that river section. To the extent that the subset of SSAP locations selected for re-occupation under the DDS program was a representative subset of the SSAP locations, then changes in surface PCB concentrations relative to the DDS results can be assumed to apply to the SSAP data set as a whole. If this is not the case, the inference about potential changes in the SSAP concentrations relative to the DDS results is much more limited. Since the DDS program was also divided by inside and outside CU areas, this examination will include this subdivision as well.

Ideally for the comparison to find changes in PCB concentrations over time between the SSAP and DDS surveys, the mean, median, and variance of PCB concentrations for the subset of targeted SSAP locations reoccupied during the DDS should be the same as that for the whole population of SSAP locations in each river section. In the event that the targeted locations have a higher mean (or median) PCB concentration than the population of SSAP locations as a whole, then 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, a process referred to as "convergence to the mean," This 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 due to the limited numbers of DDS samples available in some river sections and the skewness of the PCB concentration distributions.[16] In each comparison, the median for all SSAP data in the subdivision (*e.g.,* all 2002-2005 samples in RS 1 inside CUs) is compared to the median of the SSAP values for the targeted sites (*e.g.,* 2002-2005 locations in RS 1 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 12 to 14, corresponding to RS 1 to RS 3, respectively. The results are also summarized in Table 4.

In RS1, the comparisons show that the median of the SSAP targeted locations agrees within error with the median Total PCB concentration for all SSAP RS1 locations (although the median of the targeted locations outside the CUs appears to be low). However, 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.

In RS2, the targeted locations are statistically higher than the population as a whole for both inside CU and outside CU subdivisions. Thus, we might anticipate a change in the DDS concentrations relative to the targeted locations due to convergence to the mean. However, the DDS results are still statistically significantly lower than the entire population of SSAP samples for each subdivision as well as the targeted locations.

Finally in RS3, the targeted locations are the same as or lower than the entire population of SSAP samples for the subdivision. Here again, the DDS locations are lower than the entire population of SSAP samples and lower than the targeted locations in the case of the outside CU subdivision.

Overall, these results show that the DDS samples are consistently lower than the entire population of SSAP results for each river section, for areas inside or outside the CUs. In most instances, the DDS results are also lower than the subset of the targeted SSAP

[16] 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 substanitive skewness, as was the case in this analysis.

locations as well. The significant 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 have declined between the 2002-2005 and the 2011-2013 periods throughout much of the Upper Hudson.

9.1.2. Comparisons between the DDS Results and the SSAP Results Yield Rates of Decay Consistent with those Observed for Fish Tissue and Water Column Tri+ PCB Concentrations.

Before presenting any compilation of the half-life estimates for the rates of decay between the SSAP and DDS programs, it is important to reiterate EPA's position on the use of these and GE's earlier surveys of the surface sediments. Specifically, it is EPA's opinion that the use of the available sediment survey data as a basis to determine the rate of decay of Tri+ PCB concentrations in surface sediments in the Upper Hudson is highly uncertain. 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 objectives other than monitoring changes since previous surveys. As such, their comparisons can only provide a general but uncertain indicator of the rate of change.

The data for the DDS and SSAP programs are presented in a box-and-whisker format for each of the subdivisions described above. Figures 15 to 20 present the comparison 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. The figures show the distributions of the entire data set in each instance and not simply the uncertainty on the median, as was shown previously. In the previous presentation, the figures identified the statistically significant differences between the data sets. In this presentation, the diagrams provide a visual comparison of the sample populations themselves. Also shown is the rate of decay between the surveys, expressed as a half-life. In all instances the half-life falls between 3 and 12 years, with an average half-life of 6 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.

9.2. Analysis of Temporal Trends in Surface Sediments Across all Available Surveys Yields a Wide Range of Decline Rates, Although the Most Recent Survey Pairs Yield Half-Lives on the Scale of 5 to 10 Years.

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, EPA estimated the half-lives across nearly all possible pairings of the four available 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, since this survey only covered RS 1. The results based on comparing changes in the median concentration in each group are provided in Table 5a and 5b of this paper. EPA has chosen the median as a basis to estimate change due to the smaller sample sizes in the DDS and 1998 GE data sets. Given the high variability that is characteristic of these datasets (for example see Figures 15 to 20), 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 are shown in Table 5a and 5b, 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 between both of the earlier GE studies and the SSAP program. NOAA calculated long half-lives between the 1991 GE and 2002-2005 SSAP programs, based on average concentrations. EPA did not attempt to replicate these calculations based on medians, since the NOAA estimates were based on pairing relatively large data sets.

Perhaps most notable is the consistency of the half-lives obtained by comparing the SSAP and DDS programs. These half-lives fall between 3 and 12 years and are consistent with the 1991 to 1998 comparisons as well as the fish and water column trends. Figures 21 and 22 present the information contained in Table 4 graphically. In Figure 21, 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 5a and 5b were averaged, so that each survey pair is not represented by more than two values for each river section.[17] Figure 22 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 15 percent per year to an increase of more than 12 percent per year. Also shown on the figure are the average rates of decay for fish at the TIP and RM 152. Again, these figures serve to emphasize that sediment surveys that were not designed to define temporal trends are not an appropriate way to determine the rates of decay, and as such will provide a highly uncertain estimate for this parameter.

Figure 23 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 Review (EPA, 2010). The figure presents the estimated mean Total PCB concentration for all sediments in RS 1 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 RS 1 bracket the model trajectory for that year, which is an encouraging finding. However, EPA did not prepare this diagram to indicate that the sediments are now on track, but rather to emphasize that the sediments do not provide a definitive answer regarding the changes through time.

While the agreement between the fish, water, and many of the sediment half-lives could be used to conclude that the remedy can be expected to behave as forecast, EPA recognizes that each of

[17] 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. The NOAA estimates were presented as shown in the table.

these half-life estimates as well as the EPA model forecasts are just that, forecasts, and cannot be assumed to be precise predictions of future behavior.

10. Discussion of Key Project Time Periods and Assessments of Recovery

Due to proximity in time to releases or project activities, there is only one period of time in the project that is available to directly measure natural recovery (~ 1995 to 2008, just prior to dredging). The period 1995 to 1998 is a little more difficult to use due to the influence from upstream sources at the GE Fort Edward Plant, the GE Hudson Falls Plant, and the remnant sites. However, it is generally accepted by NYSDEC and EPA that between 1995 and 1998 potential sources that would substantially influence sediment and water (and thus fish tissue) concentrations were for the most part brought under control. Similarly, it is also difficult to assess natural recovery in fish and water between 2009 and 2015 due to implementation of the remedy. This applies equally to assessments of both the Upper Hudson River and Lower Hudson River.

Overall, when evaluating relative rates of recovery in a river system such as the Hudson, the more straightforward indicators of recovery are the fish and water data. Estimating recovery rates from sediment data is more challenging than estimating recovery rates from fish and water concentrations because localized variability in sediments can be high. This was observed among co-located SSAP cores, making it difficult to estimate overall surface concentrations. In addition, the Upper Hudson River sediment data sets were not specifically designed to assess changes in concentrations over time. In contrast, the water column and fish programs were designed to evaluate changes in PCB concentrations over time. For the Hudson project, the overall reduction in sediment concentrations is an important component of the remedy. However, recovery in fish tissue PCB concentrations that will allow reductions in the restrictions on the consumption of fish is a primary project goal.

During project development, including remedial alternative evaluations and associated recovery estimates, it was assumed that dredging would begin in 2004, and it would be accomplished using an upstream to downstream approach (necessary to minimize impacts from resuspension). However, implementation of the dredging remedy (2009-2015) presented several engineering challenges (such as dredging in very shallow areas and near dams) which made it difficult to adhere to this approach without significant delays. The results of the re-deposition study for RS1 (currently in preparation by EPA) indicated that resuspension due to dredging was not as great a concern as anticipated in the ROD or during initial project design. As a result, EPA authorized dredging in a general upstream to downstream fashion, while skipping over the areas that presented engineering and logistical challenges until they could be worked out (e.g., CU 60—just north of TID and the "landlocked" section of the river between the TID and the Northumberland dam). The result was that dredging occurred in multiple river section at the same time, including in the last year of dredging in 2015. In addition, during project planning it was assumed that one facility, that would process dredged material, would be located downstream of most dredging operations. During facility siting EPA determined that the project could be implemented efficiently with a single facility in Fort Edward Fort Edward (upstream of almost all of the dredging) and that a second downstream facility at the southern end of the project area was not needed.

Dredging in multiple river sections, while transporting dredge materials to the upstream facility, resulted in significant simultaneous activity occurring throughout the project area during dredging. These activities included more than 90,000 barges miles logged, over 5,000 barges unloaded, and more than 20,000 trips through the New York State Canal Corporation locks. The sum of these project activities had the potential to result in anticipated localized increases in PCB exposure levels in water, and therefore in fish tissue PCBs. PCB levels in the water column and fish were closely monitored throughout the implementation of the project and engineering adjustments were made as necessary.

Given the sum of the activities described above, trends in the observed fish data between 2004 and 2014 suggest that tissue recovery has not occurred as forecast by the model established during the remedy decision phase of the project. The trends reflect that PCB congener homologue based lipid-normalized fish tissue concentrations (Figures 6a-6b and 7a-7b) for pre-dredge (2004-06) and near-term post-dredging (2014) periods are similar. Note that this pattern is also reflected in Aroclor (wet weight) based species weighted average data for these periods. It is not unexpected for a large complex project such as this one to encounter challenges to its implementation that may not have been anticipated by the modelling and operational assumptions outlined in the ROD, and to respond with necessary adjustments. It is also possible for those adjustments to affect the rate of recovery originally projected in the ROD. However, the lack of a decline during this period was not unexpected because, due to implementation adjustments, dredging was not implemented as an upstream to downstream operation as envisioned within the ROD. When implemented, it included periods of simultaneous dredging at several locations along the entire course of the project area. Although the factors described above may have delayed the expected recovery in the river when compared to the model estimates, these changes were necessary to avoid potentially longer delays in the overall time to implement the remedy and to facilitate system recovery. Therefore, we expect some delay (several years) to the original fish recovery targets predictions. For example the first fish target predicted to be achieved is the 0.4 mg/kg (wet weight species weighted average) in RS 3 immediately following the end of dredging (year 0 of the recovery). Although the 2016 fish have not yet been collected, it is unlikely that this target will be met for several years as described above. Other targets are expected to be affected in a similar manner. It is anticipated that through the implementation period, recovery has been occurring in localized areas less affected by project activities. The yearling fish collected in the fall of each year will continue to provide a good indicator of recovery in localized areas. EPA will continue to review the monitoring program and the data it collects as part of the next five year review

11. Integration of Analyses

In the discussion above, EPA identified a large number of shortcomings in NOAA's analyses supporting their conclusion that fish tissue concentrations will not meet remedial goals until many decades after the year anticipated by model forecasts contained in the ROD. These issues are summarized below.

NOAA's Analyses Did Not Consider All the Available Evidence Regarding Improving Conditions in the Hudson

- **NOAA's Estimate of the Rate of Decay of Tri+ PCB Concentrations in Sediments did not Consider the Rates of Decay in Fish and Water.**

  NOAA's estimate of the rate of decay relied on a comparison of the 1991 and 2002-2005 surface sediment surveys. The analysis did not examine the rates of decay in surface water and fish, the matrices that are directly impacted by surface sediment PCB concentrations. The fish and water column data sets represent the only programs specifically designed and conducted to monitor change over time, and are less subject to uncertainty than any sediment-based estimates of decay. In the Upper Hudson and at RM 152 in the Lower Hudson, these water and fish PCB concentrations declined through the sediment monitoring period used by NOAA (1990-2005), as well as in the 11 years after completion of the EPA modeling analysis up to the start of dredging (1998-2008). This latter interval is effectively a period of monitored natural attenuation. Thus the rate observed during this period is expected to apply during the post-remedy period.

- **NOAA's Analysis of White Perch and Black Bass Trends are not Representative of Most Fish Trends.**
  NOAA chose to examine limited fish species data at a single station (black bass and white perch at RM 152) over a period including short term dredging related releases to support its arguments concerning the lack of recovery in fish tissue concentrations. The available data actually constitute 3 to 8 fish species at each of six long-term monitoring sites. Among these species-station pairs, there are multiple pairs in both the Upper and Lower Hudson with half-lives on the order of 5 to 10 years (decay rates of 7 to 13 percent per year). Additionally, NOAA did not limit its analysis to the MNA period (~1995 to 2008) when the river was actually recovering free of any external factors such as GE plant site releases or dredging-related releases. For the white perch, EPA obtains a rate of 5 percent per year for the 1995 to 2008 period, faster than NOAA's estimate of 3 percent per year (23 year half-life) for the period 1997-2014 at RM 152. Notably NOAA includes the period of dredging-related impacts that are not part of the long-term recovery process. Yet, it is also evident that either estimate of the rate of decay is not typical of most fish in the Upper Hudson or at RM 152. Rather, the white perch is generally an outlier in terms

of decay rates at RM 152, with most other fish exhibiting faster rates. While EPA does not dispute that white perch exhibits a slower rate of recovery at RM 152, this slow rate is not consistent with the recovery rates of most other fish (including black bass) or with the water column record. The white perch therefore is not a representative surrogate for Lower Hudson fish at RM 152, and NOAA's use of data for this species results in a lower estimated rate of decay that is not borne out by the period of observation (1995 to 2008) available for other fish species at this and other Lower Hudson stations. When appropriately examined for the MNA period (1995 to 2008), the black bass record assembled by NOAA for RM 152 acually yields a decay rate (8 percent per year) consistent with EPA 's original forecasts. In addition, NOAA's estimate will result in a similarly low rate of decay in terms of human exposure, since white perch constitute less than 8 percent of the fisherman's creel used as a basis for the risk assessment.

- **Lower Hudson Fish at and below RM 113 are Less Easily Linked to Upper Hudson Loads and are Likely Affected by Local Conditions.**
  NOAA did not fully evaluate the available measurements of PCB concentrations in Lower Hudson fish. EPA's examination of these data found that fish tissue concentrations at and below RM 113 are declining slower than the decay rates observed for PCBs in Upper Hudson fish, Upper Hudson water column, and in Lower Hudson fish at RM 152. This suggests that current Lower Hudson conditions at RM 113 and below are less likely to be strongly linked to Upper Hudson loads. However, fish tissue concentrations at these stations are substantially lower than those found in the Upper Hudson, which may offset the decreased rates of decay in achieving the remedial goals for fish in the Lower Hudson. EPA will need to continue to monitor fish tissue to track this progress.

EPA's Original Analyses used Three Independent Estimates of the Rate of Decay in PCB Concentrations in Fish, Water and Sediment. The Fish and Water Rates have since been Borne Out by Fish and Water Column Monitoring post 1998.

- **Upper Hudson Fish Tissue Concentrations Decline at Rates Comparable to the Rate for Surface Sediment PCB Concentrations Given by the 1991 to 1998 Sediment Surveys**.

  The half-lives for fish tissue in the Upper Hudson for the period 1995 to 2008 are on the order of 5 to 21 years for the TIP (equivalent to 13 percent to 3 percent decay rates, respectively), with an average half-life of 7 years, equivalent to an 10 percent per year decrease. While EPA concludes that the available sediment record is not a reliable basis to independently estimate the rate of recovery, nonetheless the EPA notes that these fish tissue half-lives compare favorably to the half-life for surface sediment Tri+ PCB concentrations, estimated by comparing the 1991 and 1998 surveys for the TIP (8 years). These more recent rates are also comparable to the effective rates produced by EPA's

HUDTOX/FISHRAND model. More importantly, the rates of decay for PCBs in Upper Hudson fish tissue are much faster than the rates estimated by NOAA for the Upper Hudson sediments (1.3 percent per year, equivalent to a 53 year half-life).

- **Lower Hudson Fish Tissue Concentrations at RM 152 Decline at Rates Comparable to the Rate for Surface Sediment PCB Concentrations Given by the 1991 to 1998 Sediment Surveys.**

  Lower Hudson River fish have variable rates of decay but at RM 152. The fish tend toward rates equivalent to a half-life of 10 years or less. The average rate of decay of PCBs in fish tissue for the period 1995 to 2008 is 8 percent per year, (equivalent to a 9 year half-life). This is consistent with the rate of sediment decay used to calibrate EPA's model, and significantly faster than the rate of decay identified by NOAA for Lower Hudson white perch at RM 152 (3 percent per year, equivalent to a 23 year half-life).

- **Water Column Concentrations Continue to Decline at Rates Comparable to the Rate for Surface Sediment PCB Concentrations Given by the 1991 to 1998 Sediment Surveys, Indicating Continued Sediment Recovery.**

  Water column concentrations have continued to decline at a rate consistent with EPA's model forecasts. Between 1990 and 2005, water column concentrations in the Upper Hudson declined at an average rate of 9 percent per year (8 year half-life). Between 1998 and 2008, the average rate was 14 percent per year (5 year half-life). In the post-1994 period, water column concentrations and loads of PCBs in the Upper Hudson are produced almost entirely as the result of interactions between the water column and the sediment, and in particular the surface sediments, which directly contact the passing water. Thus, for water column concentrations to decline, the releases from the sediments to the water must also decline. By inference, for the release of PCBs from the sediments to decline, the decline of PCB concentrations in those surface sediments must occur as the primary mechanism for reducing the gradient between sediment and water that drives the various release processes.

- **The Data Trends Used to Calibrate the EPA Models Show a Consistent Rate of Decay**

  The trends apparent in the fish tissue data for the Upper Hudson and RM 152, the water column data, and the 1991-1998 sediment survey comparison all yield rates of decay in Tri+ PCB concentrations consistent with half-lives on the order of 5 to 14 years. These data sets represent an internally consistent calibration data set that was used to develop the HUDTOX and FISHRAND models. Subsequent to the ROD, continued monitoring of the fish and water has confirmed these rates of decay, which formed the basis for the model calibration.

NOAA's Analyses Did Not Recognize the Importance of Relative Change in Concentration

- **NOAA's Discussion Focused on the Absolute Change in Tri+ PCB Concentrations when the Main Goal of the Remedy is a Relative Reduction in Tri+ PCB Concentrations.**

  The goal of the remedy was to reduce surface sediment concentrations and sediment PCB inventory so as to cause a reduction in fish tissue concentrations. Because PCB concentrations in fish tissue proportionately reflect their environmental exposure to PCBs, the remedy was designed to produce a reduction in surface sediment Tri+ PCB concentrations proportional to the targeted reduction of Tri+ PCB concentrations in fish tissue. Thus NOAA's concern that PCB concentrations in sediment were shown to be much higher than predicted by the model is not a significant issue for the river sections where the degree of reduction achieved by the remedy relative to the SSAP data is comparable to that anticipated by the ROD based on the older data. Thus for RS 1 and RS 3, the percent reductions achieved by the remedy are comparable to those expected by the ROD. Only in RS 2 does the remedy achieve a smaller proportionate reduction than expected. Monitoring over the next several years is more appropriate for assessing the success of the remedy.

NOAA's Statistical Emulation of the Output of the EPA Models is not Appropriate to Test Changes in the Models' Initial Conditions.

NOAA's incorporation of the 2002-2005 data set into its model emulation effectively changed the initial conditions of the model and was incorrect as a forecast of actual conditions. Incorporation of the 2002-205 data without an accompanying change in the sediment-to-water and sediment-to-fish exchange coefficients overestimates the measured water column concentrations and would likely also overestimate the fish tissue concentrations.

The Available Sediment Survey Data are not Sufficient to Determine the Rate of Decay of Tri+ Concentrations in Surface Sediments.

Unlike the fish and the water column data, which were specifically collected to monitor changes over time, each of the sediment surveys was originally focused on objectives other than monitoring changes since previous surveys. As such, the sediment comparisons can only provide a general indication of the rate of change. EPA estimated the half-lives across nearly all possible pairings of the four available surveys to demonstrate that the sediment surveys can only provide rough estimates of the rate of decay in surface sediment PCB concentrations. Wide ranges of half-life and rate of decay estimates are shown in Tables 5a and 5b respectively, 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). Perhaps most notable is the consistency of the half-lives obtained by comparing the SSAP and DDS programs. These half-lives fall between 3 and 12 years and are consistent with the 1991 to 1998 comparisons, as well as the fish and water column trends. While it might be possible to question certain relative sediment survey pairings, EPA conducted this exercise precisely to demonstrate that the sediment surveys do not provide a consistent, supportable basis to independently estimate the rate of improvement in Hudson River sediment PCB levels. Only the long-term records obtained by the fish and water column monitoring programs, which were explicitly collected for this purpose, provide a basis to estimate long term recovery rates for PCBs in the Hudson River.

The Analyses Presented by NOAA do not Constitute a Basis to Conclude that the Remedy will not Meet its Remediation Targets.

NOAA has conducted an interesting exercise in emulating EPA's mechanistic model by statistical regression techniques. This approach has the potential to be useful in estimating sensitivity in certain mechanistic model parameters (e.g, sediment concentrations). However, in applying its regression model, NOAA did not properly integrate the available data, and chose select subsets of the data to apply to the model. This resulted in model outcomes that are not supported by a more rigorous examination of the available data. As such, the analyses presented by NOAA do not support its assertions regarding the time to achieving remediation targets for PCB concentrations in Lower Hudson River.

Clarification Regarding NOAA Discussion of Transparency.

NOAA indicted in its manuscript that one of the advantages to their emulation approach is that it allowed them to update mechanistic model predictions without the need for access to [model] computer codes. Further they indicated their approach would enhance transparency and accountability when evaluating remedial alternatives.

As was discussed in the ROD Responsiveness Summary, the EPA mechanistic model was peer-reviewed by an independent panel of scientists (USEPA, 2000c). This peer review included examination of key variables in the models and model sensitivity. Subsequent to this peer review, the HUDTOX fate and transport model was further tested by successful validation to additional data collected by GE during 1999 (USEPA 2000d). NOAA was given the opportunity to review and offer comments on the modelling reports. In addition all project sediment, fish, and water data have been made available to the Trustees.

Regarding the assertion that the emulator can facilitate updates of original model predictions and can be used to enhance transparency and accountability of alternatives comparisons, EPA understands that emulation may be potentially useful as a sensitivity analysis tool. However EPA also understands that due to the nature of emulation approaches, there may be limitations to applications of emulation analyses. One of the reasons that NOAA used an emulator approach was that it did not entail the various calibrations and coefficient adjustments required of re-running the model (e.g, re-evaluating the physical mechanisms of the model itself). For these reasons, EPA disagrees with NOAA's conclusions regarding discrimination among alternative remedial scenarios.

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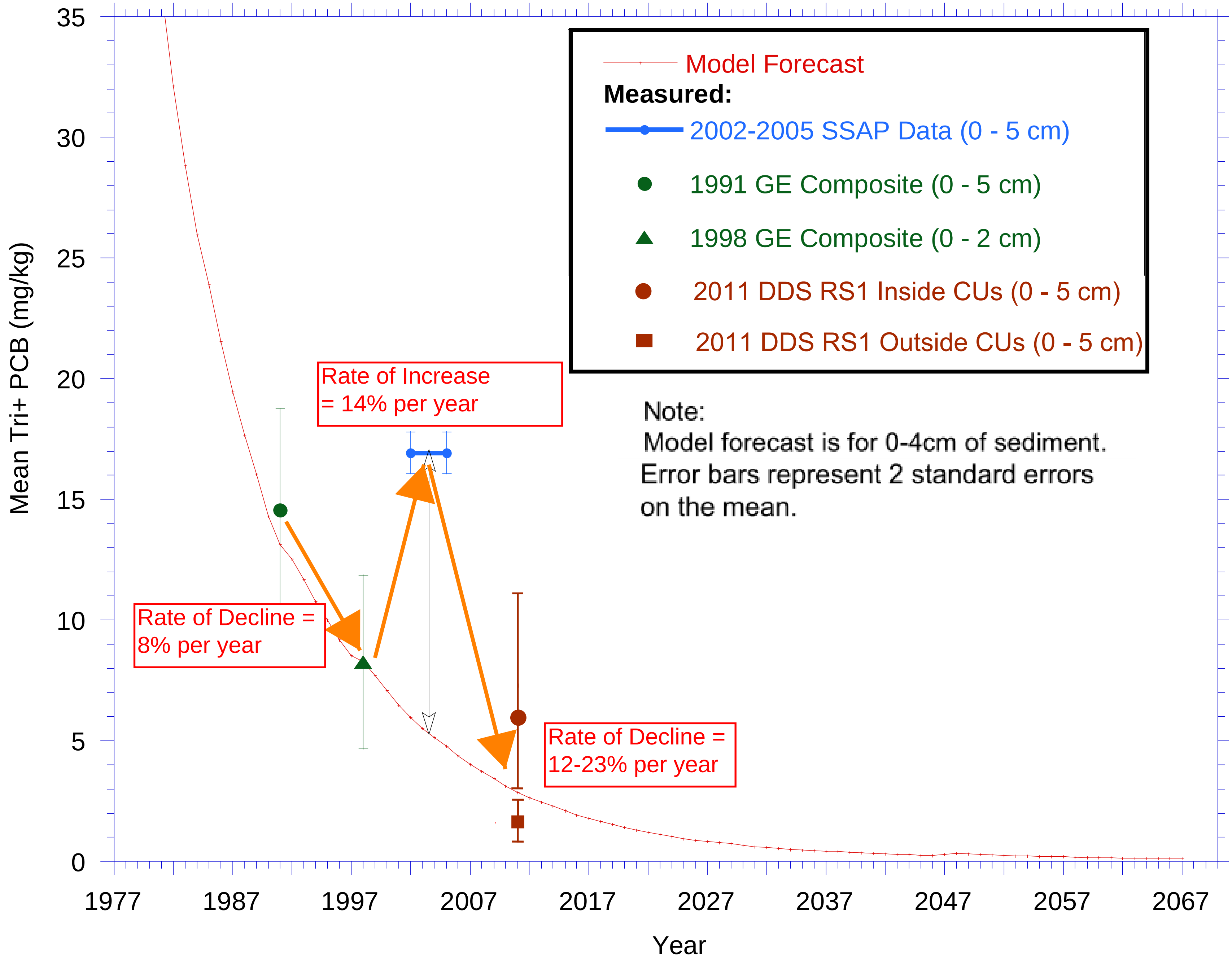
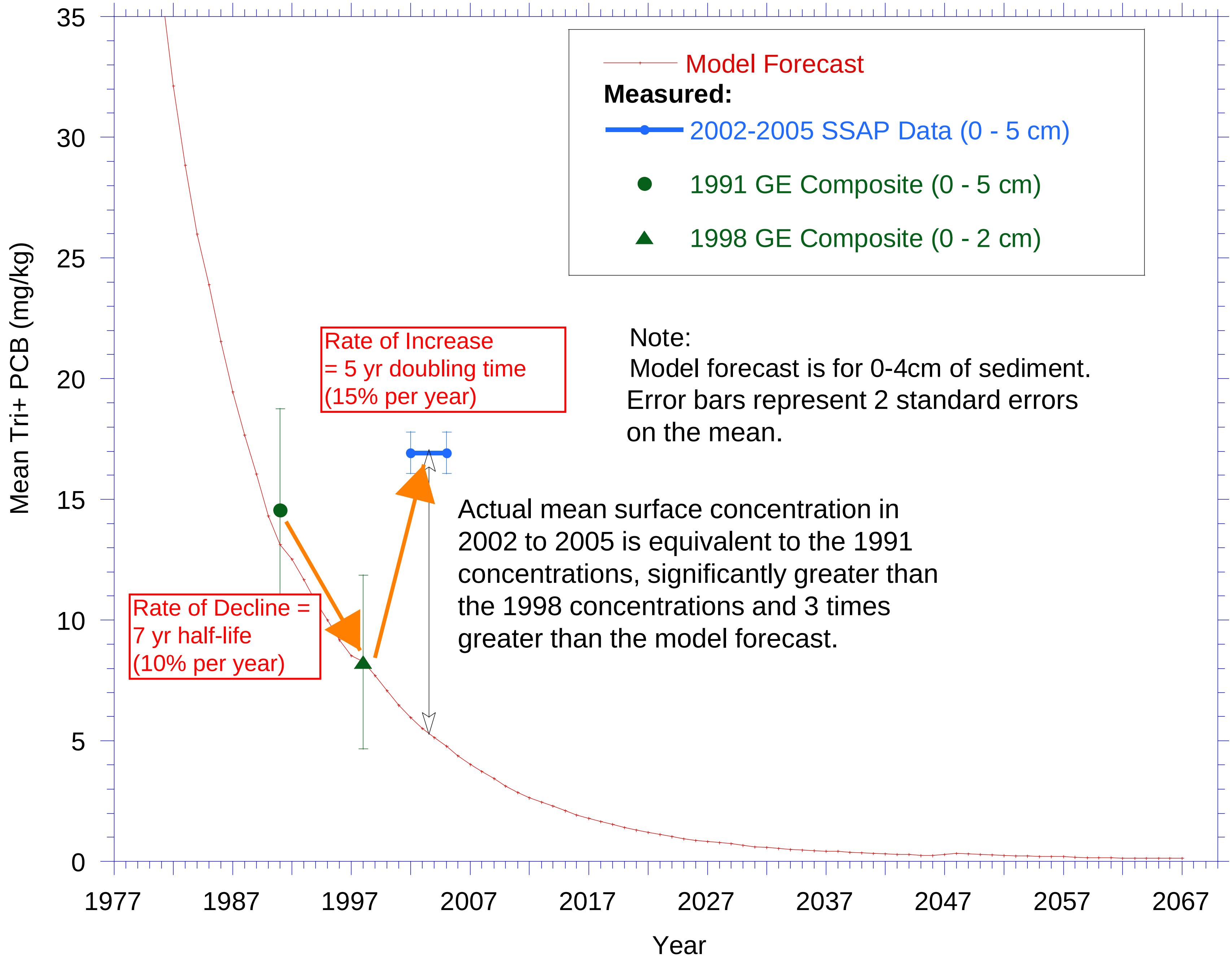


HUDTOX Model and Core Data Comparison All Sediment Types
Thompson Island Pool
(Adapted from Figure I-3-22) EPA Phase 1 Evaluation Report - Hudson River PCBs Site

Figure ES-1

2016

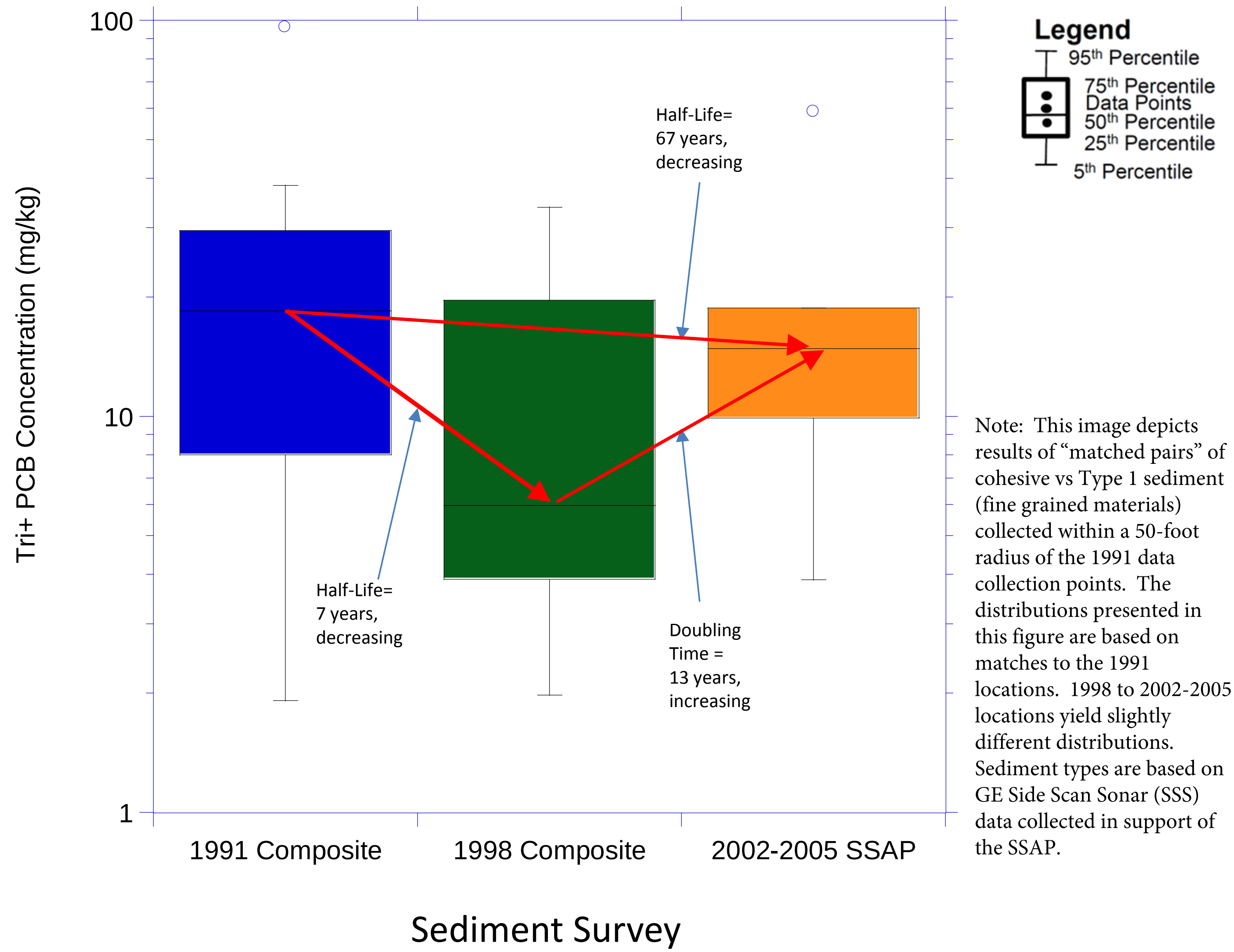


HUDTOX Model and Core Data Comparison All Sediment Types
Thompson Island Pool

Figure I-3-22 adapted from EPA Phase 1 Evaluation Report - Hudson River PCBs Site

Figure 1

2016

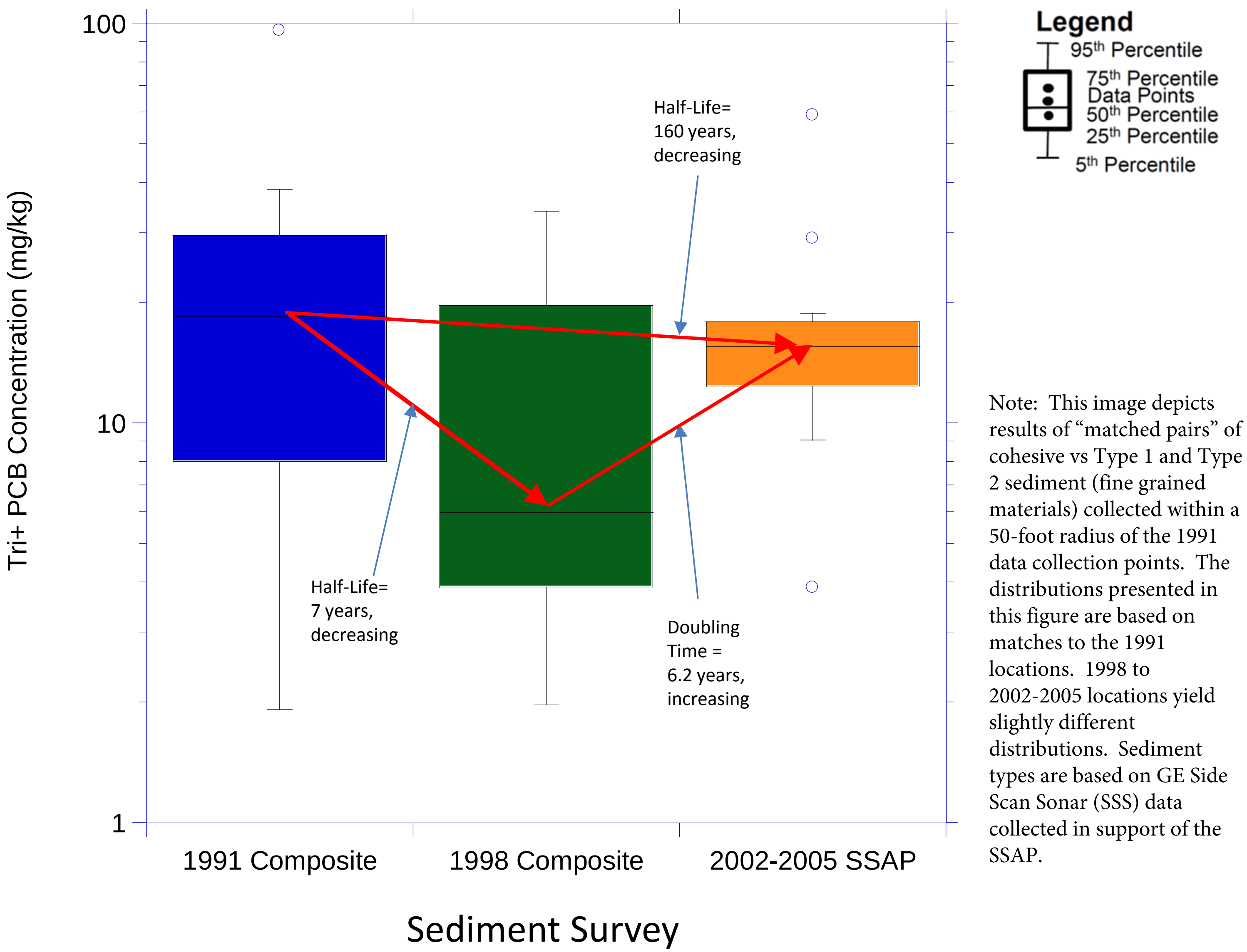


Note: This image depicts results of "matched pairs" of cohesive vs Type 1 sediment (fine grained materials) collected within a 50-foot radius of the 1991 data collection points. The distributions presented in this figure are based on matches to the 1991 locations. 1998 to 2002-2005 locations yield slightly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

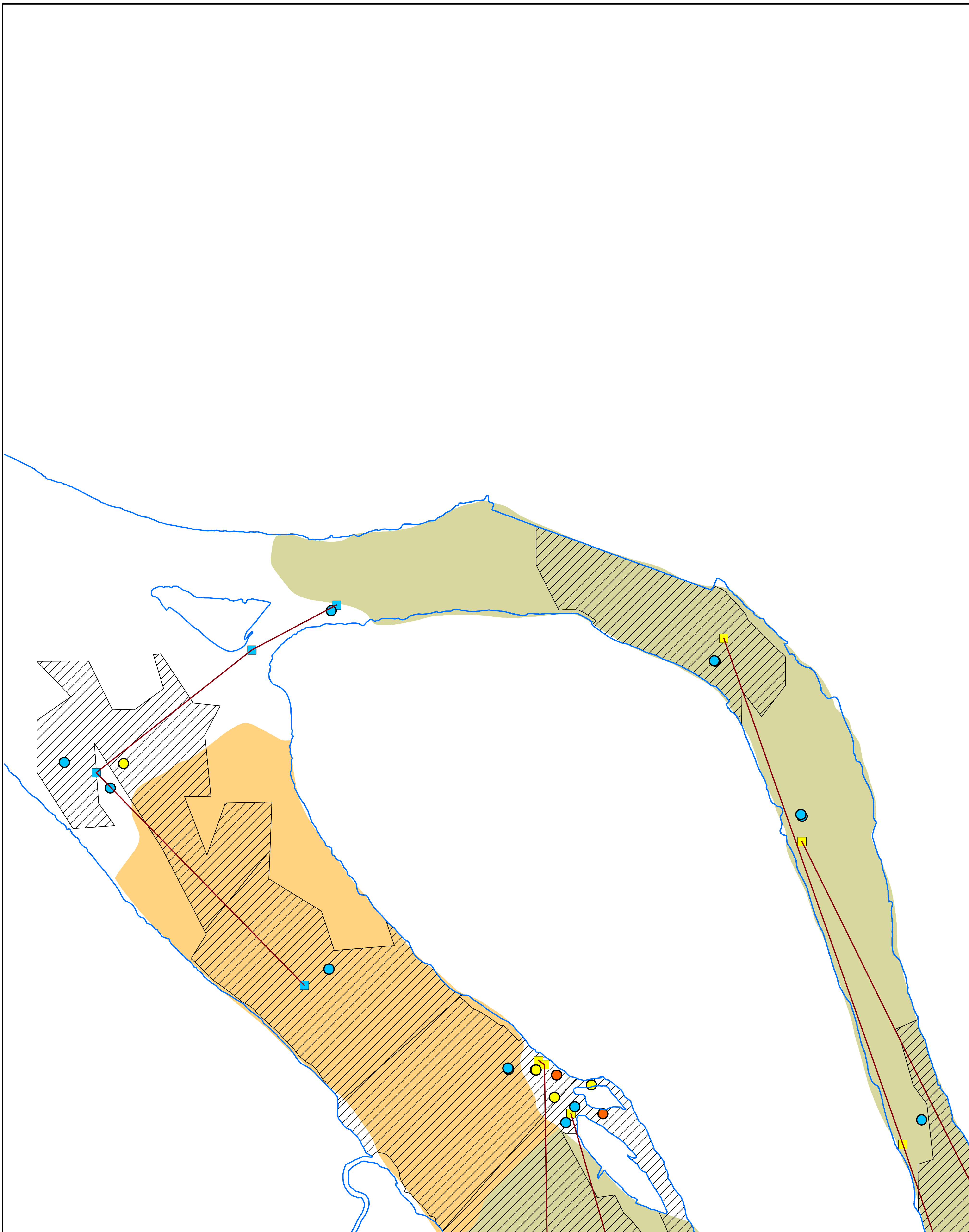
Figure 2

2016



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 3 2016



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

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

Figure 4a

2016

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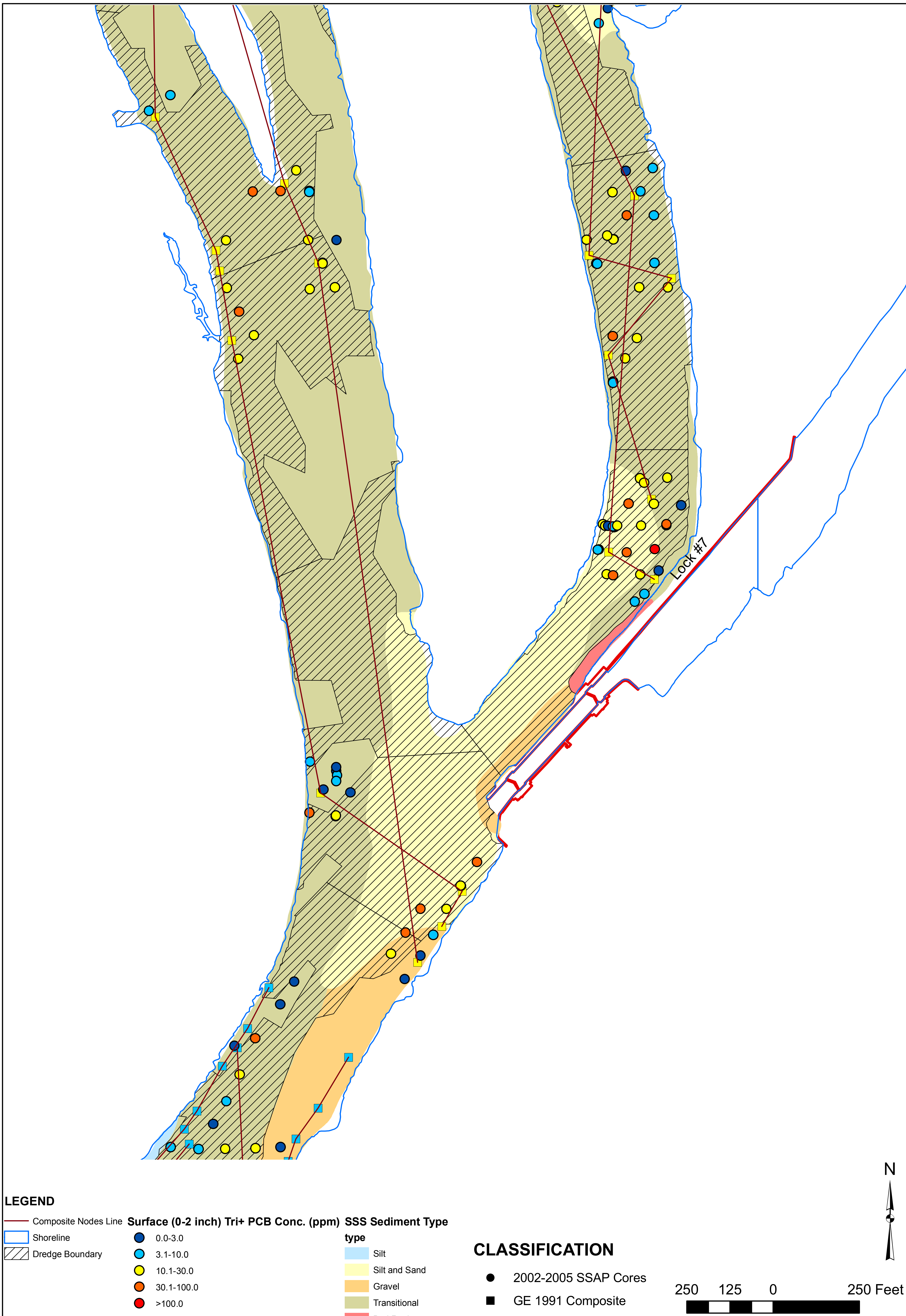

Figure 4b

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

2016

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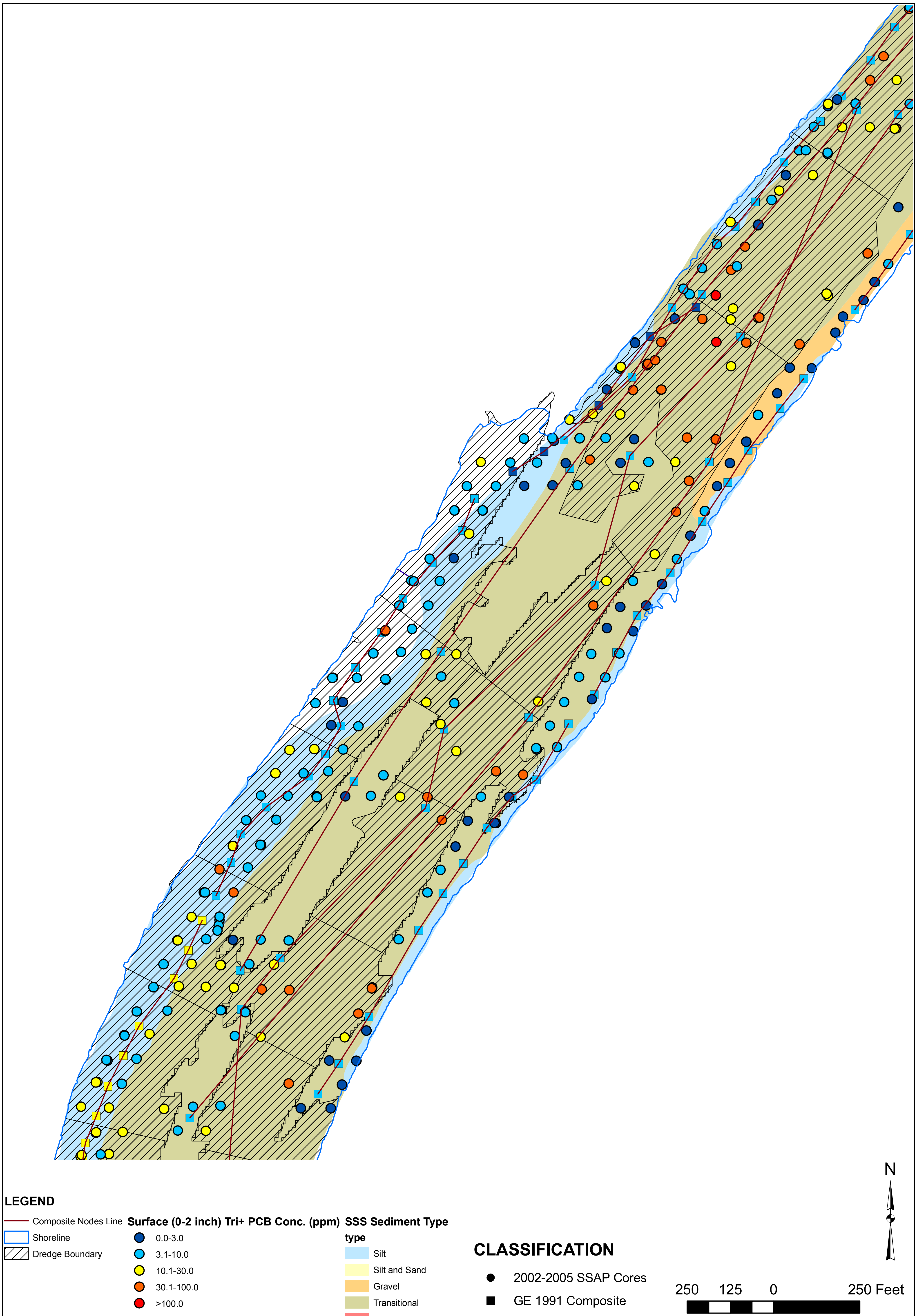

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2002 TO 2005 SSAP CORES
WITHIN 100 FEET OF 1991 COMPOSITE NODES

Figure 4c

2016

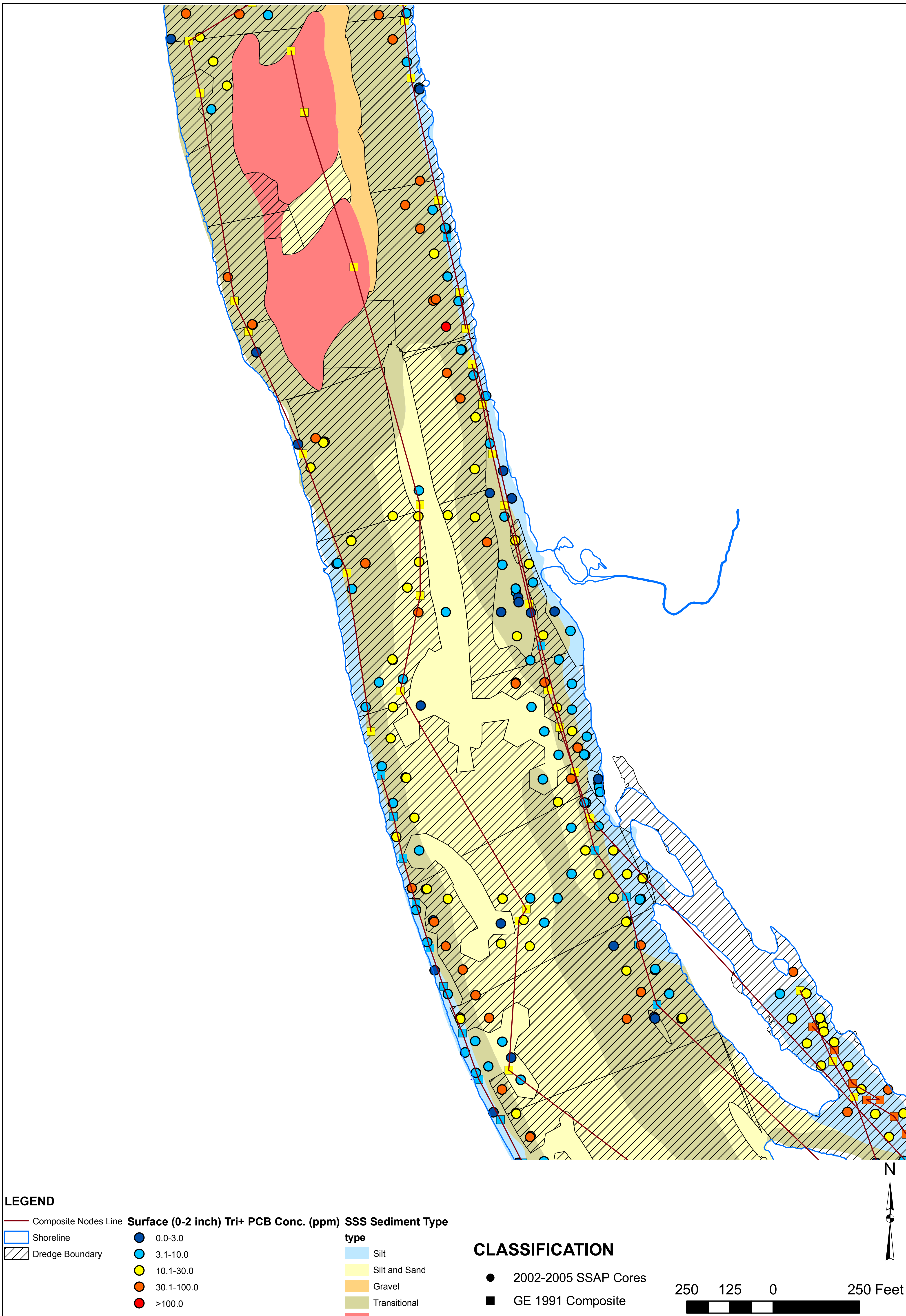

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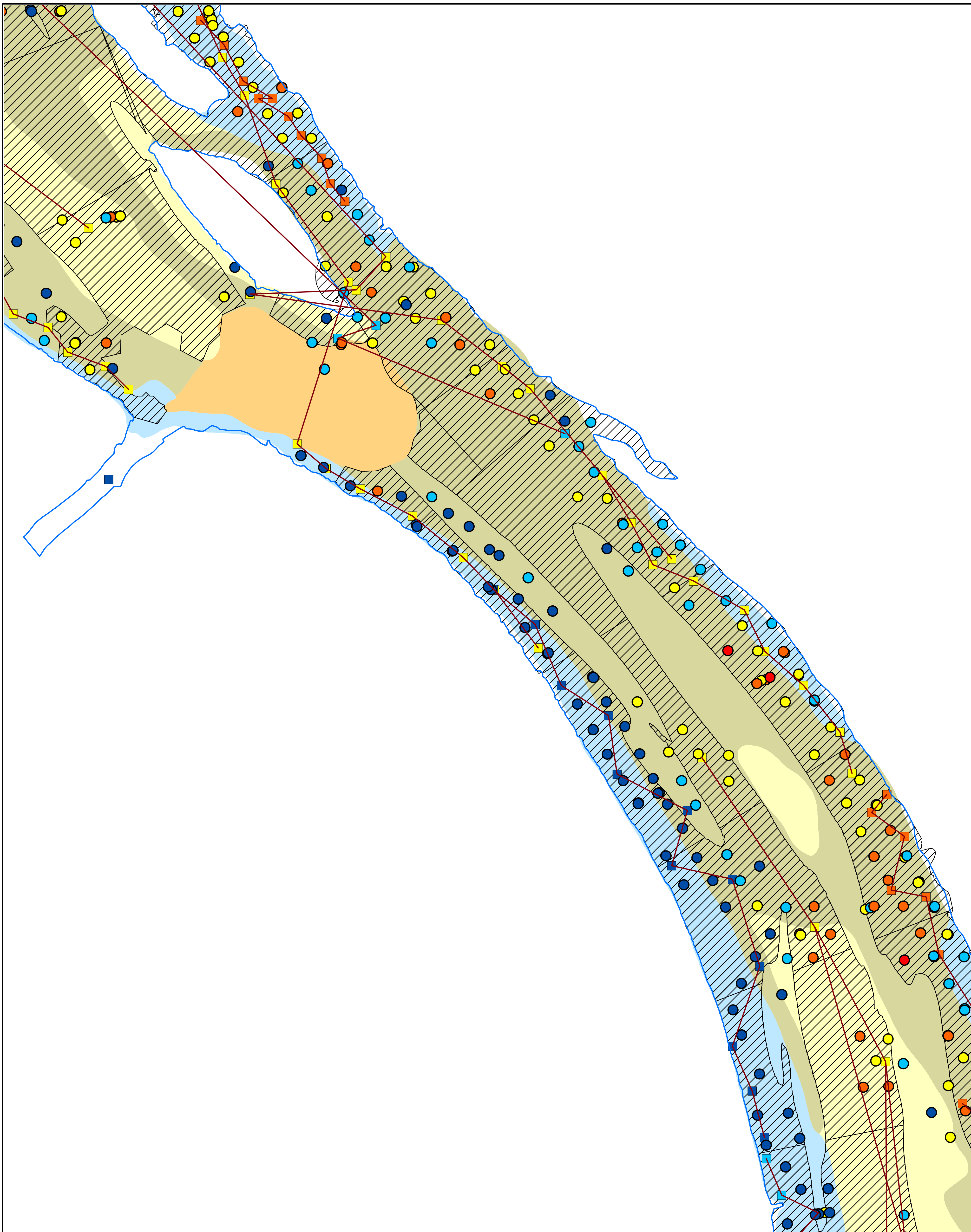
Figure 4d

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

2016



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

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

Figure 4e

2016

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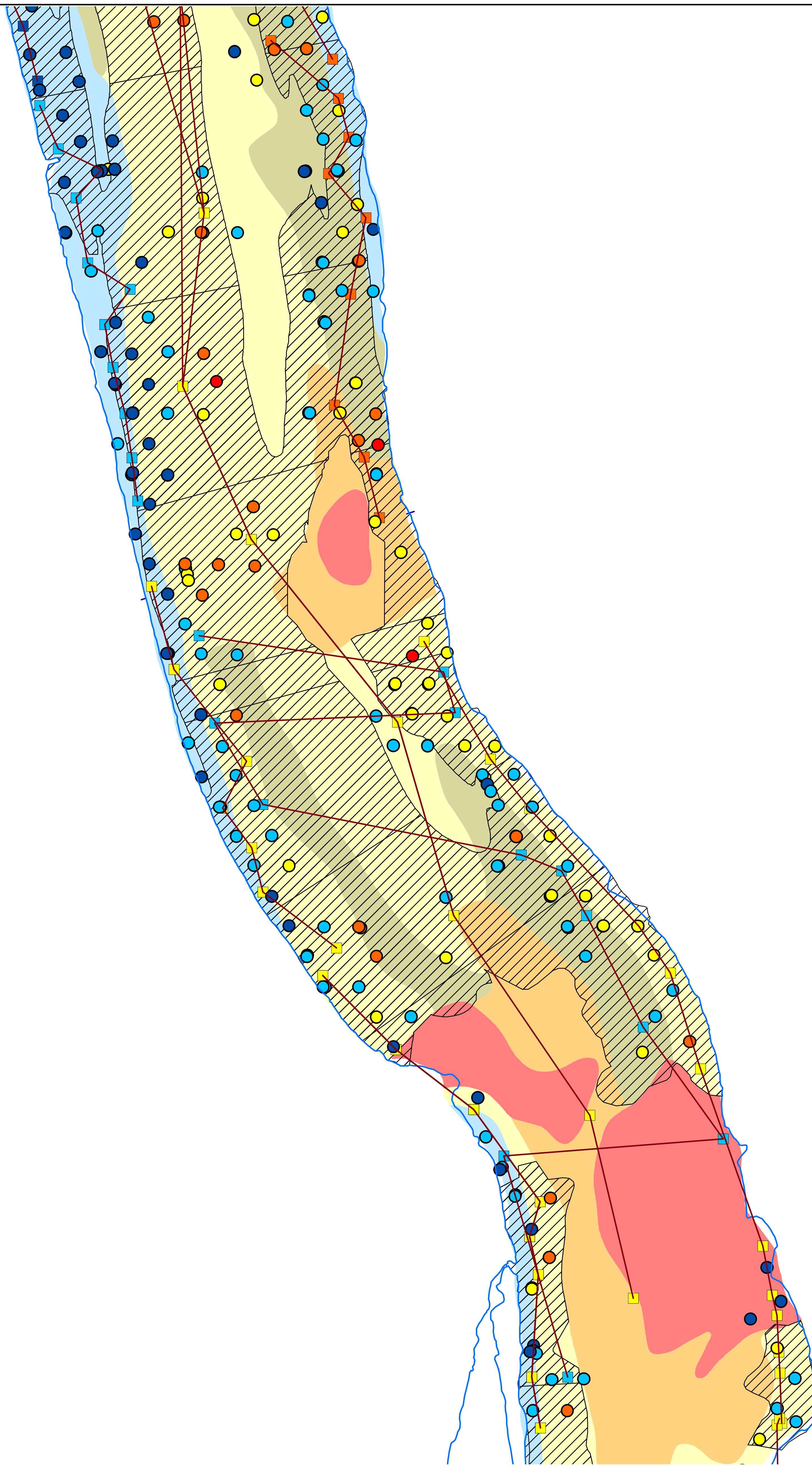

N

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 1991 Composite

250 125 0 250 Feet

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

Figure 4f

2016

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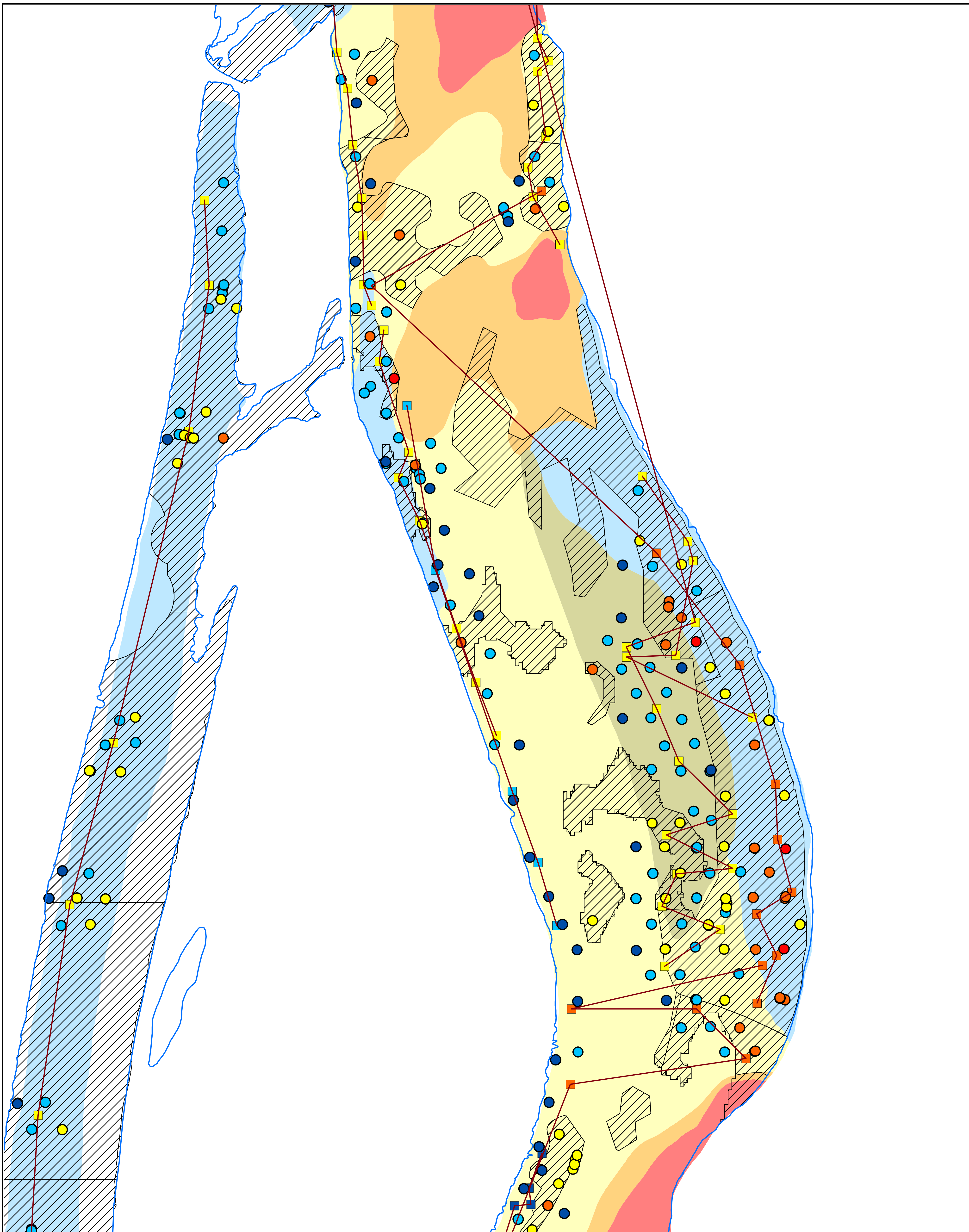


LEGEND

- 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

N

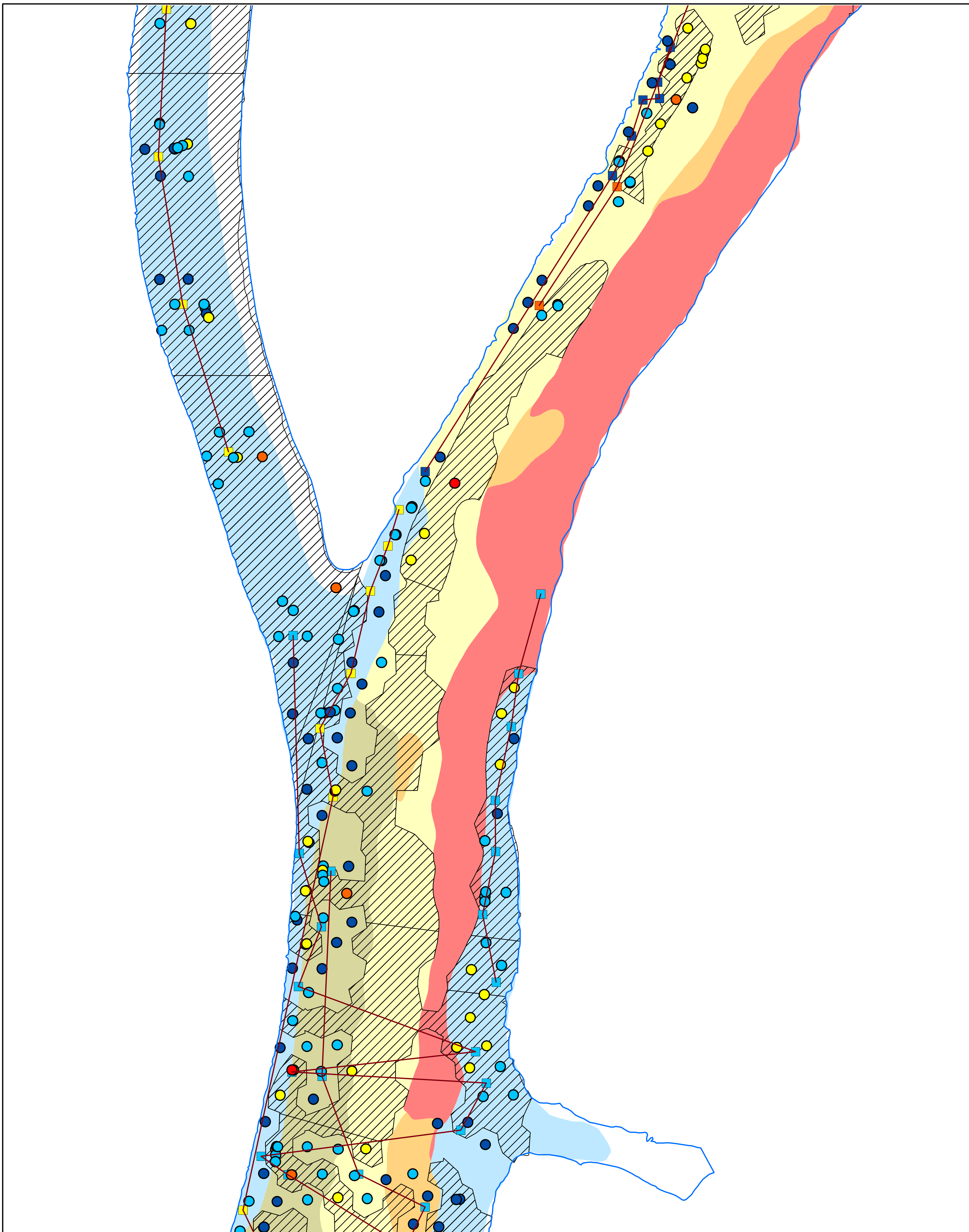
250 125 0 250 Feet

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

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

Figure 4g

2016



N

250 125 0 250 Feet

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

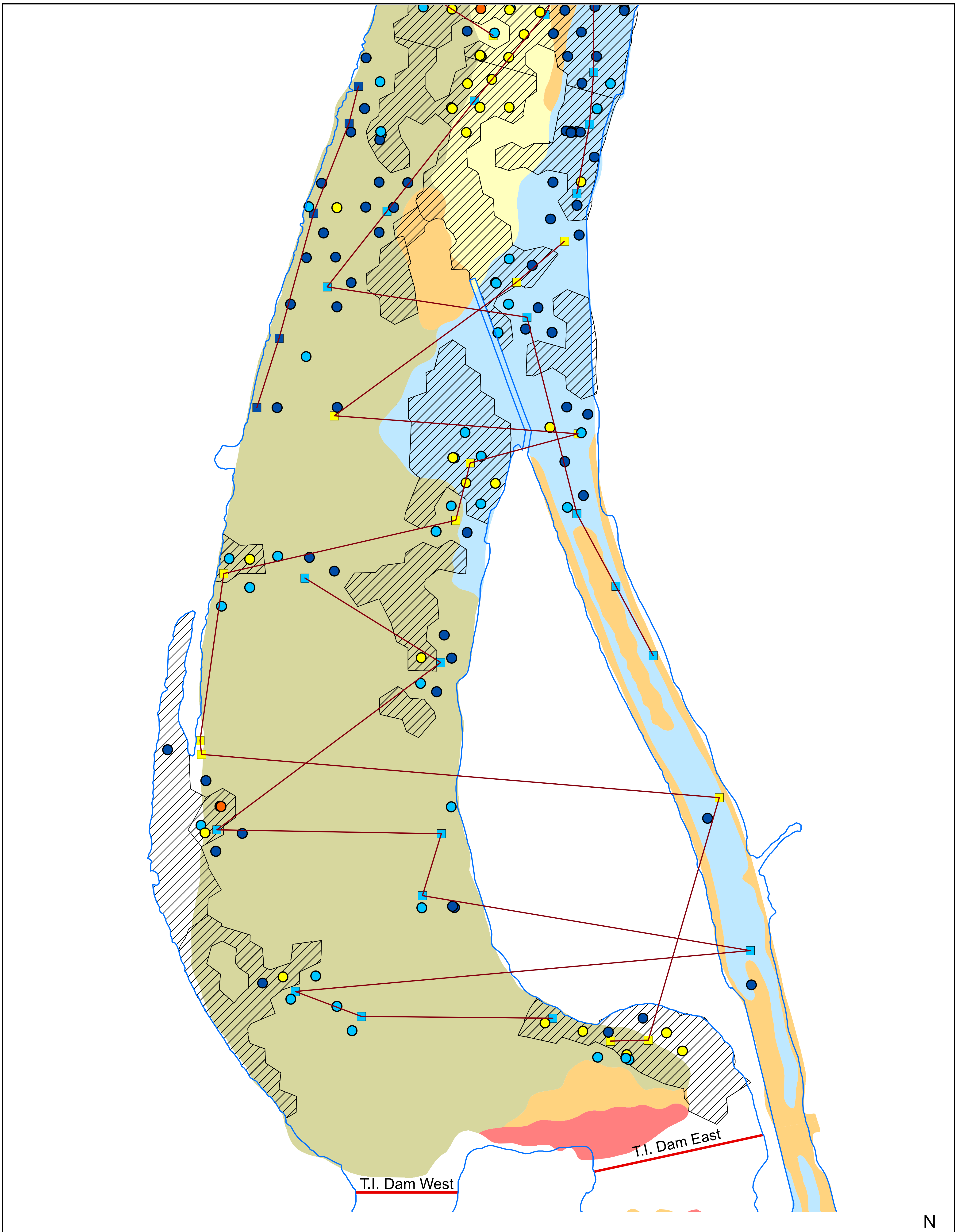
CLASSIFICATION
- 2002-2005 SSAP Cores
- GE 1991 Composite

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

Figure 4h

2016

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

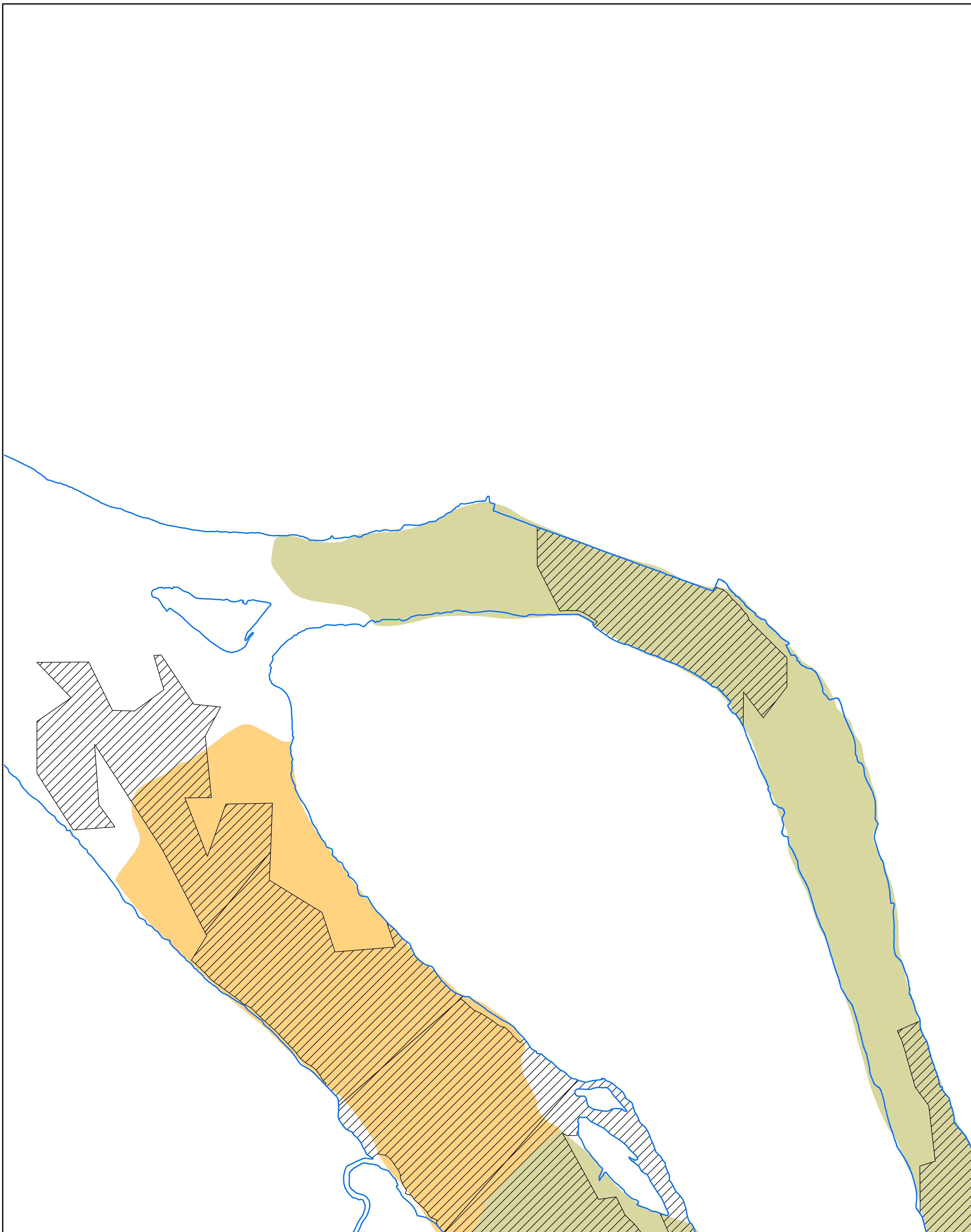
- 2002-2005 SSAP Cores
- GE 1991 Composite

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

Figure 4i

2016

Map Document: (M:\0285919\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

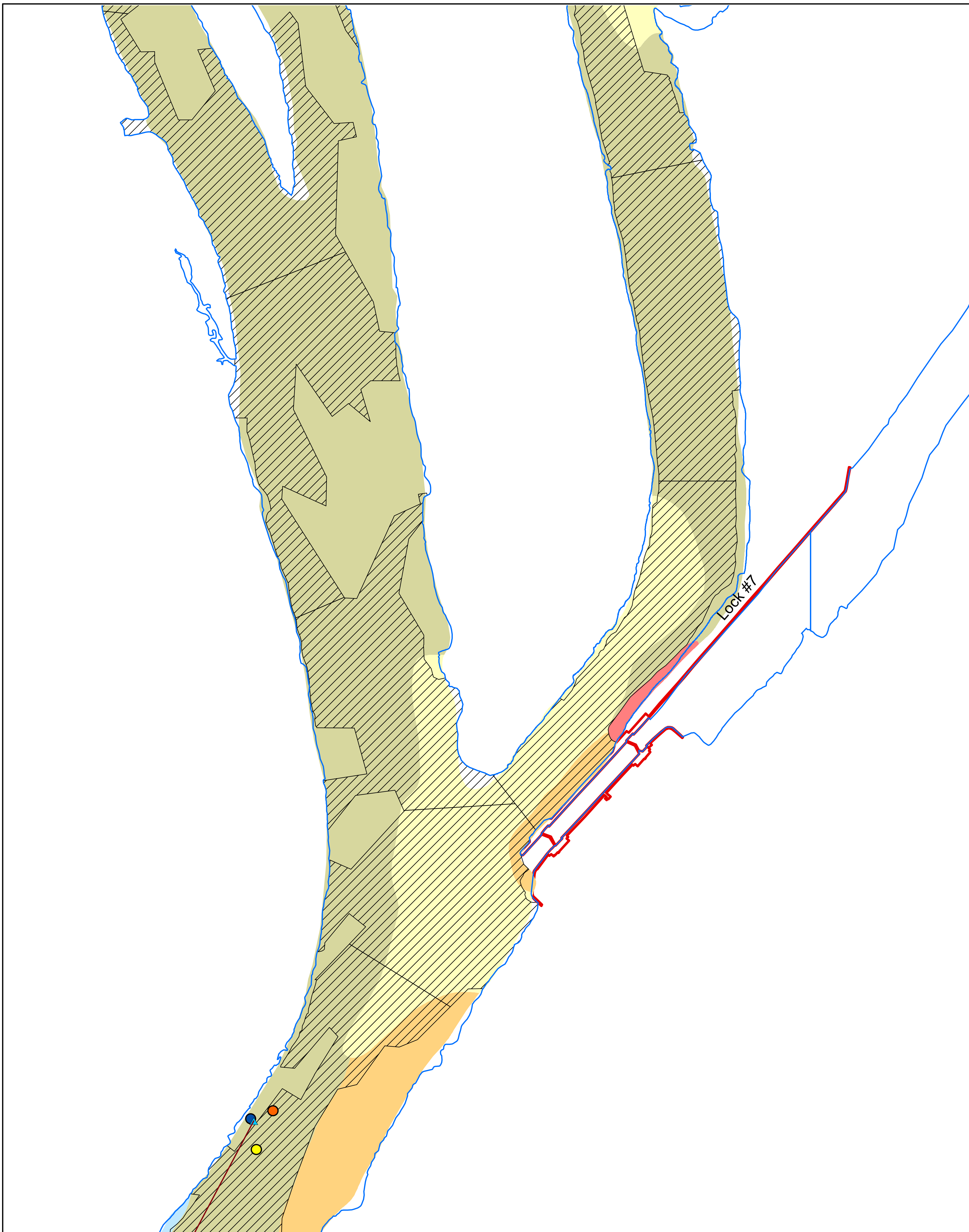
250 125 0 250 Feet

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

Figure 5a

2016

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

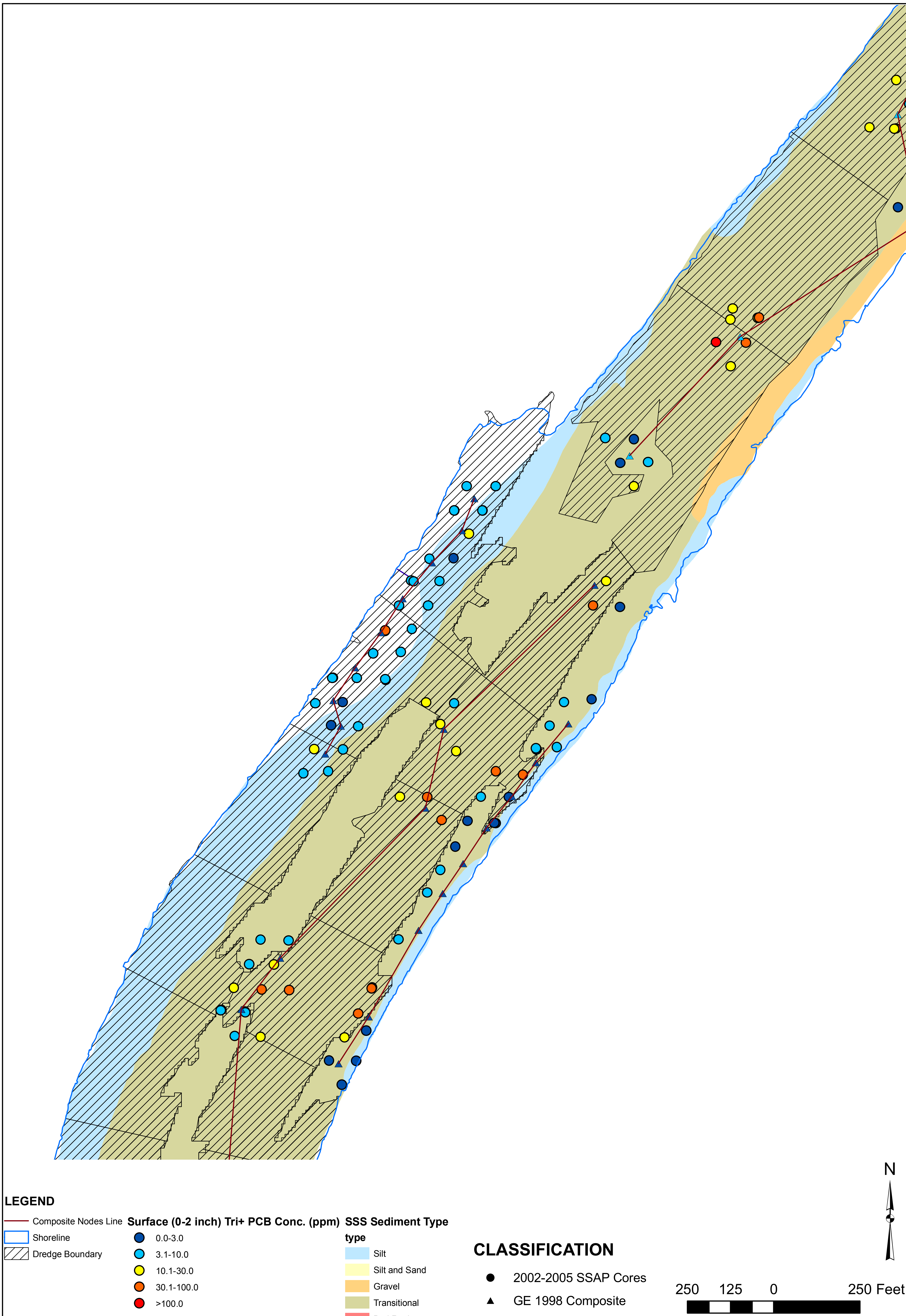
250 125 0 250 Feet

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

Figure 5b

2016

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

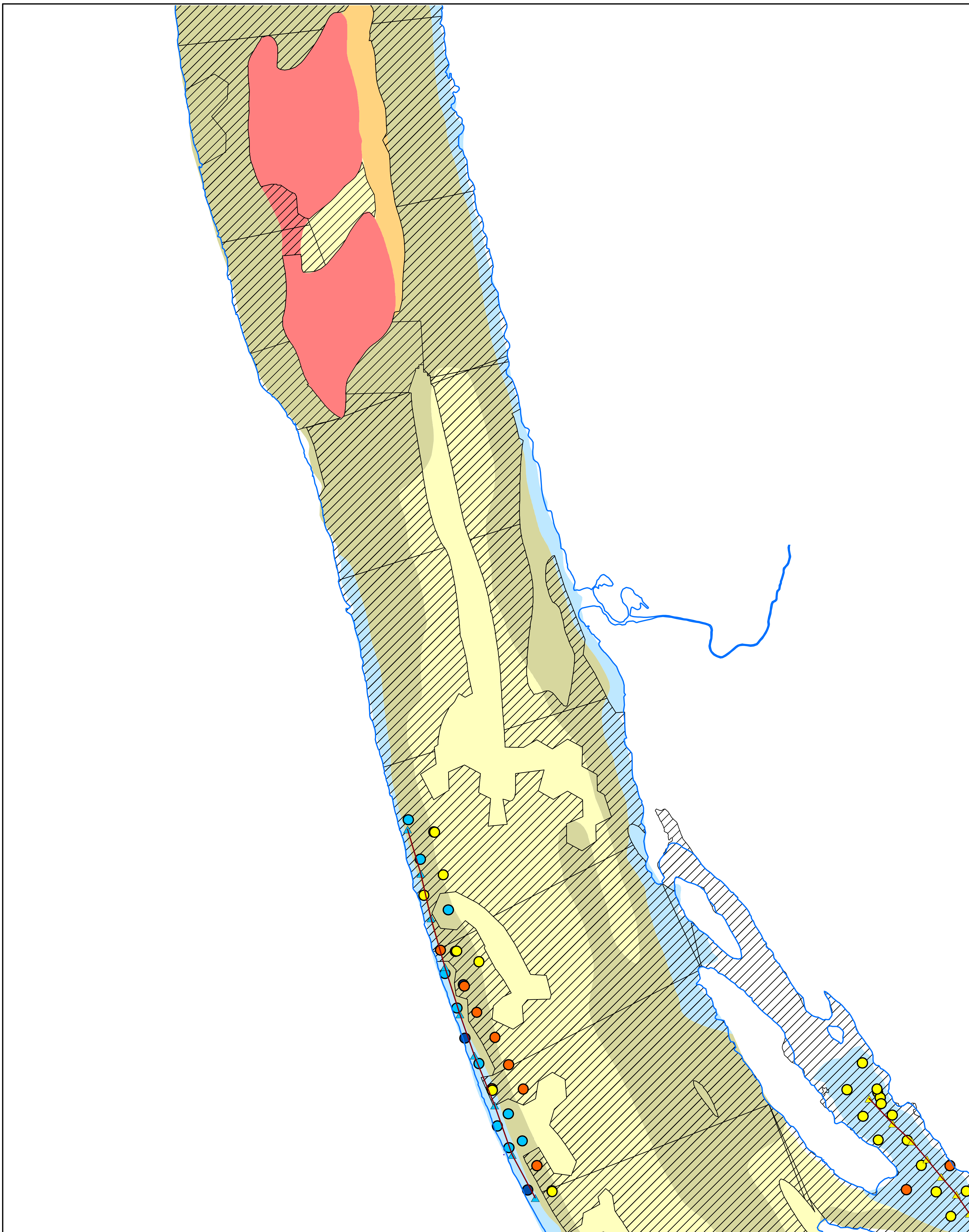


Map Document: (M:\02859191\GIS\Phase1Evaluation\GE_Composite91_98_SSAPCores.mxd) 8/18/2010 -- 4:50:17 PM

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

Figure 5c

2016



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

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

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

Figure 5d

2016

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

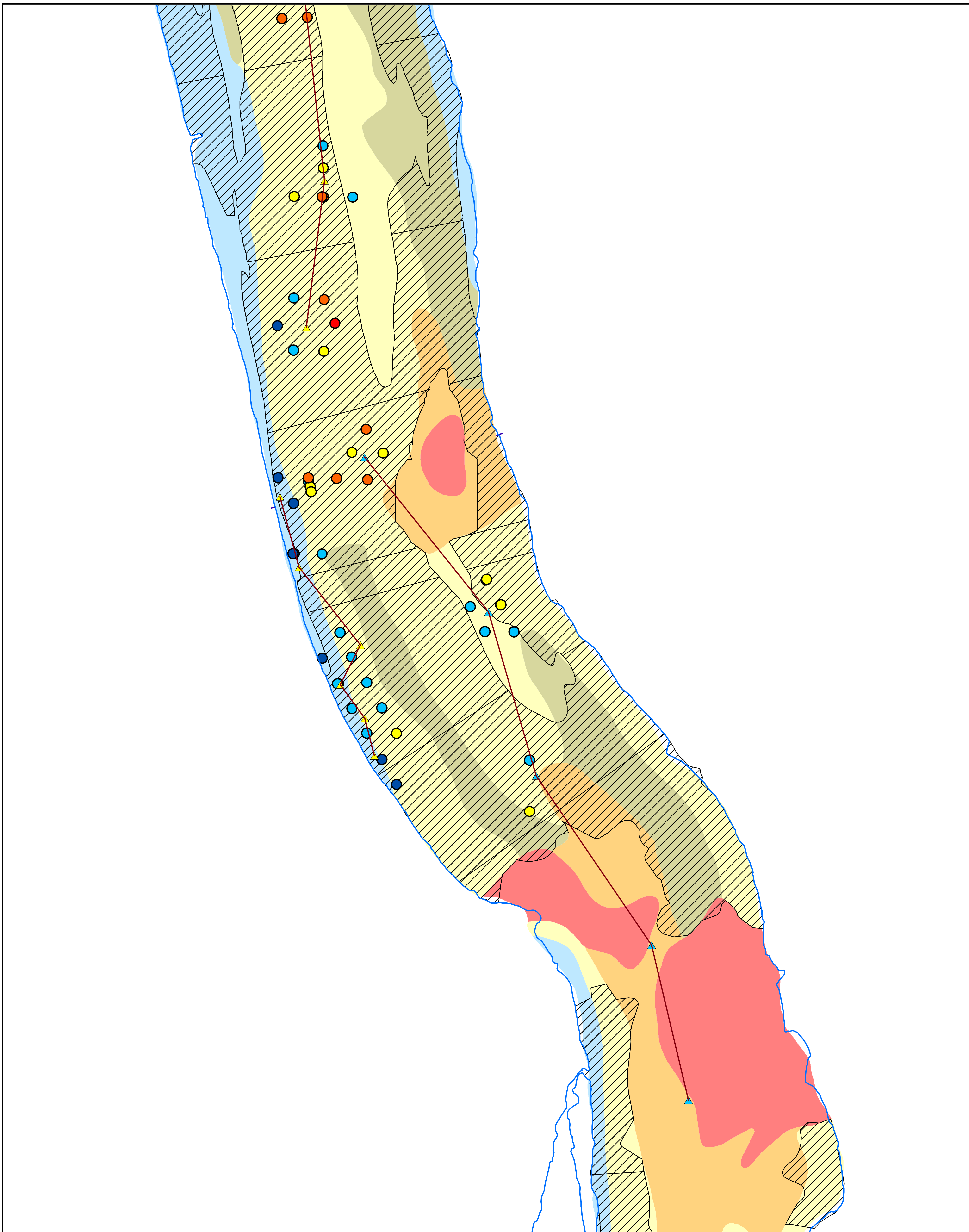
250 125 0 250 Feet

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

Figure 5e

2016

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 1998 Composite

N

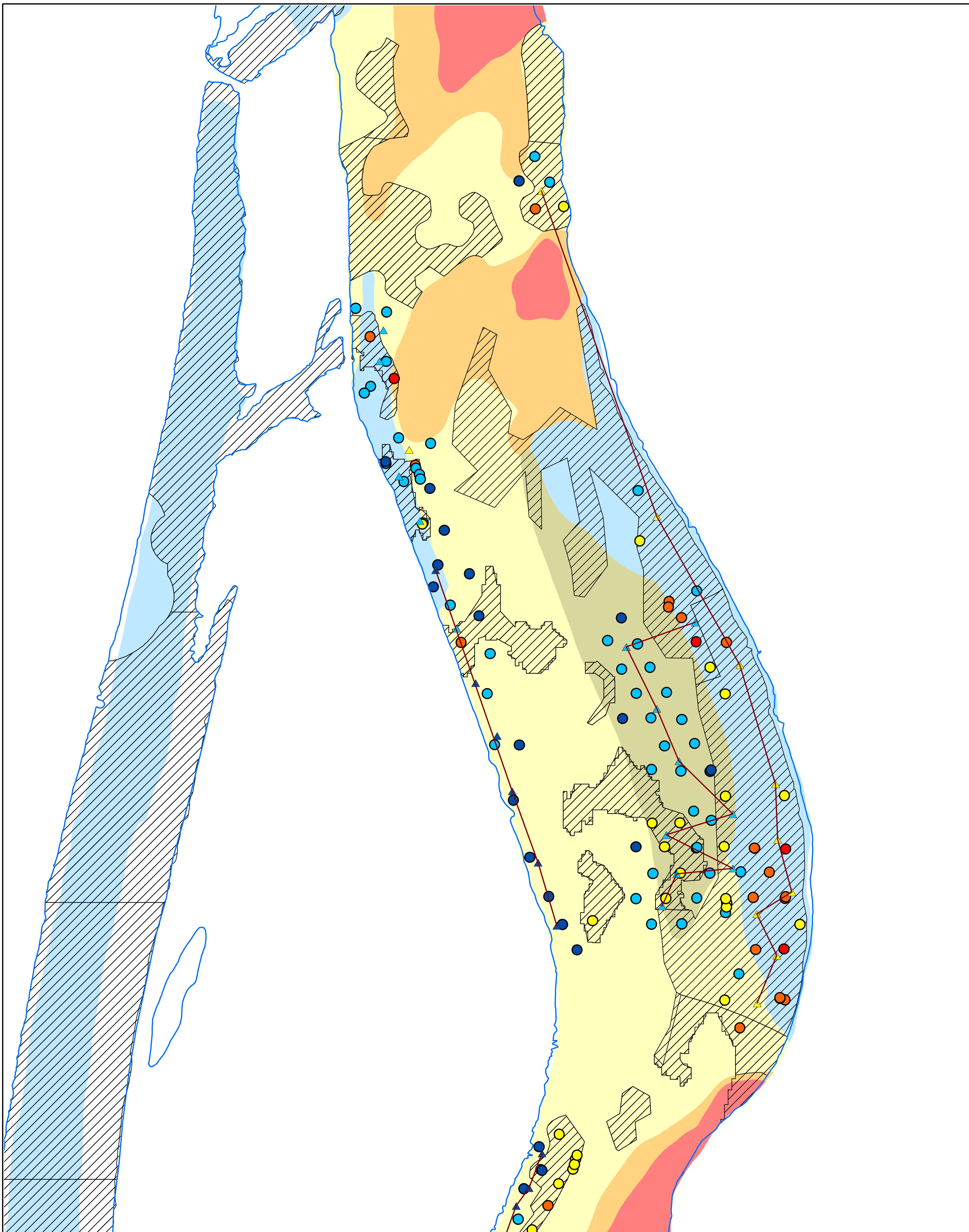
250 125 0 250 Feet

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

Figure 5f

2016

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 1998 Composite

N

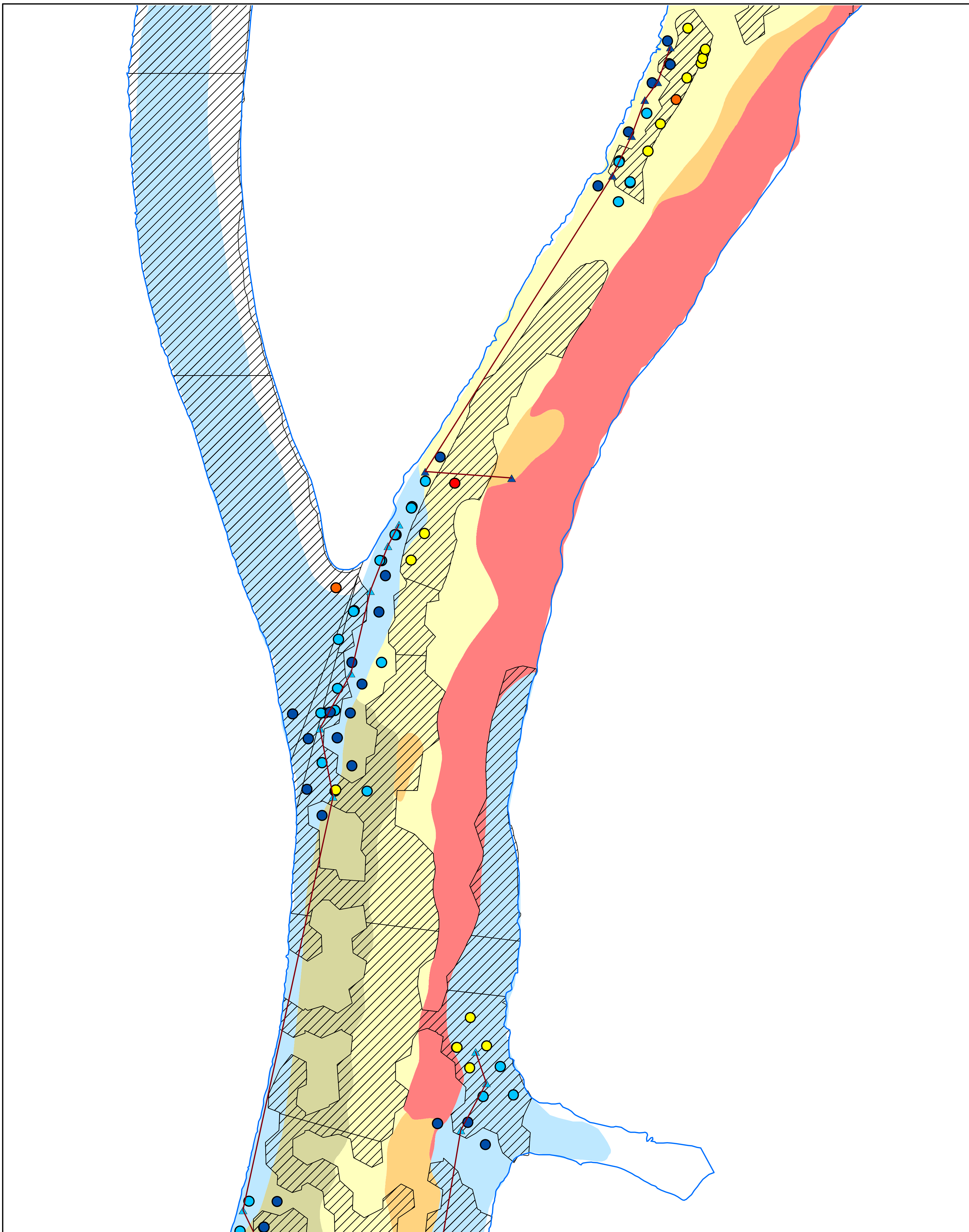
250 125 0 250 Feet

Figure 5g

2016

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

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 1998 Composite

N

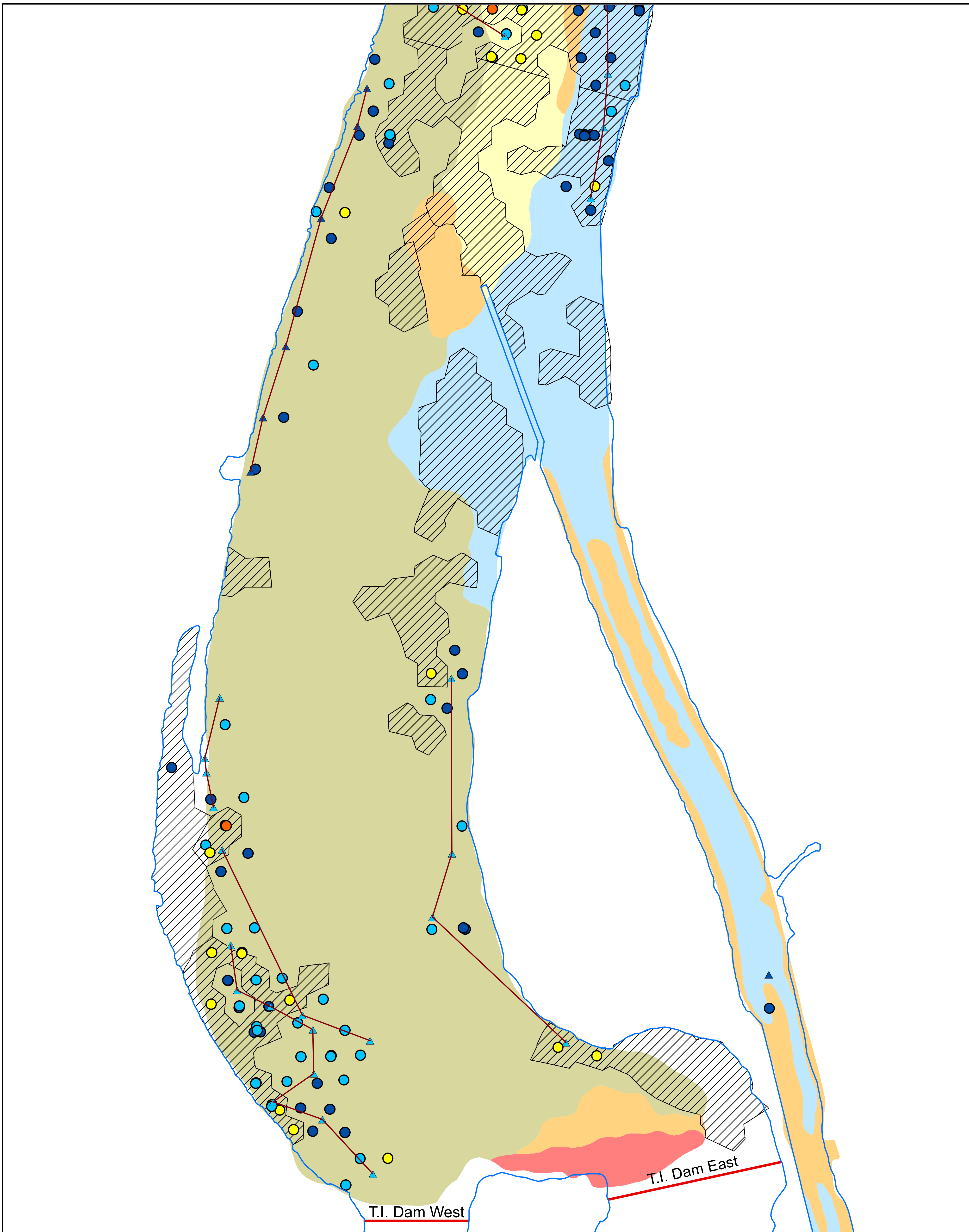
250 125 0 250 Feet

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

Figure 5h

2016

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 1998 Composite

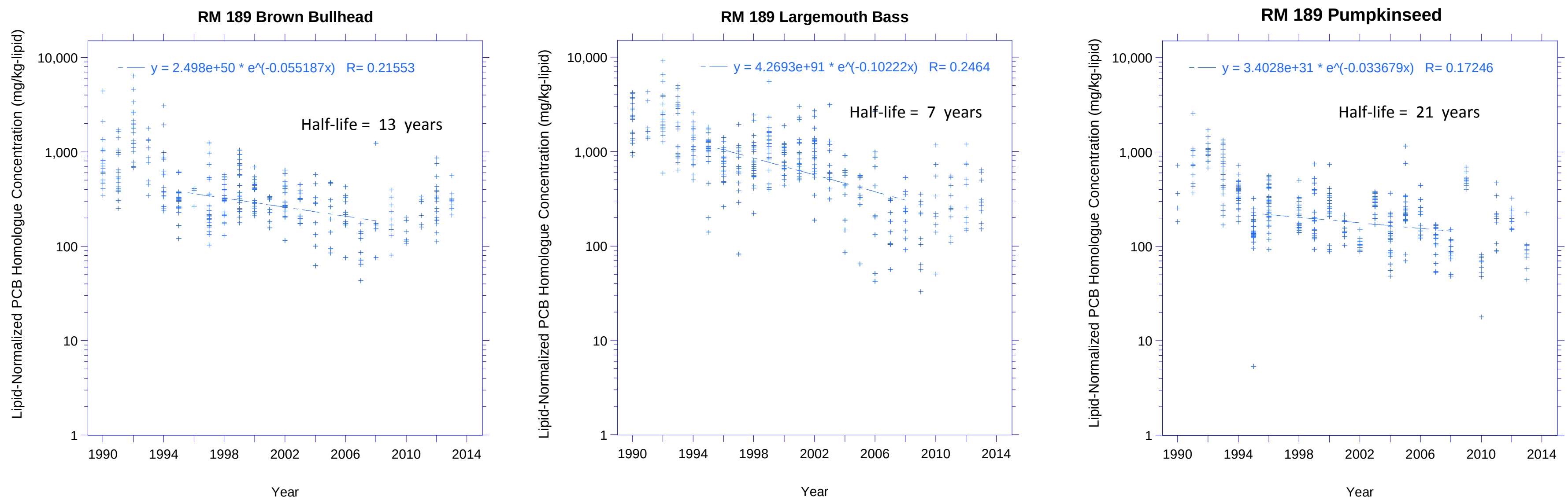
250 125 0 250 Feet

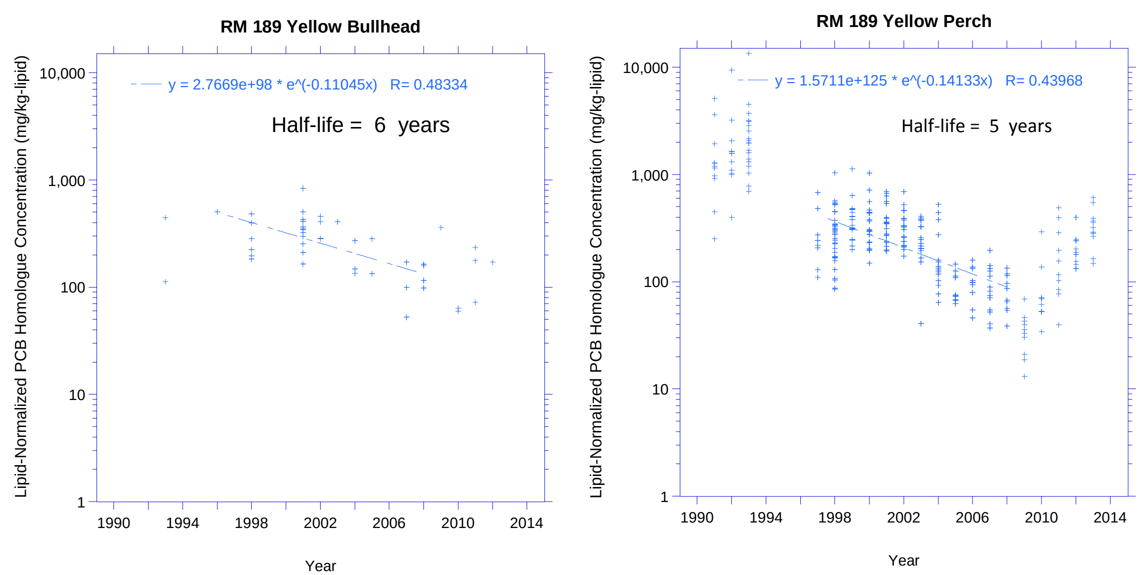
2002 TO 2005 SSAP CORES
WITHIN 100 FEET OF 1998 COMPOSITE NODES

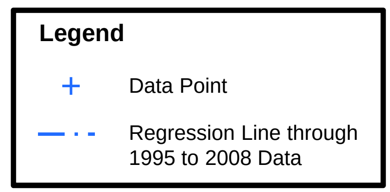
Figure 5i

2016

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







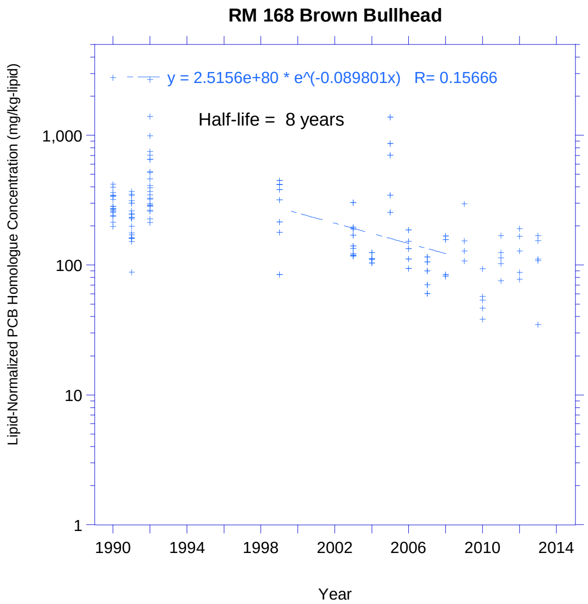
Note: PCB Homologue Concentrations derived from original values which were reported on an Aroclor basis.

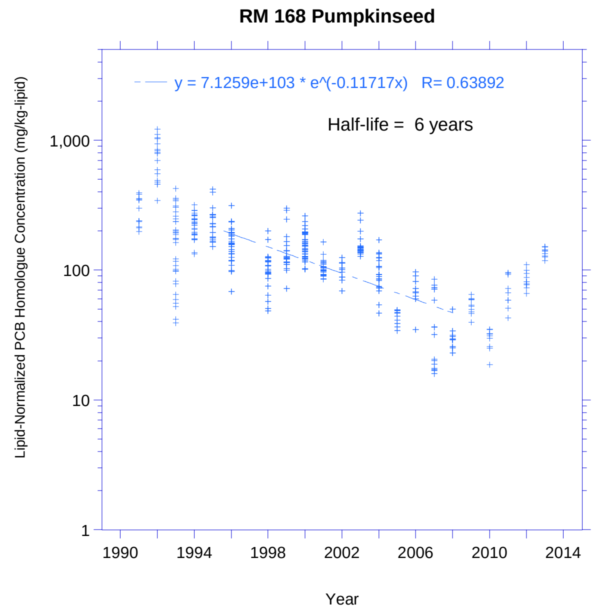
Hudson River PCBs Superfund Site

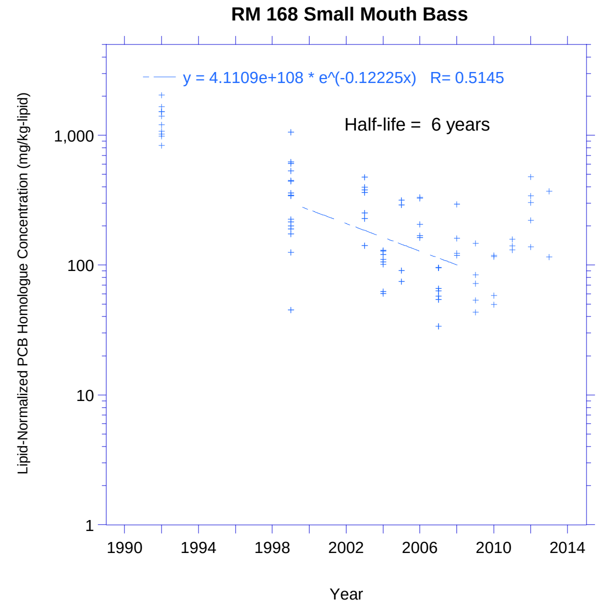
Fish Tissue Trends at RM 189

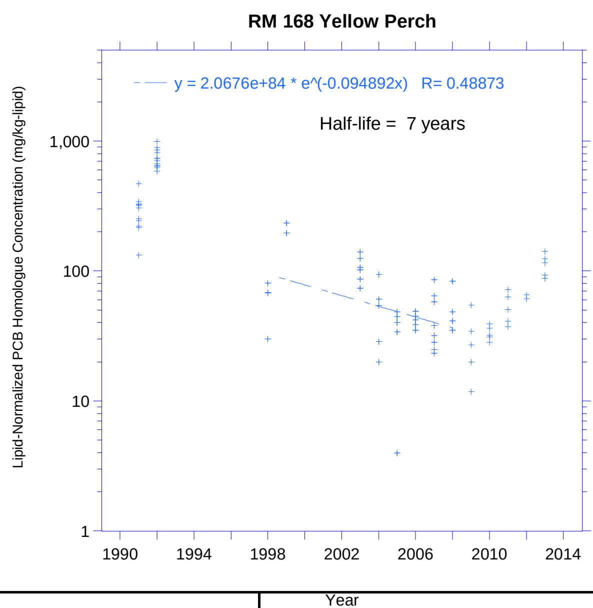
Figure 6a

2016









Legend

+ Data Point

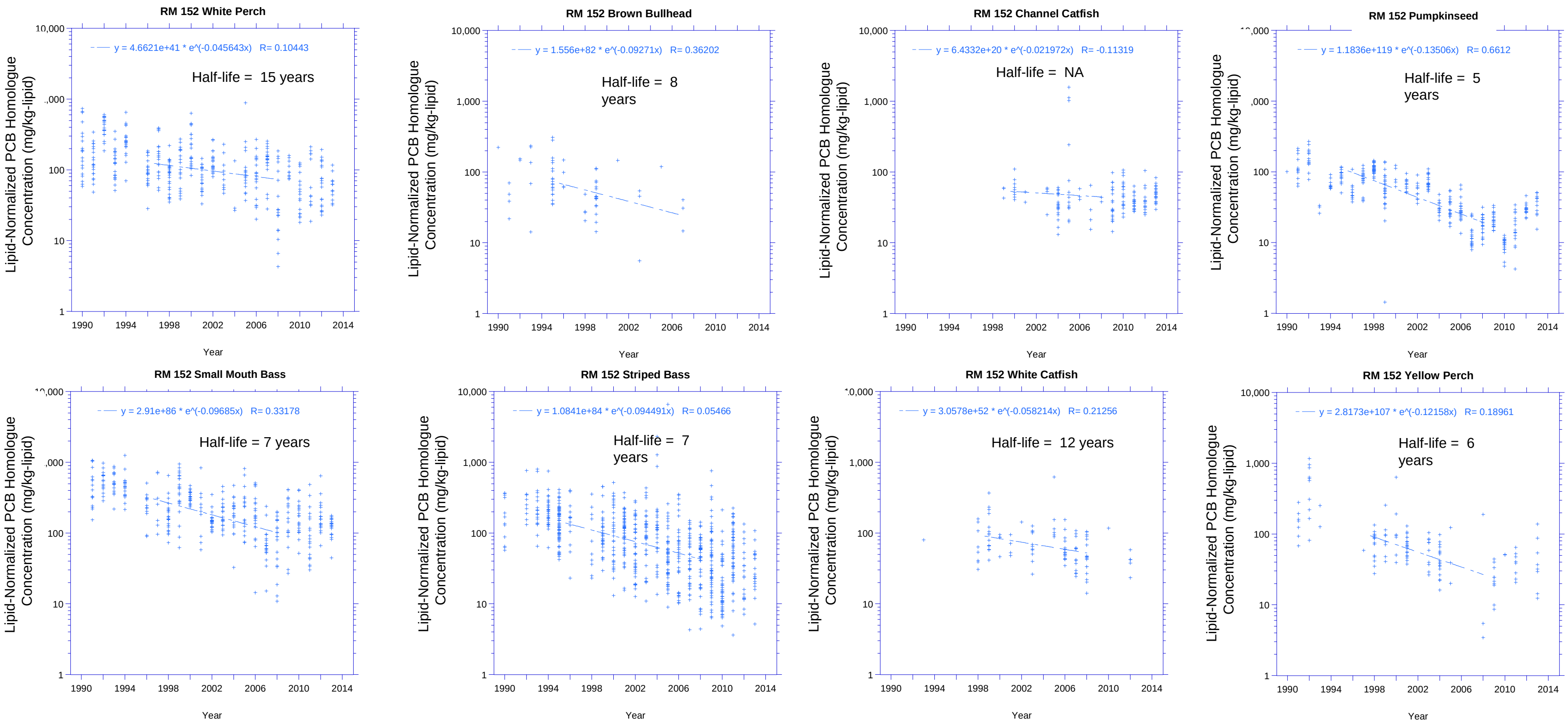
— · · Regression Line through 1995 to 2008 Data

Note: PCB Homologue Concentrations derived from original values which were reported on an Aroclor basis.

Fish Tissue Trends at RM 168

Figure 6b

2016



Legend

+ Data Point

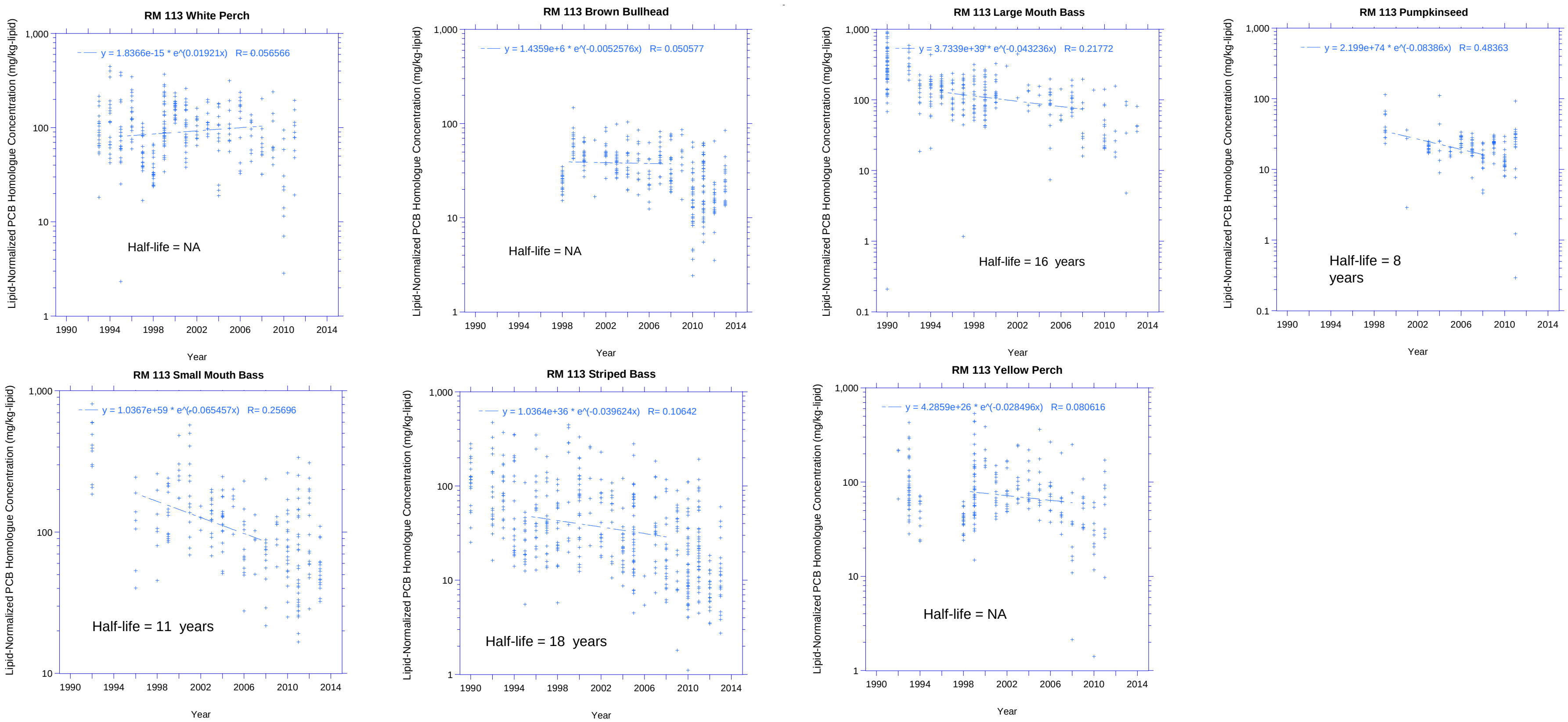
Regression Line through 1995 to 2008 Data

Notes:
1. PCB Homologue Concentrations derived from original values which were reported on an Aroclor basis.
2. Half-life = NA indicates change in concentration with time is not statistically significant.

Fish Tissue Trends at RM 152

Figure 7a

2016



Legend

+ Data Point

Regression Line through 1995 to 2008 Data

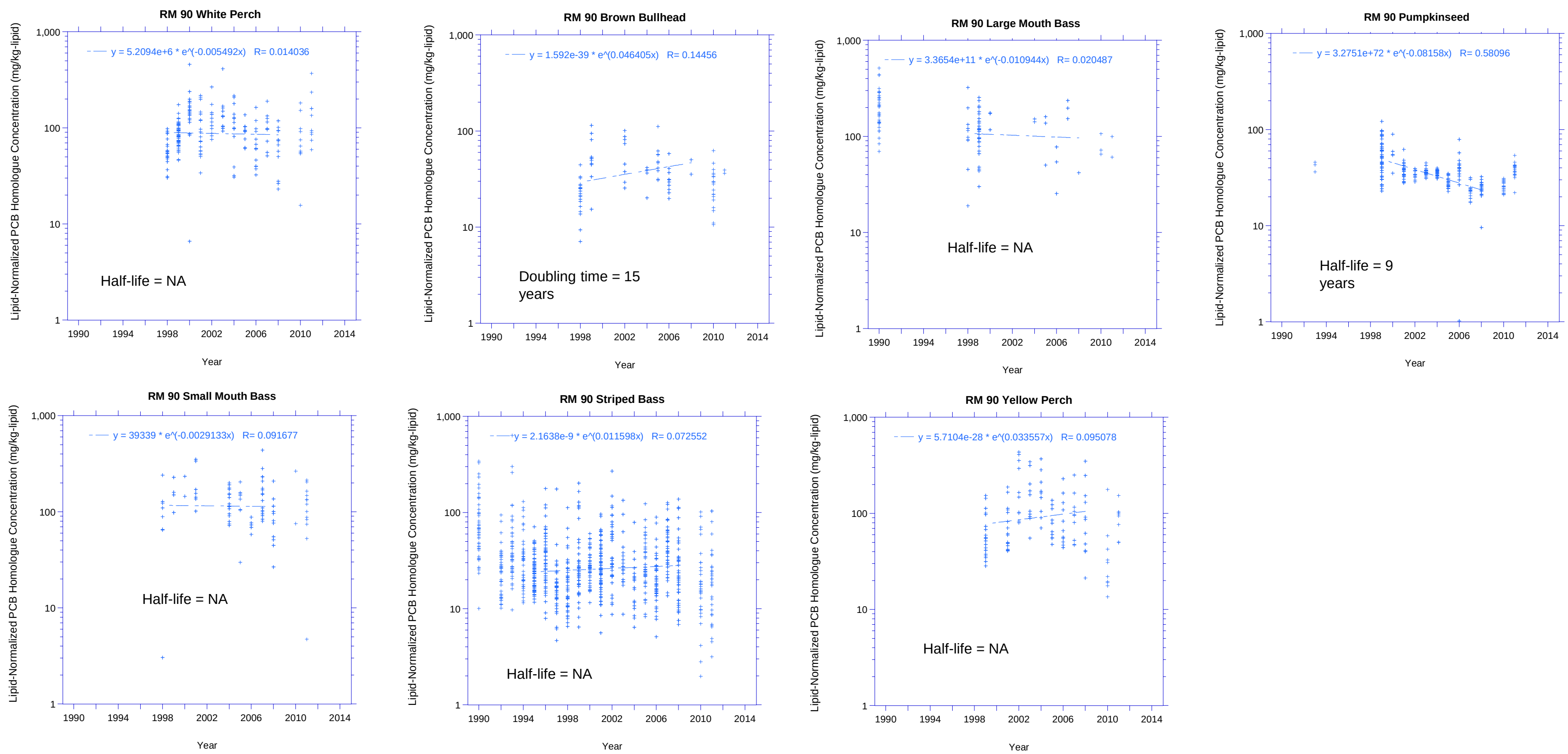
Notes:

1. PCB Homologue Concentrations derived from original values which were reported on an Aroclor basis.
2. Half-life = NA indicates change in concentration with time is not statistically significant.

Fish Tissue Trends at RM 113

Figure 7b

2016



Legend

+ Data Point

— · · Regression Line through 1995 to 2008 Data

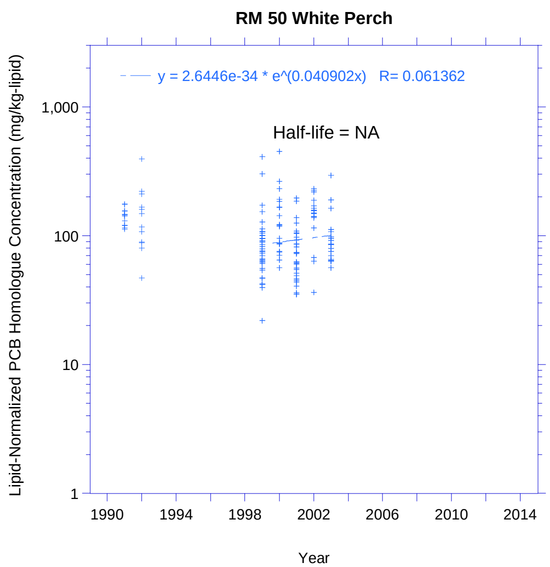
Notes:
1. PCB Homologue Concentrations derived from original values which were reported on an Aroclor basis.
2. Half-life = NA indicates change in concentration with time is not statistically significant.

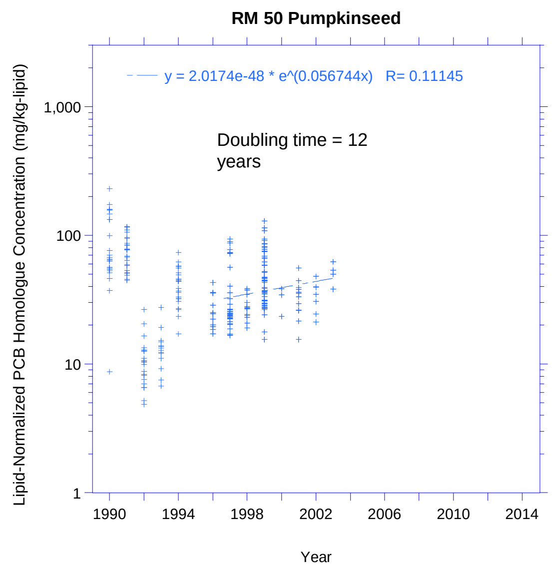
Hudson River PCBs Superfund Site

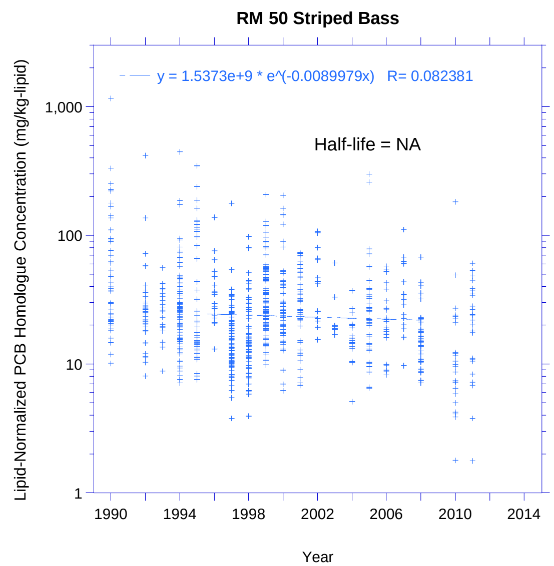
Fish Tissue Trends at RM 90

Figure 7c

2016







Legend

+ Data Point

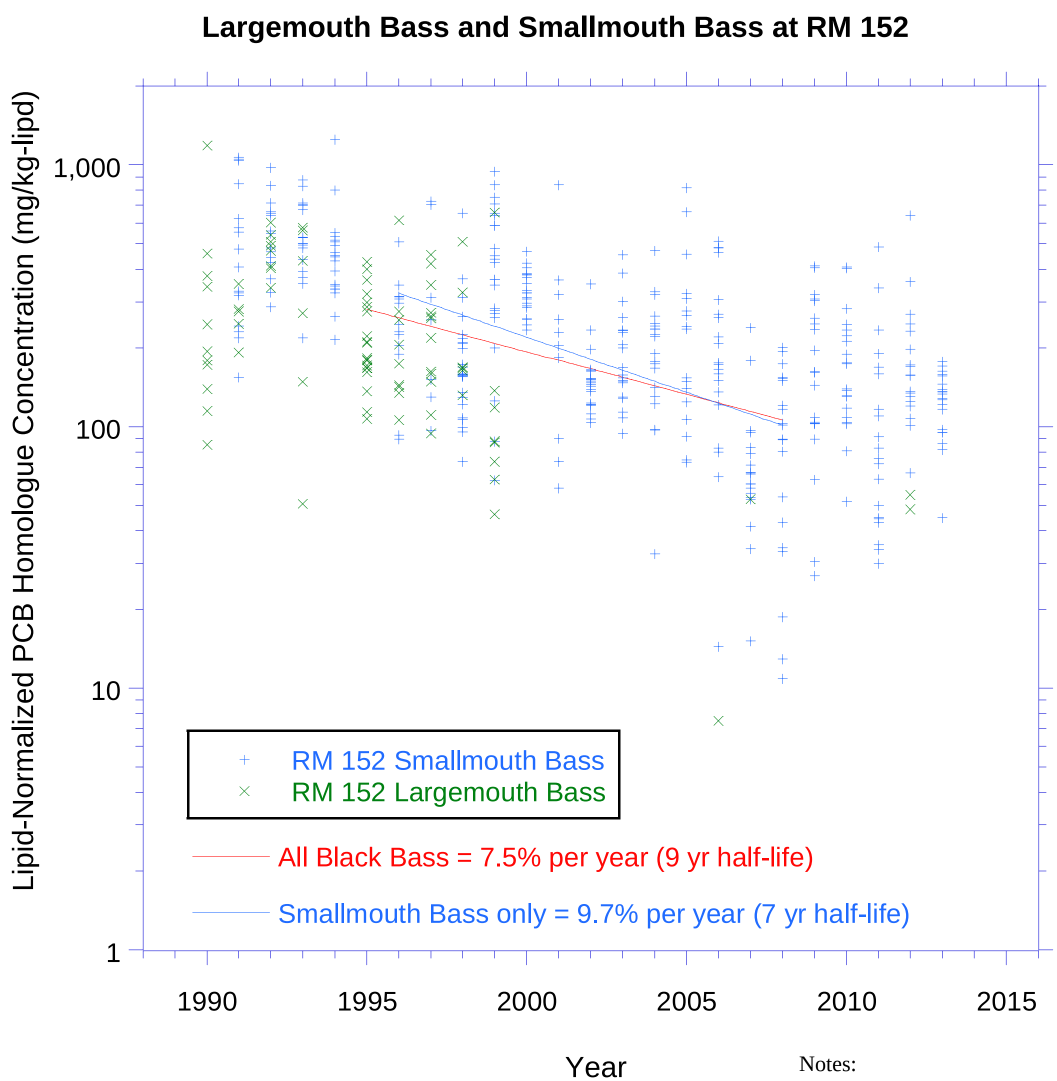
— · · Regression Line through 1995 to 2008 Data

Notes:
1. PCB Homologue Concentrations derived from original values which were reported on an Aroclor basis.
2. Half-life = NA indicates change in concentration with time is not statistically significant.

Fish Tissue Trends at RM 50

Figure 7d

2016



Notes:

1. PCB Homologue Concentrations derived from original values which were reported on an Aroclor basis.
2. Regression covers years 1996 to 2008 for smallmouth bass and 1995 to 2008 for all black bass.

Hudson River PCBs Superfund Site

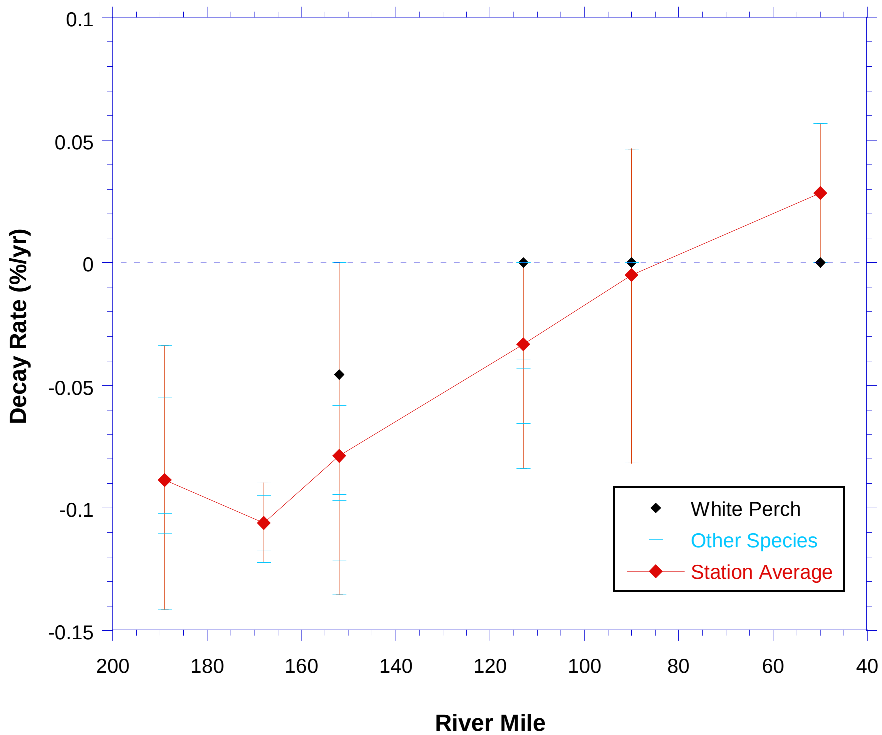
Decay Rates for Black Bass at River Mile 152

Figure 7e

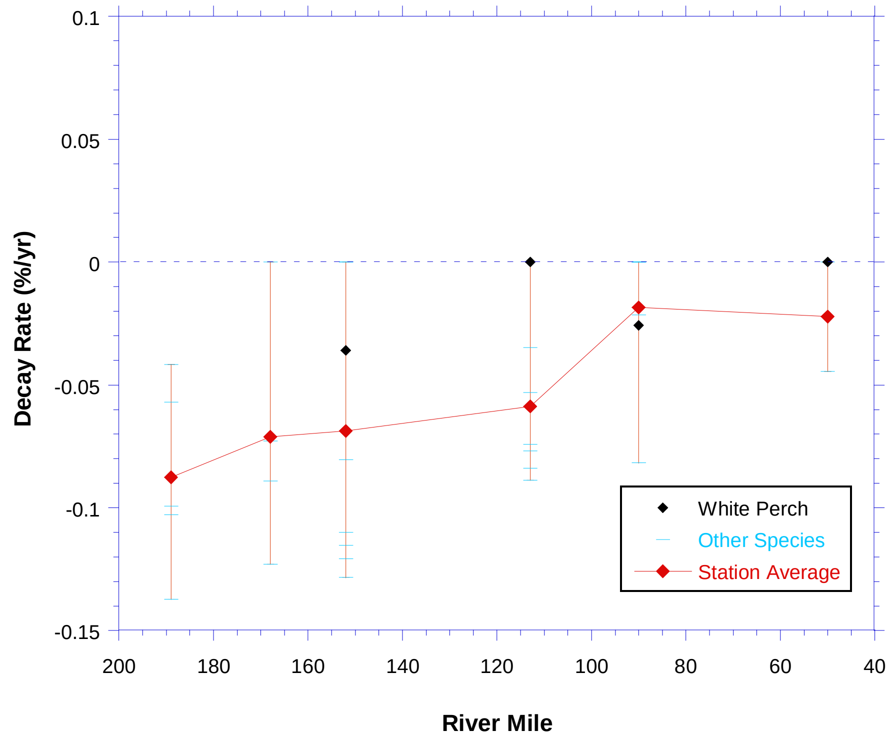
2016

Annual Decay Rates by Species and Station
(Based on Lipid-Normalized Total Homologues)

(Homologue Concentrations Derived from Aroclor Data)



Annual Decay Rates by Species and Station
(Based on Lipid-Normalized Sum of Aroclors)

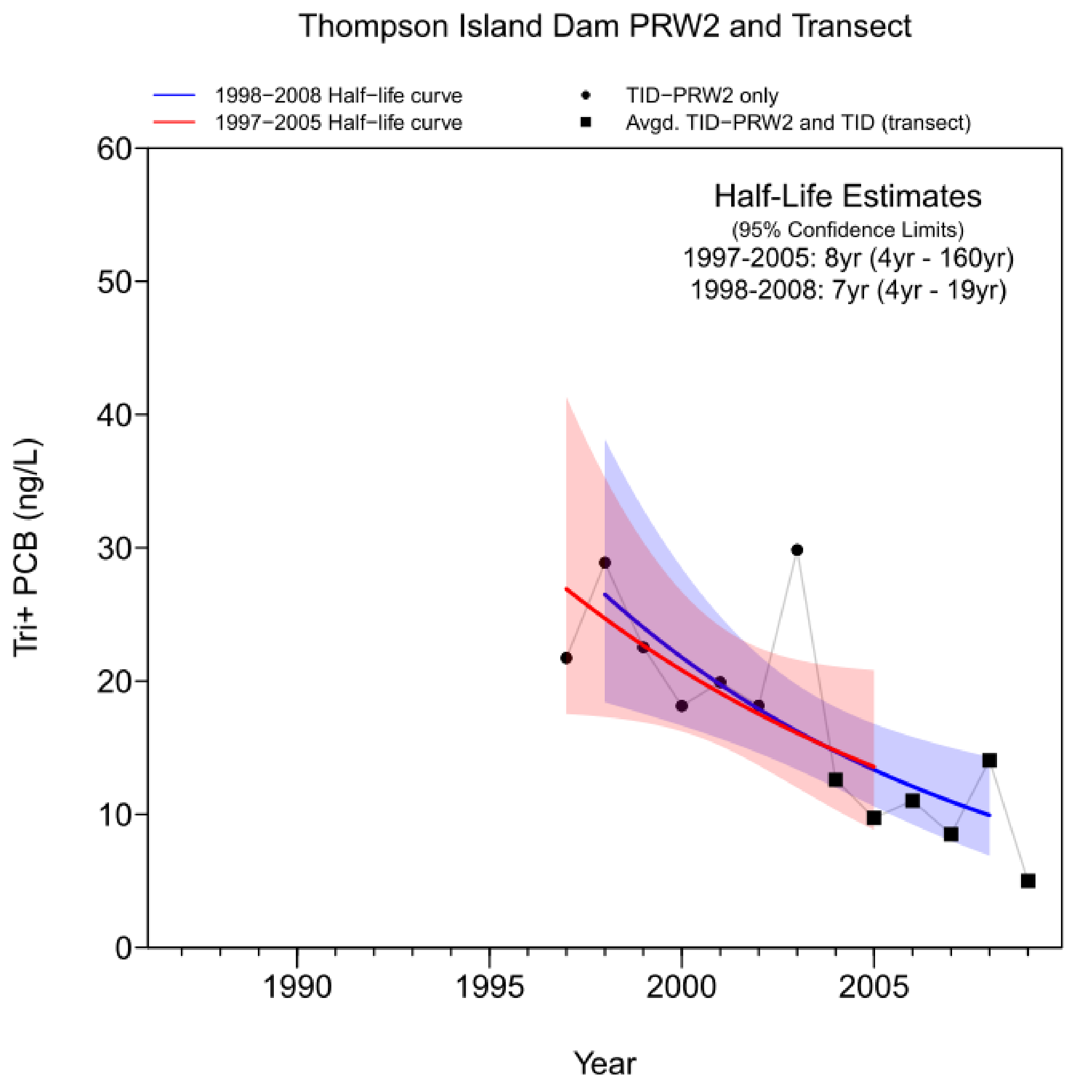


Decay Rates for All Fish Species *vs.* River Mile

Figure 7f

2016

Shaded areas represent 95 percent confidence intervals about the regression curve fit.



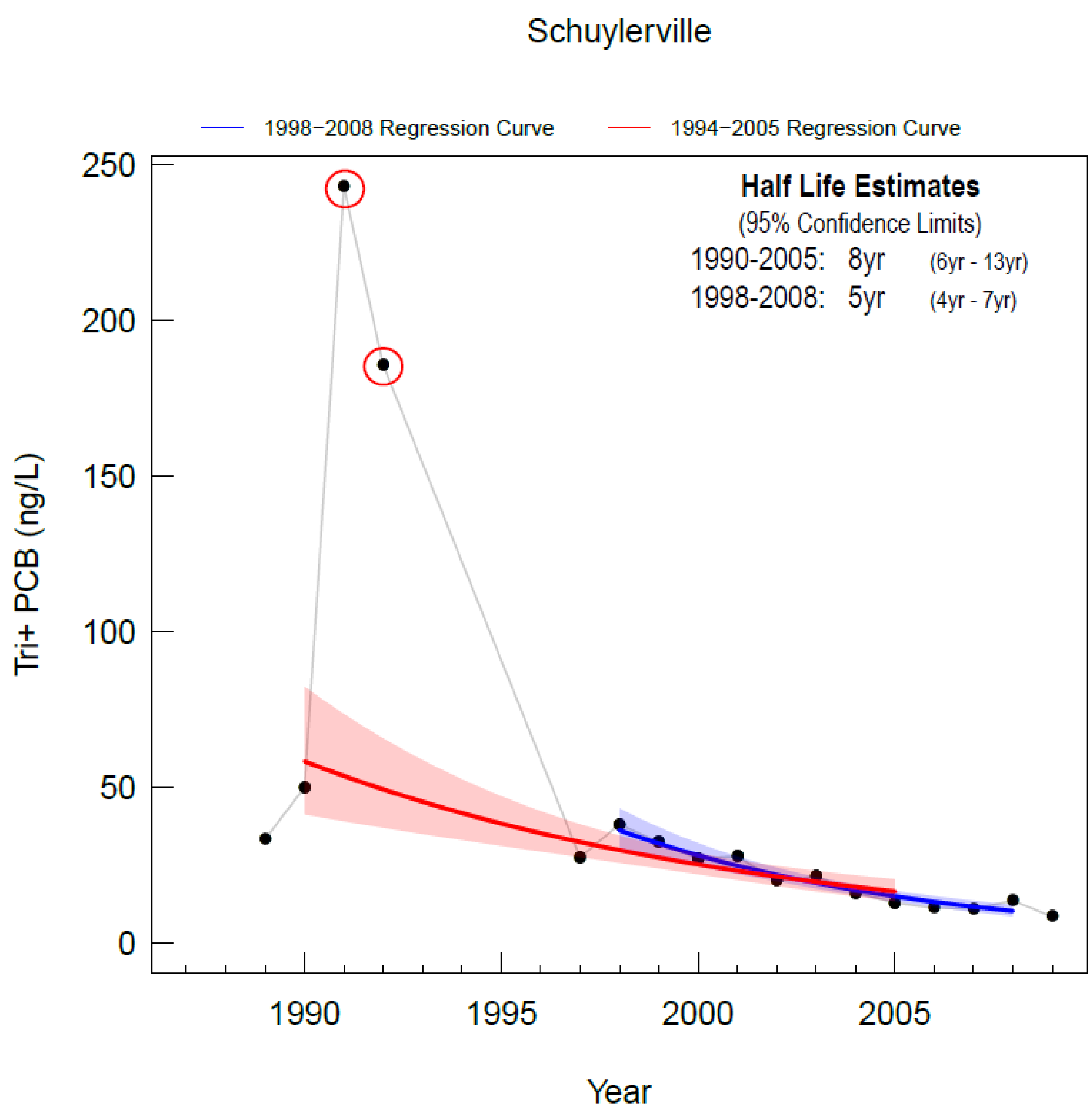
Tri+ PCB Concentrations at the TID-PRW2 Station and Associated Transect Station over Time

Figure 8

2016

Red circled data represent years impacted by the Allen Mill releases and were excluded from the regression analysis.

Shaded areas represent 95 percent confidence intervals about the regression curve fit.



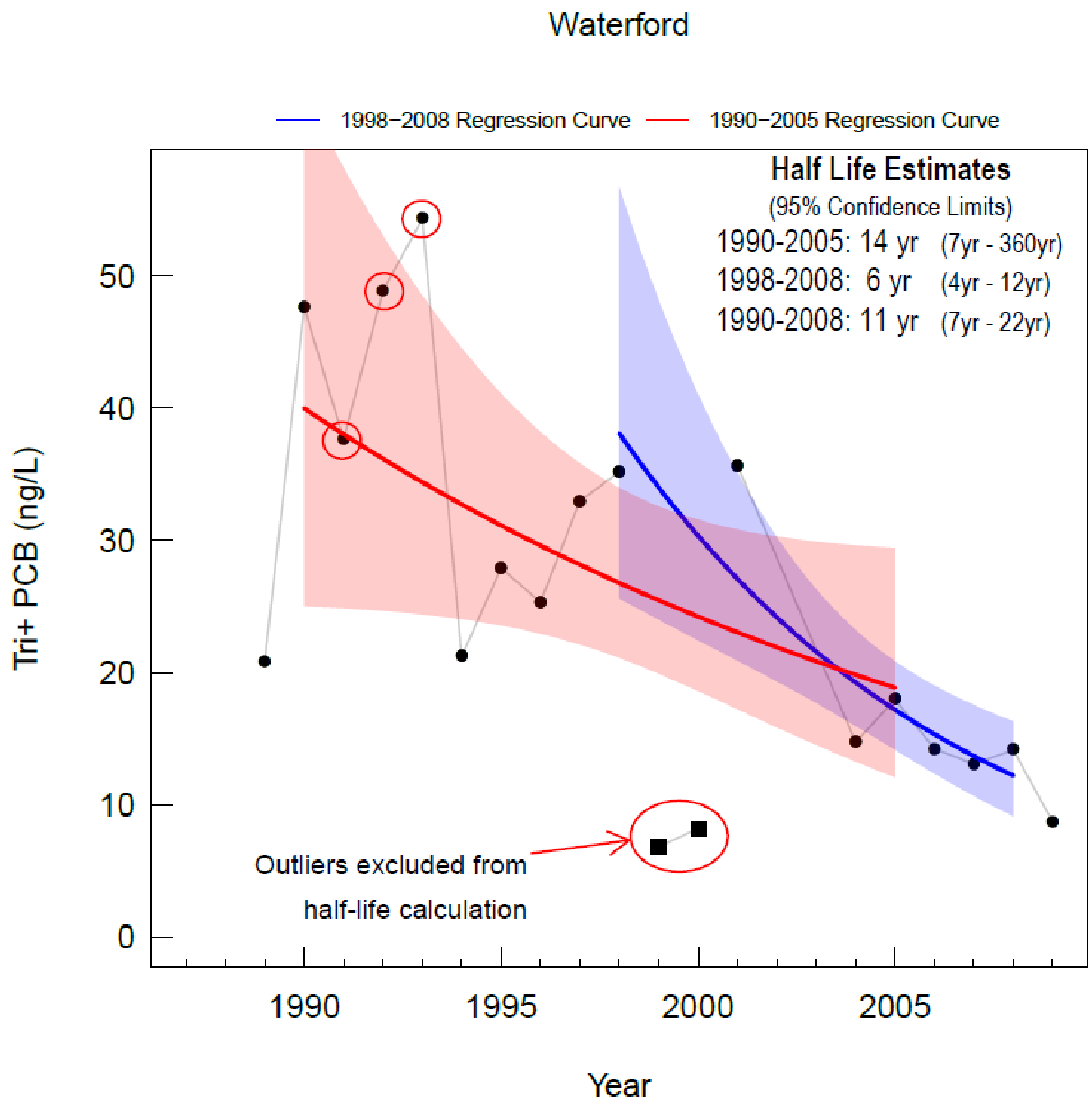
Tri+ PCB Concentrations at Schuylerville over Time

Figure 9

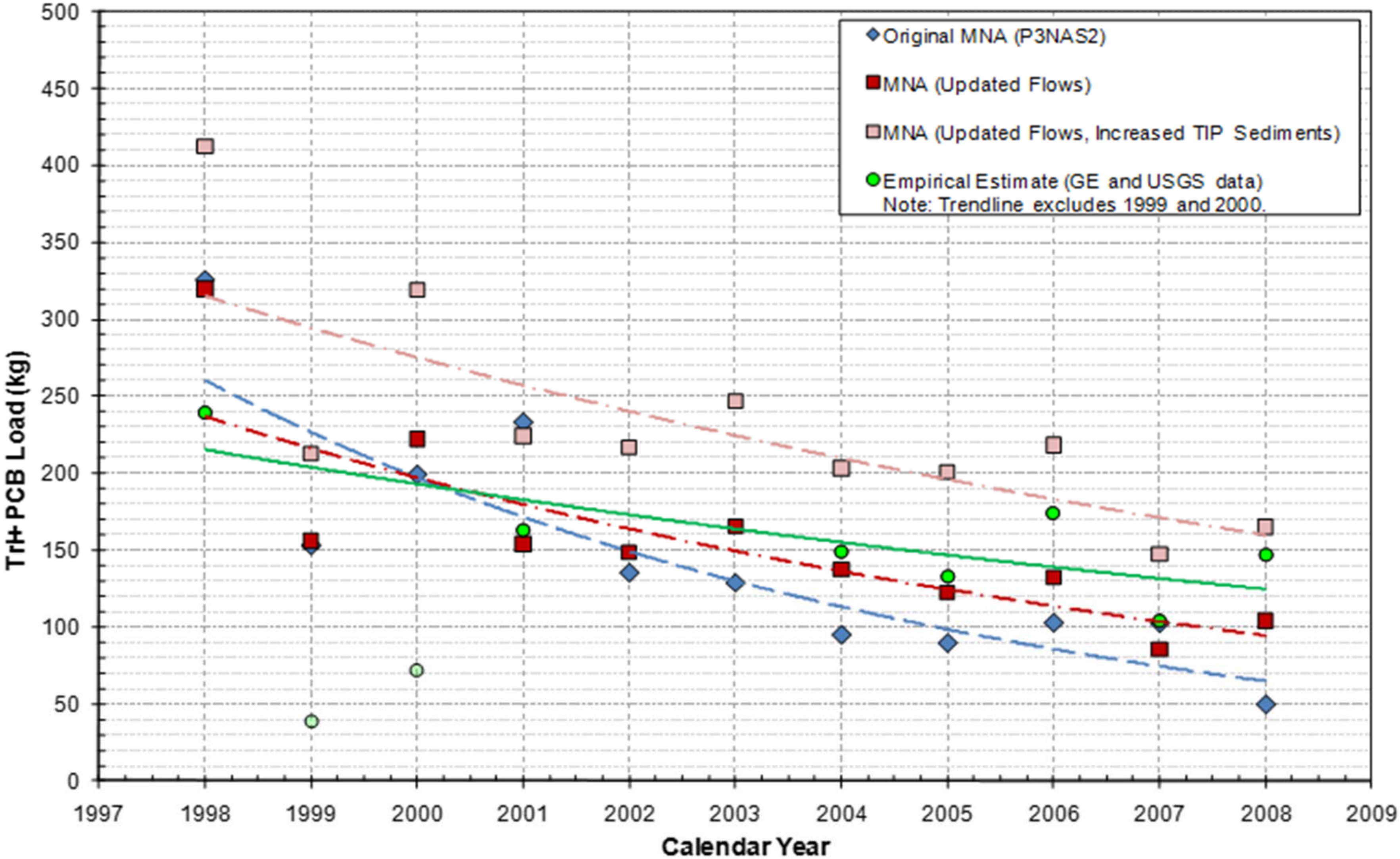
2016

Red circled data represent years impacted by the Allen Mill releases and were excluded from the regression analysis.

Shaded areas represent 95 percent confidence intervals about the regression curve fit.

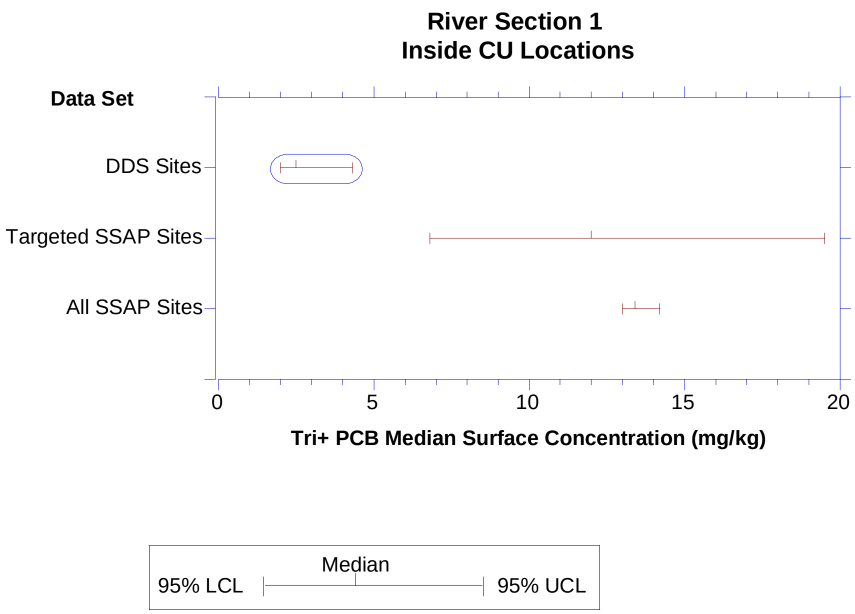


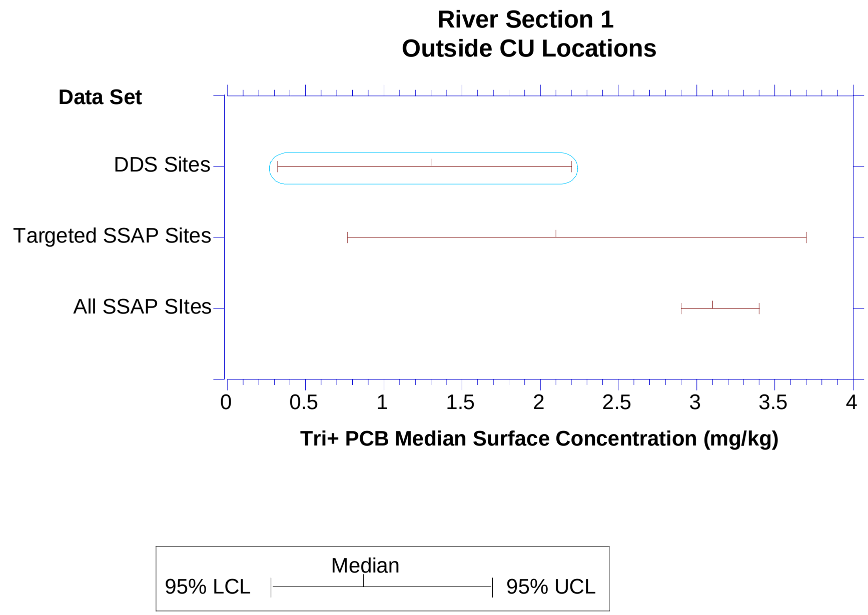
	Tri+ PCB Concentrations at Waterford over Time	Figure 10
		2016



Model curve with 2002-2005 data consistently overestimates load to Lower Hudson
(pink symbols =- model, green symbols = data based estimate)

	Annual Tri+ PCB Mass Load at Waterford Showing Overestimate using 2002-2005 Data	Figure 11
	HUDTOX LimnoTech Memo	2016





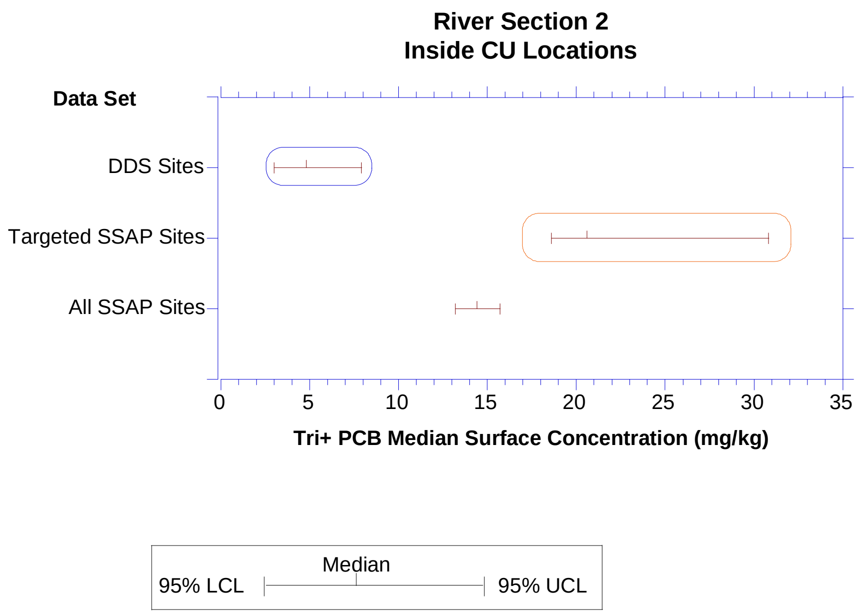
Ellipse colors correspond to the following:

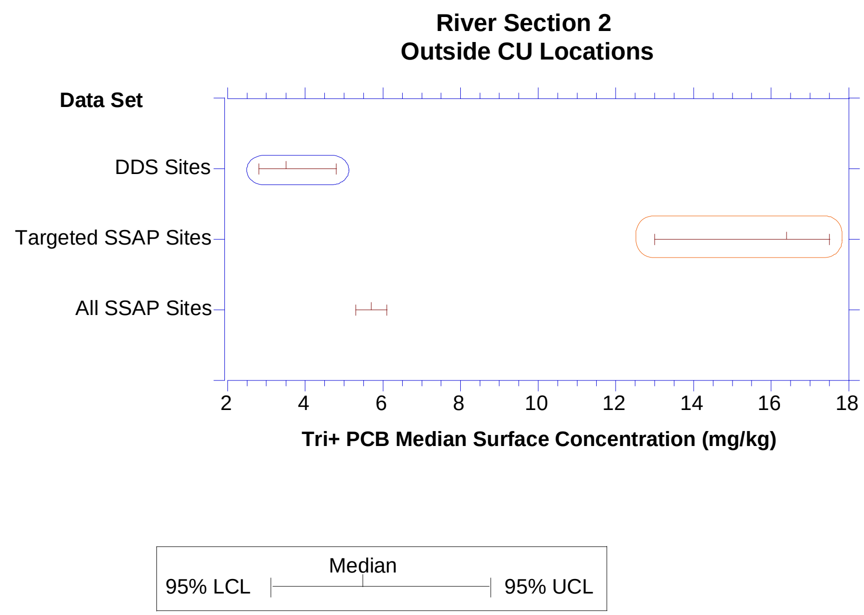
- Median significantly higher than result for all SSAP locations in category
- Median significantly lower than result for all SSAP locations in category
- Median significantly lower than result for all SSAP locations and all Co-located SSAP locations in category

Comparison of DDS Samples with SSAP Results
River Section 1 Median Values

Figure 12

2016





Ellipse colors correspond to the following:

Median significantly higher than result for all SSAP locations in category

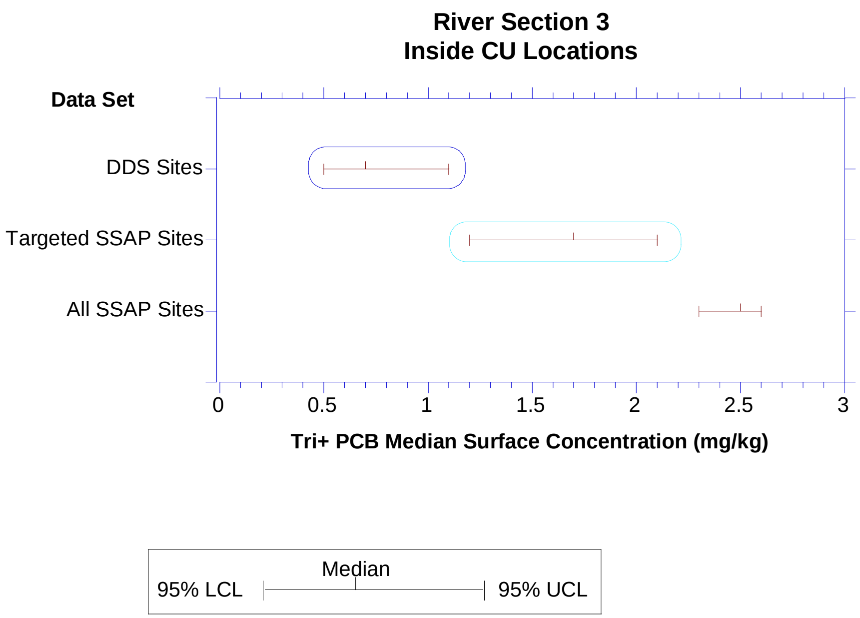
Median significantly lower than result for all SSAP locations in category

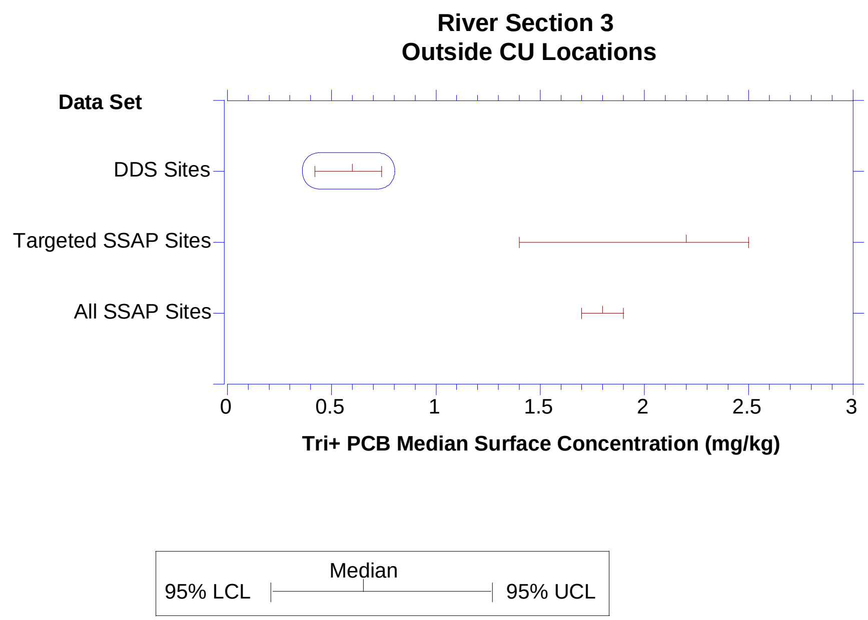
Median significantly lower than result for all SSAP locations and all Co-located SSAP locations in category

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

Figure 13

2016





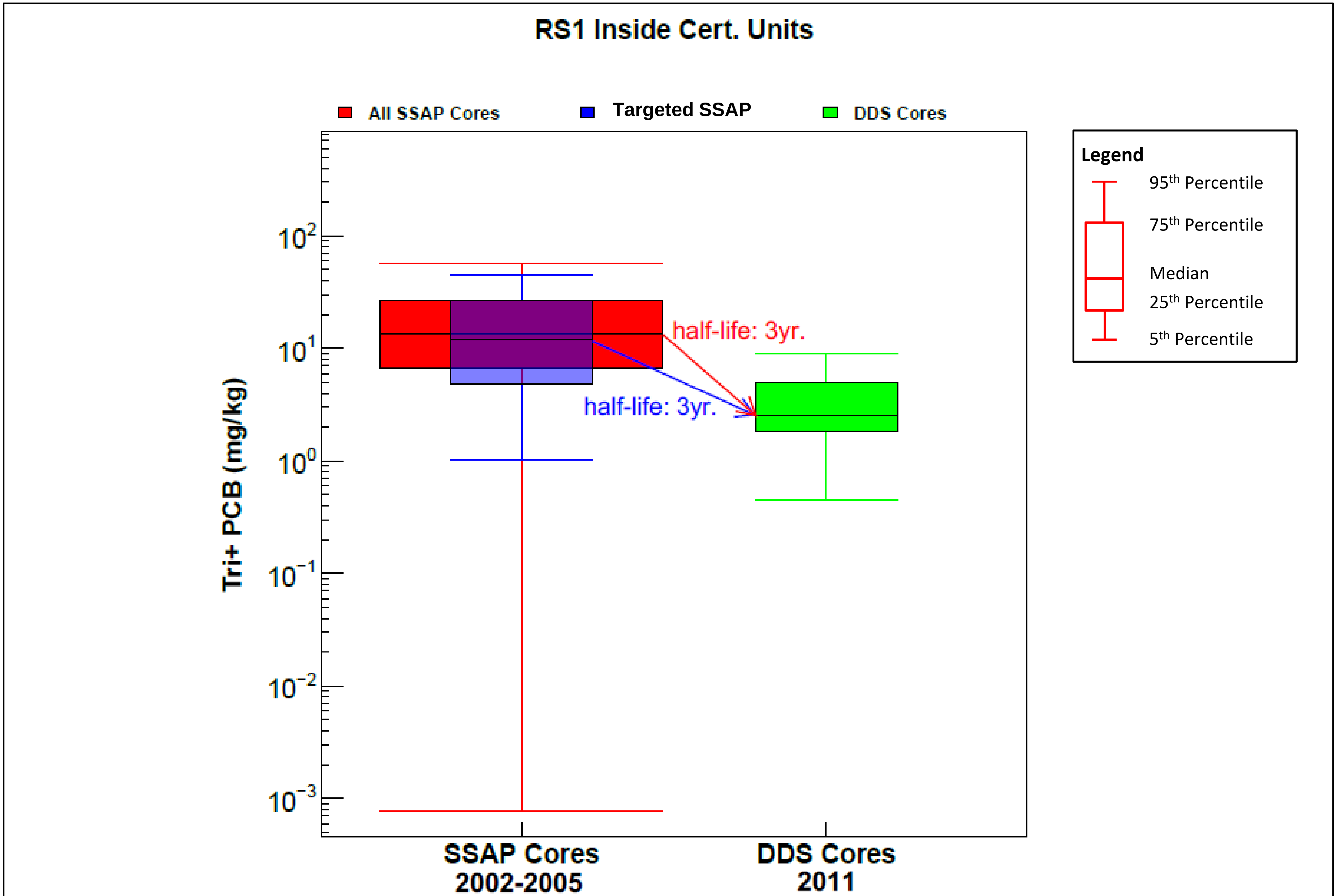
Ellipse colors correspond to the following:

- 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 14

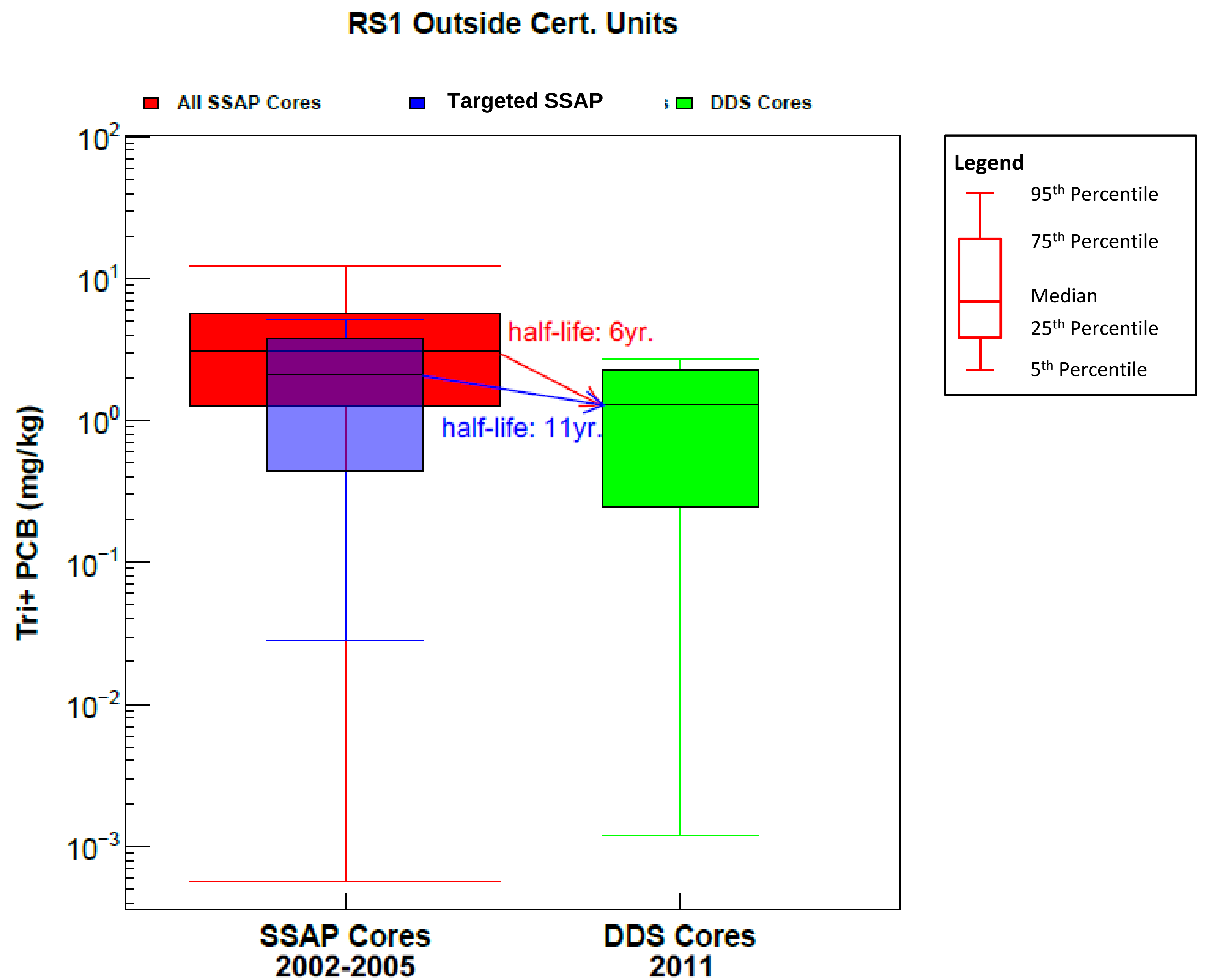
2016



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

Figure 15

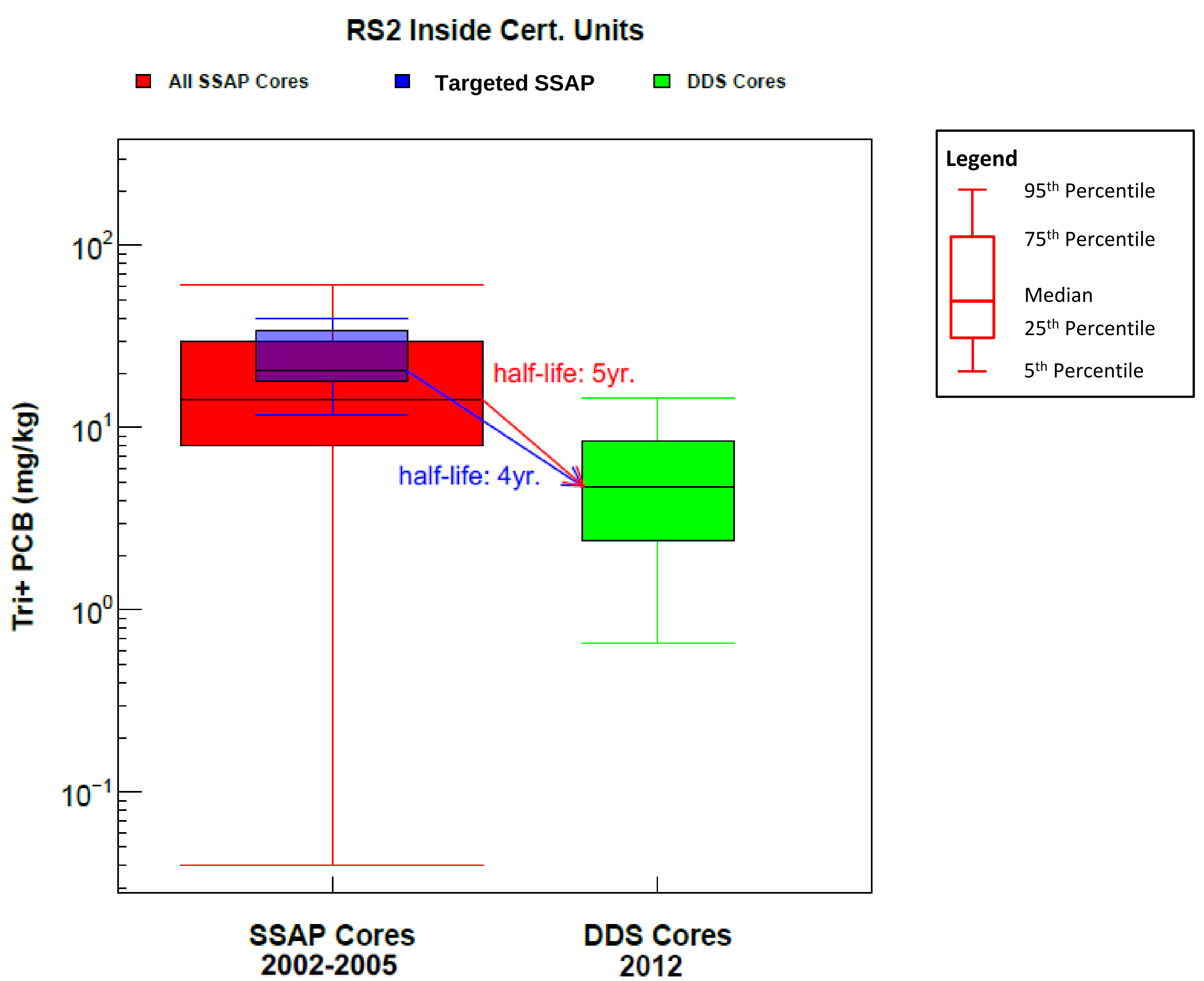
2016



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

Figure 16

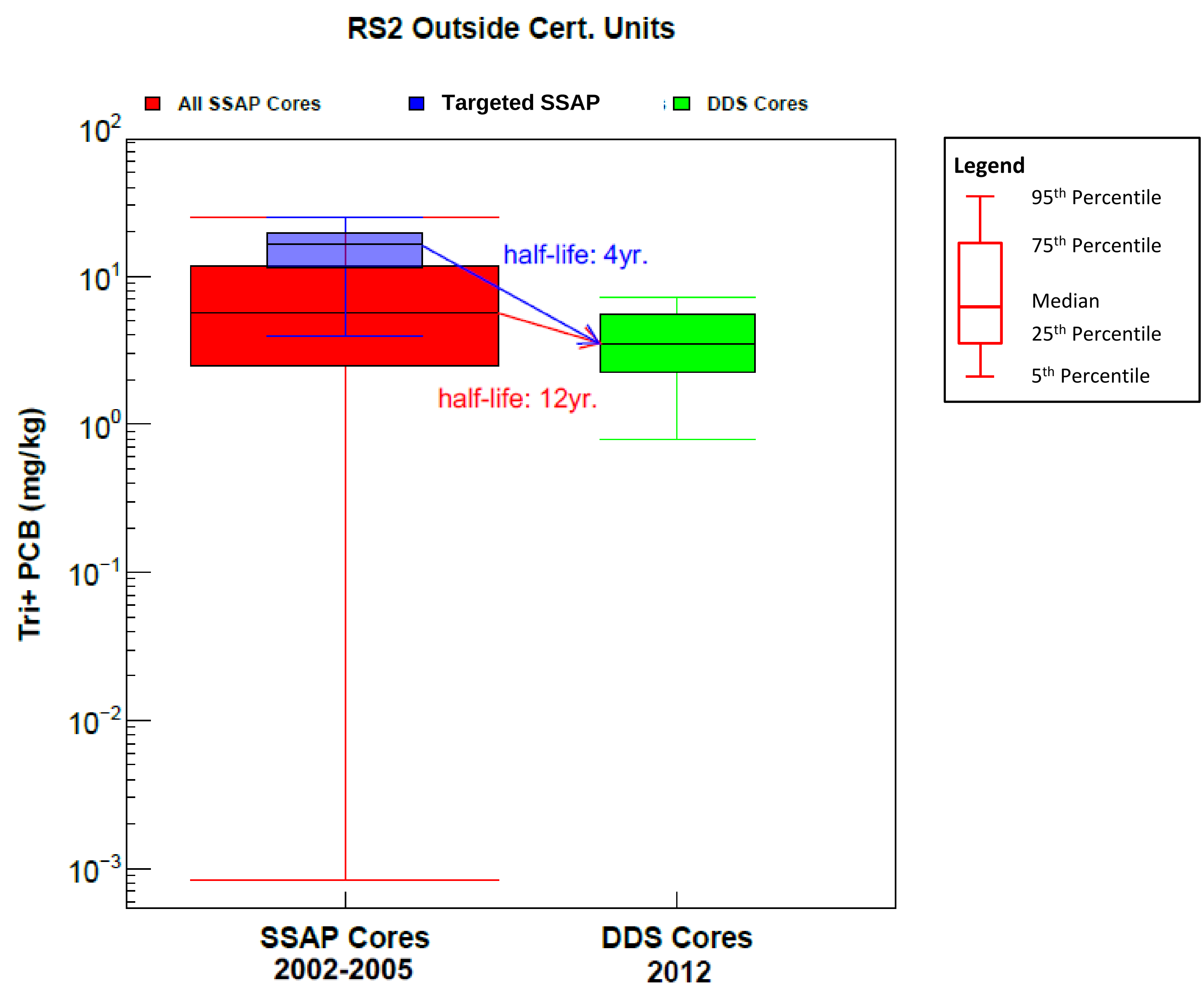
2016



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

Figure 17

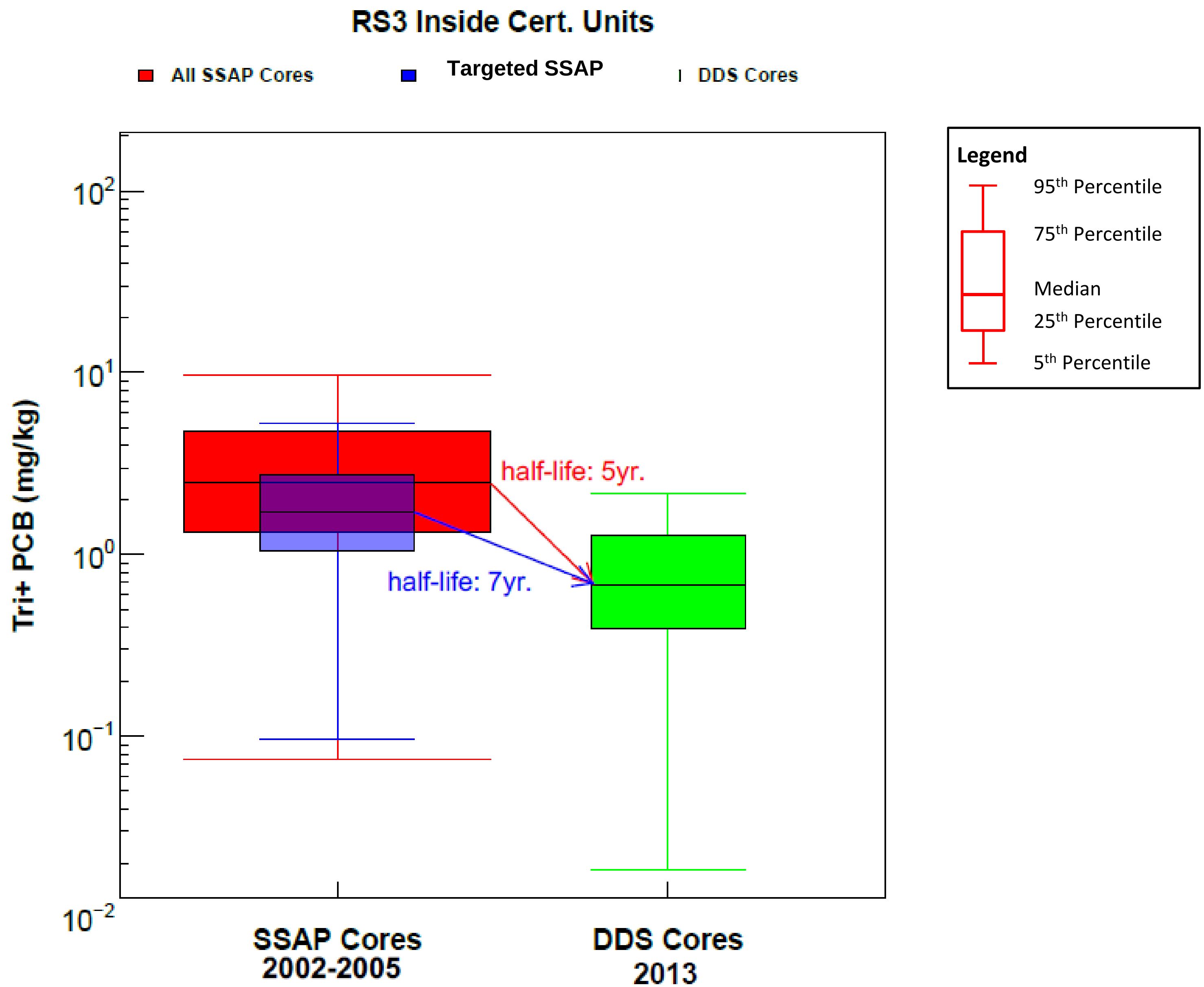
2016



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

Figure 18

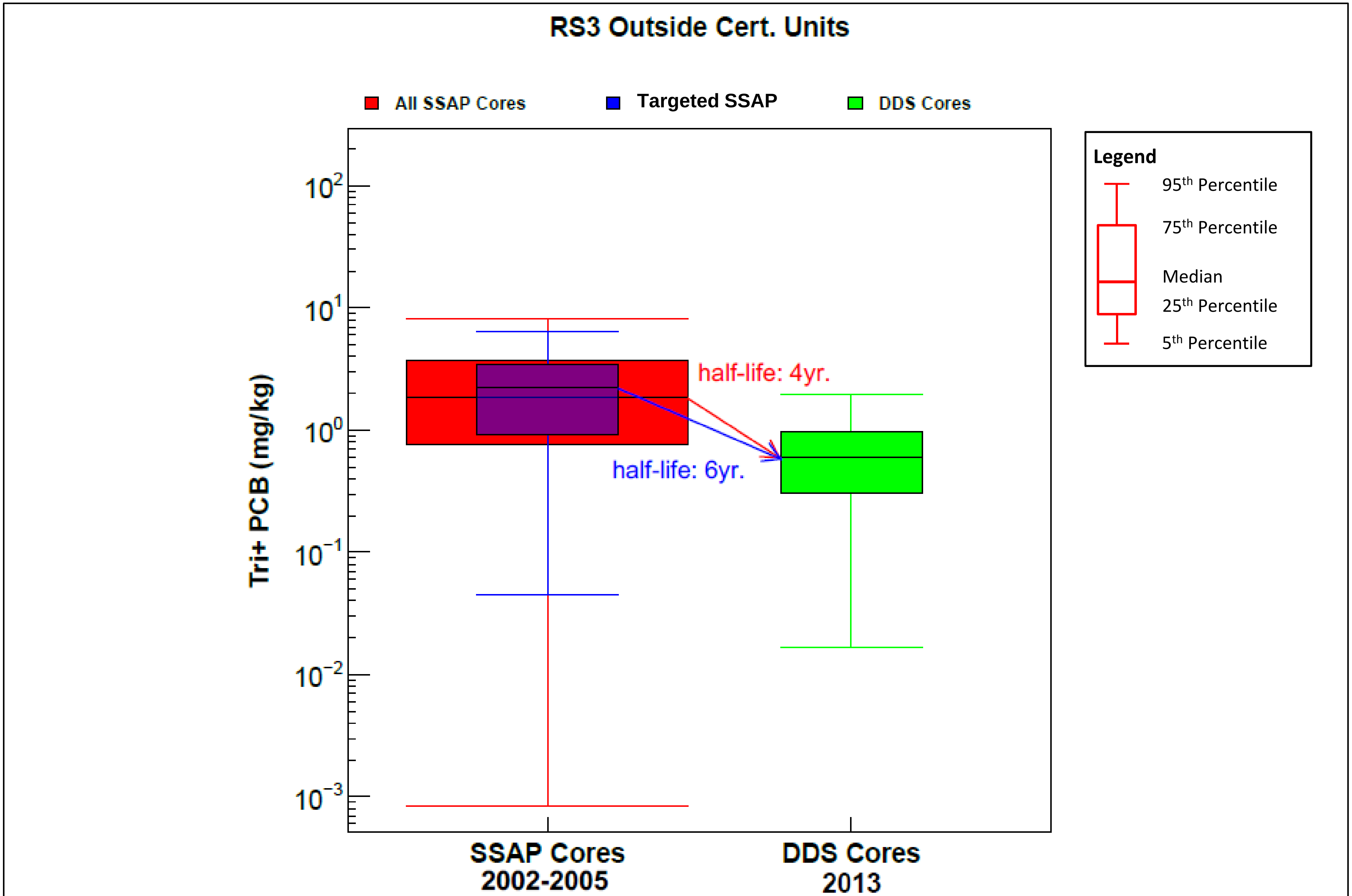
2016



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

Figure 19

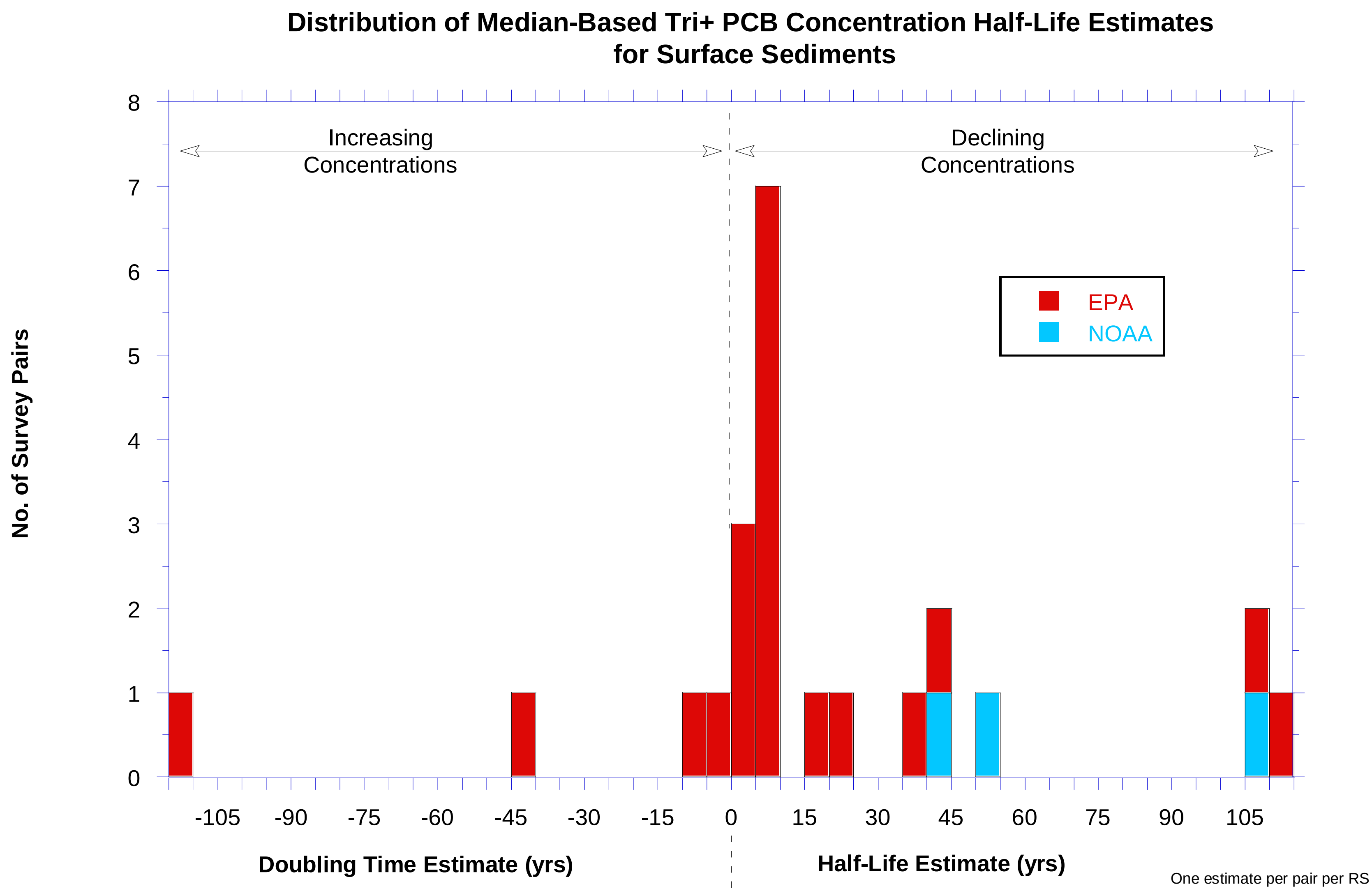
2016



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

Figure 20

2016

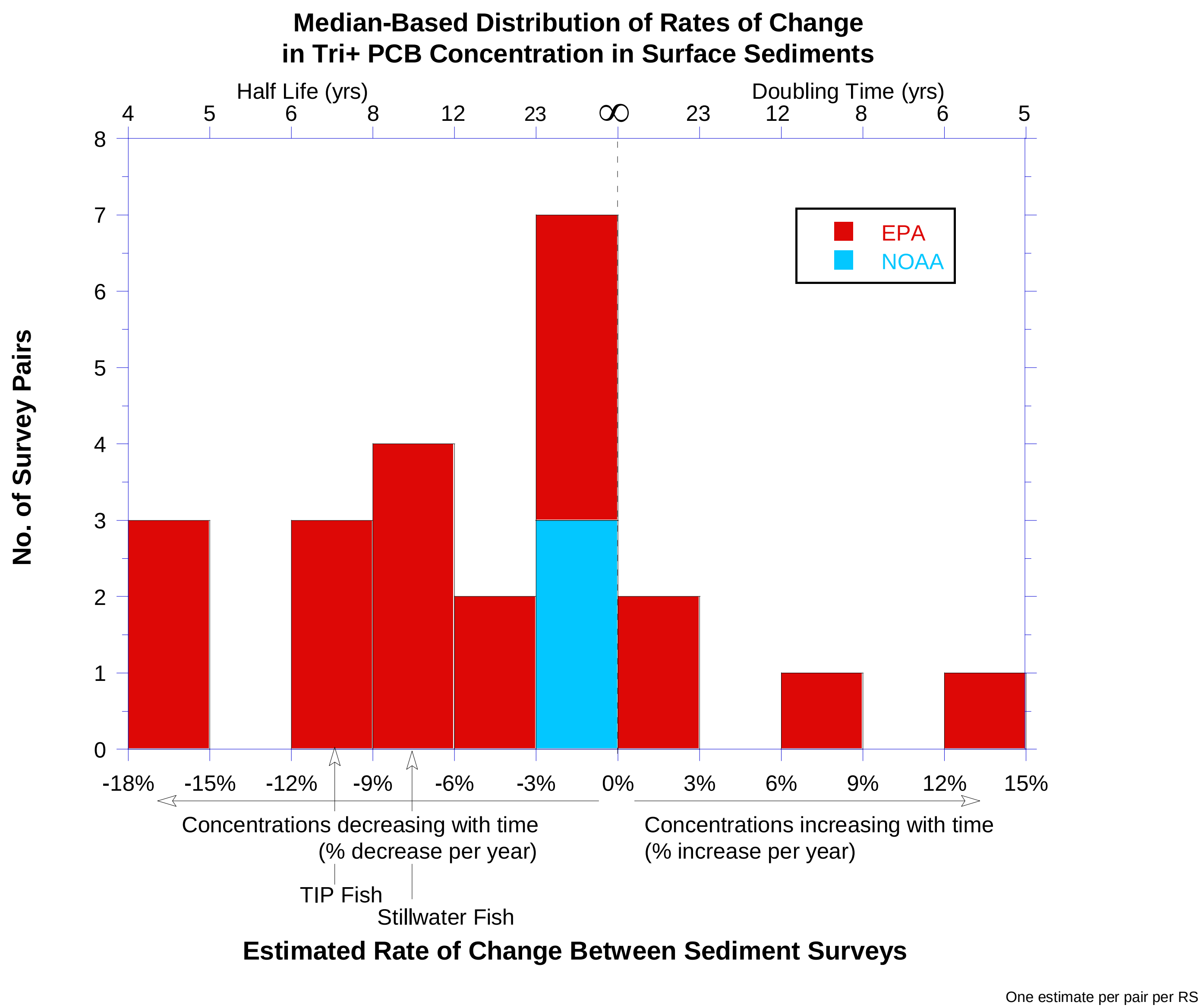


Hudson River PCBs Superfund Site

Sediment Half Life Histogram

Figure 21

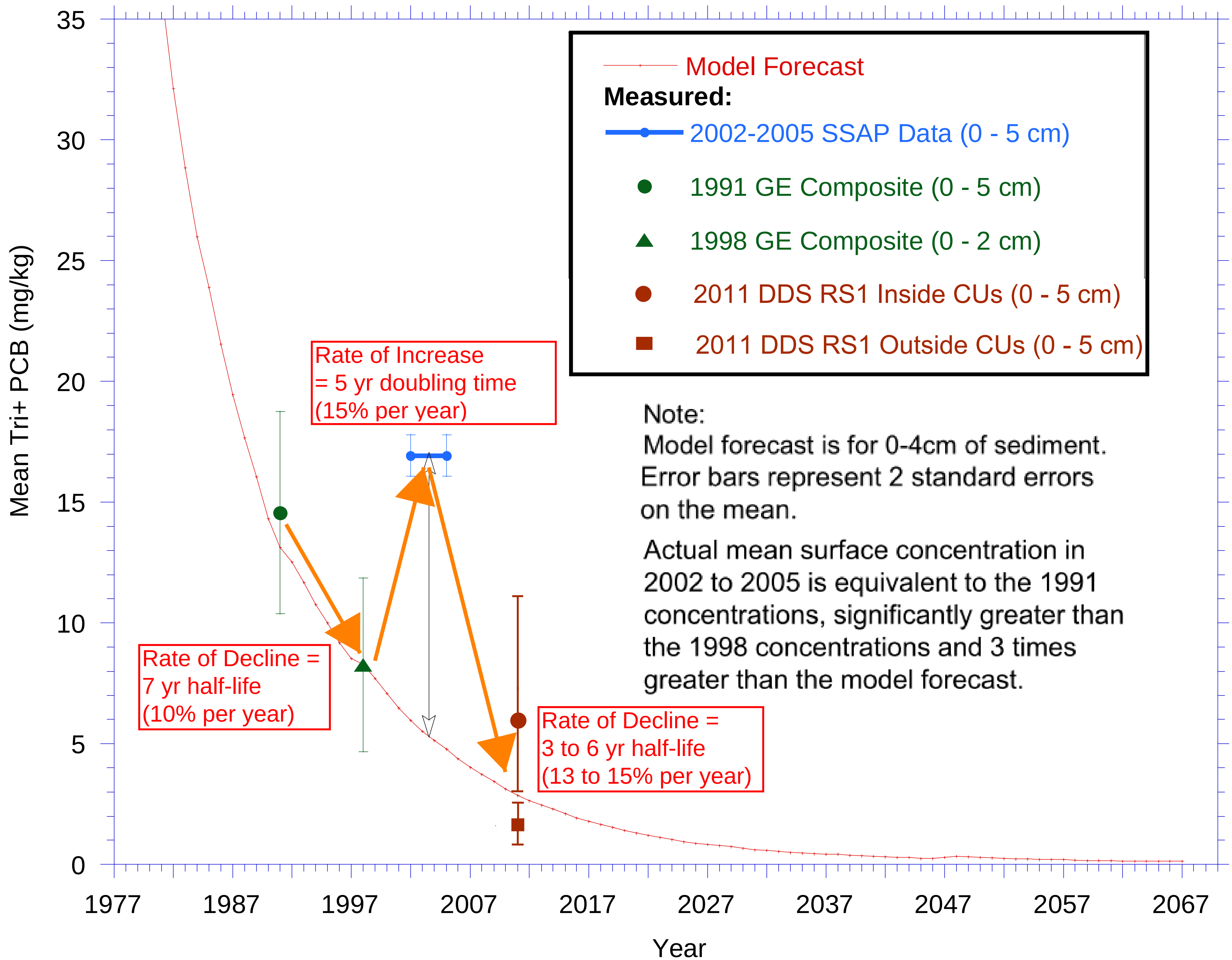
2016



Rate of Sediment Change Histogram

Figure 22

2016



	HUDTOX Model and Core Data Comparison All Sediment Types Thompson Island Pool (Adapted from Figure I-3-22) EPA Phase 1 Evaluation Report - Hudson River PCBs Site	**Figure 23** 2016

Table 1: Summary of Half Life Estimates For Upper Hudson Fish Tissue Tri+ PCB Concentrations

Location	Species	1995-2008	
		Data-Based Decay Rate (%/yr)	Data-Based Half Life (yrs)
TIP	Brown Bullhead	-6%	13
(RM 189)	Large Mouth Bass	-10%	7
	Yellow Bullhead	-11%	6
	Yellow Perch	-14%	5
	YoY Pumpkinseed	-3%	21
	Average	**-9%**	**8**
Stillwater	Brown Bullhead	-9%	8
(RM 168)	Small Mouth Bass	-12%	6
	Yellow Perch	-9%	7
	YoY Pumpkinseed	-12%	6
	Average	**-11%**	**7**

Notes:

1. Average half life is based on average rate of decline, not average of half-life values.

2. Values indicated on this table are based on lipid-normalized total homologues (derived from Aroclor data).

Table 2: Summary of Half Life Estimates For Lower Hudson Fish Tissue Tri+ PCB Concentrations

Location	Species	1995-2008	
		Data-Based Decay Rate (%/yr)	Data-Based Half Life (yrs)
152	White Perch	-5%	15
	Black Bass*	-8%	9
	Brown Bullhead	-9%	7
	Channel Catfish	0%	-
	Striped Bass	-9%	7
	Small Mouth Bass	-10%	7
	White Catfish	-6%	12
	YoY Pumpkinseed	-14%	5
	Yellow Perch	-12%	6
	Average	**-8%**	**9**
113	White Perch	0%	-
	Brown Bullhead	0%	-
	Large Mouth Bass	-4%	16
	Striped Bass	-4%	17
	Small Mouth Bass	-5%	13
	Yellow Perch	-3%	24
	YoY Pumpkinseed	-8%	8
	Average	**-4%**	**19**
90	White Perch	0%	-
	Brown Bullhead	5%	-15
	Large Mouth Bass	0%	-
	Striped Bass	0%	-
	Small Mouth Bass	0%	-
	Yellow Perch	0%	-
	YoY Pumpkinseed	-8%	8
	Average	**-0.50%**	**138**
50	Striped Bass	0%	-
	White Perch	0%	-
	YoY Pumpkinseed	6%	-12
	Average	**2%**	**-37**

Notes:

Average half life is based on average rate of decay, not average of half-life values.

Decay rate of zero indicates concentration change with time is not statistically significant.

Half life is not defined for decay rate of zero.

Negative half lives indicate doubling times in years

*Black bass not included in RM152 average since smallmouth bass was included and represents the majority of the black bass species.

Table 3: Summary of Half Life Estimates For Water Column Tri+ PCB Concentrations

Station	River Mile	1990-2005		1998-2008	
		Rate of Decay (%/yr)	Data-Based Half Life (yrs)	Rate of Decay (%/yr)	Data-Based Half Life (yrs)
TID	188.5	-	-	-10%	7
Schuylerville	185.5	-9%	8	-14%	5
Waterford	157	-5%	14	-12%	6
	Average	-7%	10	-12%	6

Notes:

Average half life is based on average rate of decay, not average of half-life values.

The long term record at TID center channel station does not begin until 1997, so a 1990-2005 rate was not calculated.

Table 4
Comparison Among Median Concentrations for SSAP and DDS cores Based on Bootstrap Analysis.

River Section	Location	All SSAP Locations		Targeted SSAP Locations		Co-located DDS Locations	
		n	Median Surf. Tri+ PCB (upper, lower 95% CI)[1]	n	Median Surf. Tri+ PCB (upper, lower 95% CI)[1]	n	Median Surf. Tri+ PCB (upper, lower 95% CI)[1]
RS1	Inside CU	2486	13.4 (13.0, 14.2)	36	12.0 (6.8, 19.5)	36	2.5 (2.0, 4.3)
	Outside CU	1007	3.1 (2.9, 3.4)	25	2.1 (0.77, 3.7)	25	1.3 (0.32, 2.2)
RS2	Inside CU	700	14.4 (13.2, 15.7)	18	20.6 (18.6, 30.8)	18	4.8 (3.0, 7.9)
	Outside CU	959	5.7 (5.3, 6.1)	31	16.4 (13.0, 17.5)	31	3.5 (2.8, 4.8)
RS3	Inside CU	724	2.5 (2.3, 2.6)	24	1.7 (1.2, 2.1)	24	0.7 (0.5, 1.1)
	Outside CU	2608	1.8 (1.7, 1.9)	50	2.2 (1.4, 2.5)	50	0.60 (0.42, 0.74)

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

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 targeted SSAP locations in category

Table 5a

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	-5		
		2	-112			
		3	-42			
	Sediment Type or Pair Match	1	*50*, 67, 160	-6.2, -13		
		2	*41*			
		3	*107*			
DDS 2011	Inside CUs	1	8	10	3	3
	Outside CUs				6	11
DDS 2012	Inside CUs	2	20		5	4
	Outside CUs				12	4
DDS 2013	Inside CUs	3	17		5	7
	Outside CUs				4	6

Notes:

1. Negative values and red shading indicate increasing trends and associated doubling times in years.
2. Italics indicate NOAA estimates, which are based on comparisons of mean concentrations, and not medians.
3. Sediment Type or Pair Match indicates samples were compared between surveys after matching for sediment category or by sample location.
4. Multiple entries indicate different sample pairing bases.
5. Grey cells indicate not calculated or already contained elsewhere in the table.

Table 5b

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

(Median Decay Rate Estimates in Percent per Year)

Survey	Pairing	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)[6]			
SSAP 2002-2005	All Data	1	-1.8	13		
		2	0.62			
		3	1.7			
	Sediment Type or Pair Match	1	*-1.4* , -1.0 -0.43	11, 5.3		
		2	*-1.7*			
		3	*-0.65*			
DDS 2011	Inside CUs	1	-8.4	-7.3	-22	-21
	Outside CUs				-12	-6.6
DDS 2012	Inside CUs	2	-3.5		-13	-17
	Outside CUs				-5.7	-18
DDS 2013	Inside CUs	3	-4.1		-14	-10
	Outside CUs				-17	-12

Notes:

1. Positive values and red shading indicate increasing rate of change.
2. Italics indicate NOAA estimates, which are based on comparisons of mean concentrations, and not medians.
3. Sediment Type or Pair Match indicates samples were compared between surveys after matching for sediment category or by sample location.
4. Multiple entries indicate different sample pairing bases.
5. Grey cells indicate not calculated or already contained elsewhere in the table.
6. An area-weighted average of these two rates yields approximately -8 percent per year (8 year half-life), which is referenced throughout the text for the 1991 to 1998 survey comparison.