Data Evaluation Report No. 1: "Summary of Major Sediment and Water Investigations Conducted in the Lower Passaic River"

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LOWER EIGHT MILES OF THE LOWER PASSAIC RIVER DATA EVALUATION REPORT NO. 1: SUMMARY OF MAJOR SEDIMENT AND WATER INVESTIGATIONS CONDUCTED IN THE LOWER PASSAIC RIVER

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1 INTRODUCTION

This document is part of a series of data evaluation reports describing different aspects of the Lower Passaic River, which were prepared to support the Remedial Investigation (RI) and Focused Feasibility Study (FFS). Where necessary, data evaluation reports are cross-referenced to direct the reader to another report that contains further explanation. Topics discussed in this series include major sediment and water investigations conducted in the river, boundary conditions on the river, historical sediment contamination, surface sediment contamination, contaminant inventory calculations, and biota analysis. This report describes major sampling programs conducted on the river.

1.1 Overview of the FFS Study Area

The FFS Study Area is located within the Lower Passaic River Study Area (LPRSA), which is the 17-mile, tidal portion of the Passaic River from Dundee Dam [located at River Mile (RM[1]) 17.4] to the confluence with Newark Bay at RM0 and the watershed of this river portion, including the Saddle River (RM15.6), Third River (RM11.3) and Second River (RM8.1) [Figure 1-1]. During a comprehensive study of the Lower Passaic River, the sediments of the lower eight miles were found to be a major source of contamination to the rest of the river and Newark Bay. Therefore, the United States Environmental Protection Agency (USEPA) completed the FFS to evaluate alternatives to address those sediments in the lower eight-mile stretch from RM0 to RM8.3, near the border between the City of Newark and Belleville Township. The entire 17-mile Lower Passaic River is the subject of another Remedial Investigation/Feasibility Study (RI/FS) being implemented by the Cooperating Parties Group (CPG; a group of approximately 70 potentially responsible parties who signed an agreement with USEPA in 2007), under

[1] The FFS uses the "River Mile" (RM) system developed by the United States Army Corps of Engineers (USACE), which follows the navigation channel of the Lower Passaic River. The Data Evaluation Reports (Appendix A), Empirical Mass Balance (Appendix C) and Lower Passaic River-Newark Bay model (Appendix B) were initially developed at the beginning of the 17-mile Remedial Investigation and Feasibility Study (RI/FS), and thus follow a RM system developed for that RI/FS, which follows the geographic centerline of the river. RM0 is defined by an imaginary line between two marker lighthouses at the confluence of the Lower Passaic River and Newark Bay: one in Essex County just offshore of Newark and the other in Hudson County just offshore of Kearny Point. River miles then continue upriver to the Dundee Dam (RM17.4). The two RM systems are about 0.2 miles apart.

USEPA oversight. The Upper Passaic River watershed (the portion of the Passaic River located above the Dundee Dam) contributes solids, water, and contaminants that cross over the head-of-tide, which is represented by the Dundee Dam[2], into the Lower Passaic River.

1.2 Overview of the Major Sediment and Water Investigations Conducted in the Lower Passaic River

This report summarizes major sediment and water investigations conducted in the Lower Passaic River that yielded data considered for the FFS Study Area. Field investigations to characterize contamination in the Lower Passaic River and Newark Bay have been conducted from the 1990s up to the present by federal and state agencies, potentially responsible parties under USEPA oversight, such as the CPG and Occidental Chemical Corporation (with Tierra Solutions, Inc (TSI) performing the work), and academic institutions. All datasets are available on the project web site "ourPassaic.org".

The report is comprised of the following sections in addition to the introduction:

- *Section 2, Sediment Investigations*: provides a brief narrative describing historical and recent sediment investigations conducted in the Lower Passaic River and Newark Bay. These studies were evaluated to support the FFS.
- *Section 3, Water Investigations*: provides a brief narrative describing historical and recent water investigations conducted in the Lower Passaic River.
- *Section 4 Bathymetric, Geophysical, Geotechnical, and Hydrodynamics Investigations*: provides a summary of bathymetric, geophysical, geotechnical, and hydrodynamics surveys conducted in the Lower Passaic River.
- *Section 5, Acronyms*: defines the acronyms used in this report.
- *Section 6, References*: lists the references used in this report.

[2] The Dundee Dam represents a hydraulic boundary. The head-of-tide actual location is downstream of the dam because even though the tides can influence the water level near the dam, the upper-most extent of saltwater (*i.e.*, the salt front) typically stops several miles below the Dundee Dam (refer to Lower Passaic River System Understanding of Sediment Transport [HQI and Sea Engineering Inc, 2011] for further details on the salt front migration).

2 SEDIMENT INVESTIGATIONS

The following section briefly describes the major sediment investigations that were conducted on the Lower Passaic River and in Newark Bay, summarized in Table 2-1. The other data evaluation reports and the FFS also incorporate the results of these studies, as well as other historical and current datasets, to evaluate the nature and extent of contamination in the river. The results were also used to develop a contaminant fate and transport model. All data described herein are available on www.ourPassaic.org.

2.1 1991 and 1993 TSI Sediment Coring Program (Nature and Extent of Contamination)

Following the implementation of the interim cleanup plan at the former Diamond Alkali upland property in 1990, TSI conducted several sediment sampling programs in the estuary under USEPA oversight. Two prominent sediment sampling programs were the 1991 and 1993 sediment coring programs.

Field work conducted in November and December 1991 consisted of 26 sediment cores collected throughout the Lower Passaic River, Upper Passaic River, Hackensack River, and Newark Bay. One core was located in the Upper Passaic River in Dundee Lake; six cores were located in the Hackensack River and Newark Bay; and the remaining 19 cores were located in the Lower Passaic River with the majority of coring sites located below RM8. TSI conducted a similar sediment coring program in 1993 (consisting of two field programs: one occurred in March 1993 and the other occurred in July 1993) with 28 sediment cores collected in the estuary. Two cores were collected in Newark Bay; four cores were collected in the Kill van Kull and the Lower New York Harbor; and one core was collected in the Hackensack River. The remaining 21 cores were collected in the Lower Passaic River, including two cores located at the mouth of Third River and three cores at the mouth of Second River.

Sediment cores extended from 3 feet deep to about 20 feet deep, but were processed in a discontinuous fashion. A discontinuous core is defined as a sediment core where only

selected sediment horizons were sampled, instead of sampling continuously from core top to core bottom. For example, for the 1991 sediment program, one 2-inch sediment sample may have been collected at a depth 2 feet from the top of a particular core, with the next 2-inch sediment sample collected at a depth 3 feet from the core top, skipping the 10 inches of sediment between these two intervals. Each 2-inch interval was processed and shipped for chemical analyses. Additional, but separate, 2-inch intervals were also obtained from each core and were processed for radiological analyses; however, the chemical and radiological samples were not directly linked nor was there a discernable correspondence among sample intervals in different cores.

For both the 1991 and 1993 programs, a suite of chemical parameters was analyzed to characterize the sediment samples. These parameters consisted of polychlorodibenzodioxin/furan (PCDD/F) congeners, polychlorinated biphenyl (PCB) Aroclors, polycyclic aromatic hydrocarbon (PAH) compounds, pesticides, semivolatile organic compounds (SVOC), metals including mercury, total petroleum hydrocarbons (TPH), and total organic carbon (TOC). Volatile organic compounds (VOC) were only analyzed during the July 1993 sampling event, and butyltins were analyzed from selected samples during the 1991 and 1993 sampling program.

The data collected from the 1991 and 1993 TSI sediment coring programs have been used extensively. Specifically, these data have been used to characterize the following:

- Surface sediment samples (0-2 inches) provide a historical representation of surface sediment conditions in the river, including an early 1990s sample above the Dundee Dam.
- The very long sediment cores obtained during these studies provide important estimates of the depth of contamination as well as rough estimates of contaminant inventories. These long cores are particularly important as a basis to extrapolate sediment concentrations in shorter cores that were obtained in other programs but did not penetrate the entire depth of contamination.
- Radiological data [cesium-137 (Cs-137) and lead-210 (Pb-210)] provide affirmation that much of the contaminated sediment inventory was deposited after the 1940s,

although these radiological data are not sufficient in number and distribution to permit segment year assignments.[3]

2.2 1995 TSI Remedial Investigation Program (Nature and Extent of Contamination – RM1 to RM7)

Sampling in the Lower Passaic River continued in 1995 with a field investigation conducted by TSI under USEPA oversight as part of a remedial investigation. In contrast to the previous 1991 and 1993 TSI programs with sediment cores distributed at selected locations throughout the estuary, the 1995 RI program was designed to follow a systematic (*i.e.*, unbiased) sampling scheme. Sediment cores were collected from a portion of the river that was historically defined as the "Passaic River Study Area," stretching from approximately RM1 to RM7. A total of 97 sediment cores was collected in sets of three along transects spaced at quarter mile intervals. A pre-determined sampling program prescribed a 6-foot depth for most cores; however, one-third of the cores penetrated beyond 6 feet. Each core was divided longitudinally. One side of the core was designated for chemical analyses and segmented into continuous 1-foot intervals, except the core top, which was defined as the top 6 inches. The other side of the core was designated for radiological analyses and segmented in a discontinuous fashion.

Similar to the 1991 and 1993 TSI programs, a suite of chemical parameters was analyzed to characterize the sediment samples. These parameters consisted of PCDD/F congeners, PCB Aroclors, PAH compounds, pesticides, SVOC, VOC, metals including mercury, TPH, and TOC. Unlike the previous TSI investigations, herbicides were analyzed, but not butyltins. An executive summary prepared by TSI was submitted to USEPA; however, a formal report summarizing these data has not been published.

This dataset has proven to be very valuable because the sediment cores collected were continuous and radiological data are available. However, the pre-determined sampling

[3] Cs-137 and Pb-210 are particle-reactive radioisotopes (with different source terms) that are used to geochronologically date sediment cores. Refer to Data Evaluation Report No. 5 for further discussion.

depth did result in some limitations on data usability. The 1995 TSI dataset has been used to characterize the following:

- Surface sediment conditions (0 to 6 inches) provide a historical representation of surface sediment conditions in the Lower Passaic River (RM1 to RM7) as well as a possible characterization of the routinely resuspended surface materials.
- Some dated down-core profiles provide an estimate of contaminant loading over time; however, most cores are limited by the pre-determined depth and do not capture the full vertical extent of contamination in the river.
- Beryllium-7 (Be-7) was detected in about 15 percent of the sampling locations. Surface samples from these locations were examined to assess contamination levels in solids deposited *circa* 1995.[4]

2.3 1999 and 2000 TSI Environmental Sampling Programs (Risk Assessment Support)

To assess ecological and human health risks in the Passaic River Study Area, TSI conducted two environmental sampling programs under USEPA oversight. The fall sampling event occurred from September 1999 to October 1999 while the spring sampling event occurred in May 2000. In general, the fall 1999 event was more extensive than the spring 2000 event and resulted in a greater quantity of biological data.

During the fall event, surface sediment samples (0-6 inches) and co-located tissue samples were collected from 14 shoal areas in the Lower Passaic River between RM1 and RM7. The 14 locations that were sampled in the fall were re-occupied in the spring; however, fewer sediment and tissue samples were collected in the spring (co-located sediment samples were collected at only 4 of the 14 locations).

Sediment and tissue samples from both environmental sampling programs were analyzed for a suite of chemical parameters, including PCDD/F congeners, PCB Aroclors and

[4] Be-7 is a naturally occurring, particle-reactive radioisotope with a short half-life (53 days). The presence of Be-7 in surface sediments (0-1 inch) indicates that the associated solids were generally deposited on the sediment bed within the last 6 to 12 months (termed "recently-deposited surface sediments") prior to collection. Refer to Data Evaluation Report No. 4 for further discussion.

congeners, PAH compounds, pesticides, SVOCs including butyltins, metals including mercury, and herbicides. Sediment samples were also analyzed for TPH, TOC, pH, and ammonia. A formal report summarizing these data has not been published. Assessment of the usability of the 1999 and 2000 biological datasets indicates:

- Surface sediment samples (0 to 6 inches) provide a historical representation of sediment conditions in the shallow areas near the Mean Low Water (MLW) elevation in the Lower Passaic River (RM1 to RM7).
- Tissue samples from several species and trophic levels provide data on exposure levels to contaminated sediment for the local biota.

2.4 2005 Sedflume Testing (Sediment Bed Erosion Susceptibility)

The Sedflume is an apparatus designed to measure erosion rates with varying flow velocities for cohesive sediments. As part of the Lower Passaic River Restoration Project (a joint study conducted by the USEPA, United States Army Corps of Engineers [USACE] and New Jersey Department of Transportation [NJDOT]), sediment cores were collected at 14 sites (Stations 1 through 15 were proposed; however, only 14 could be completed) along the Lower Passaic River from May 17, 2005 through May 20, 2005. Two cores, considered replicate cores and differentiated by an “A” and “B” designation, were attempted at each location. Both cores were successfully obtained at all stations except Station 10. The material at this location consisted of a high viscosity fluid mud overlying an impenetrable coarse-grained material. A total of 28 cores were collected as part of this investigation, and the distance between replicate cores varied from 1 to 10 meters (3.3 to 33 feet).

Lexan core tubes (10-inch diameter) were manually advanced into the sediment bed to the maximum possible depth (*i.e.*, either to the entire core tube length or to refusal) to collect the cores. Where water depth precluded the use of the lexan tube alone, a box corer was used to obtain a sediment bed sample, and a lexan tube was used to core the material retrieved within the box corer. Core lengths ranged from 22.75 centimeters (cm) [9 inches] (Station 1B) to 65.5 cm [2 ft 2 inches] (Station 9A).

Once the sediment cores were collected, river water was decanted from the top. The cores were then stored in a 40-gallon barrel filled with cool water (on the sampling vessel) and with cool water and ice (onshore). Ice and water were replenished daily. Collected cores were then subjected to Sedflume testing to measure erosion rates with varying flow velocities down the length of the core. Sedflume testing was performed on the cores in a 24-foot trailer which housed a mobile laboratory and the equipment needed to perform the procedure. This mobile lab was based at the USEPA Passaic River field office during May and June of 2005.

In addition, physical properties were measured in each sediment core during the erosion tests at intervals of approximately 2 to 3 cm (0.8 to 1.2 inches). To accomplish this, the Sedflume procedure was paused, the apparatus drained, and a sample manually extracted from the sediment bed. Measurements included bulk density, grain size distribution, and organic content. The findings of the Sedflume testing are reported in the Erodibility Study of Passaic River Sediments (USACE, 2006) and the Lower Passaic River Sediment Transport Model Report in Appendix B.

2.5 2008 Sedflume Testing (Effects of Consolidation on Erodibility)

The purpose of the Sedflume Consolidation Analysis was to characterize the properties of deposited sediments during the consolidation process, and to determine the effects of consolidation on sediment density and susceptibility to erosion over time. Surface sediment was collected from a single location on the Lower Passaic River from May 16 to 20, 2008 by Sea Engineering, Inc. for USEPA and USACE. This location corresponded to the collection point of the Malcolm Pirnie, Inc. high resolution sediment core obtained at RM2.2 (see Section 2.7). A box core was used to retrieve 15 gallons of surface sediment from the top 15 cm of the sediment bed. This material was composited into a single sample and then re-constructed into four laboratory cores (as described below) that could be subjected to Sedflume testing to determine the effects of consolidation on stored sediments.

Collected sediments were composited with water at the Sea Engineering, Inc. laboratory and poured into prepared core barrels. Each core was 50 cm in length, and inspected for length and quality immediately after preparation. Four approved cores so generated were capped and stored in the laboratory until the testing assigned to that core was to be performed, allowing consolidation to occur within the core tubes. The densities of the Sedflume cores were determined by sub-sampling locations within each core and using wet/dry sample weights to calculate the bulk density in each sub-sample. Particle size analysis was also performed.

The cores were successively tested after being stored and allowed to consolidate for four different lengths of time: 1 day, 7 days, 17 days, and 28 days. In addition, each core was sub-sampled at vertical intervals to determine bulk properties. Measurements included bulk density and particle-size distribution. Additional information can be found in the report Sediment Consolidation Analysis, Passaic River, New Jersey (SEI, 2008).

2.6 2005 Gust Microcosm Testing (Near-surface Sediment Erodibility)

Additional sediment erosion experiments were performed on sediment cores collected from May 16, 2005 through May 20, 2005 by Chesapeake Biogeochemical Associates for USEPA, USACE, and NJDOT. The purpose of this investigation was to determine the erodibility of near-surface sediments using the Gust Microcosm apparatus for comparison with parameter estimates yielded by Sedflume testing. Gust Microcosm testing uses techniques outlined by research performed at the University of Maryland Center for Environmental Science, and measures erodibility of undisturbed sediment cores by applying a series of controlled shear stresses representative of the flows in the river. This device uses a rotating disc with central suction to apply a known shear stress to a field-collected sediment core sample. Data generated from the Gust Microcosm was analyzed using the erosion formulation of Sanford and Maa (2001) to determine the erodibility of the sediment. Compared to Sedflume, the Gust Microcosm system is able to measure the erodibility at the very near surface. Additional information can be found in the report "Passaic River Erosion Testing and Core Collection: Field Report and Data Summary" (Chesapeake Biogeochemical Associates, 2006).

2.7 2005-2007 USEPA High Resolution Sediment Coring (Historical Water Column Suspended Matter Contaminant Loads)

Malcolm Pirnie, Inc. collected high resolution sediment cores from 14 locations in the Lower Passaic River and Upper Passaic River in September and October 2005 on behalf of the USEPA and USACE. The objectives of the program were to obtain several cores with consistent geochronologies (*i.e.*, dateable cores) that could then be used to assess historical contaminant loads on water column suspended matter and to evaluate current (2005) suspended matter concentrations. A dateable high resolution sediment core can be used to characterize historical water column suspended matter, because an interpretable geochronology is a direct result of steady accumulation in a continuously-depositional area. As sediments deposit, they bring with them the particle-borne chemistry of the water column at the time of their deposition. Like a strip recorder, the consistently depositional location preserves the chronology of particle-borne water column chemistry. Unlike the systematic, unbiased sampling approach necessary to determine the lateral and vertical extent of contamination, this approach needs a small number of highly selective sampling locations, similar to the approach for long-term water column monitoring of the system. It is important to find suitable (continuously depositional) locations that represent boundary conditions of the system ("end members") and locations intended to capture potential changes along the length of the Lower Passaic River due to external inputs such as tributaries or resulting from significant variations in flow regime.

Coring locations were pre-selected and identified as potential continuously depositional sites through a review of available data and a field reconnaissance program (August 29, 2005 to September 8, 2005) to confirm that sediments at the target locations contained Be-7 at the surface (0 to 1 inch) and had a fine-grained sediment texture. Coring locations were selected in "backwaters" or other areas unlikely to have experienced anthropogenic disturbances (*e.g.*, dredging) or significant erosional events. Cores collected from these apparently continuously depositional locations were finely segmented into approximately 40 sediment intervals per core with the top 8 intervals being half the thickness of the deeper intervals. Samples for analysis of metals, including mercury, and TOC from every

sediment segment were shipped immediately for chemical analysis. Samples from alternating segments were also shipped for radiological analysis including Cs-137. The remaining samples were retained for possible future analyses by freezing in accordance with the Quality Assurance Project Plan (Malcolm Pirnie, Inc., 2005b) and accompanying addenda.

Radiological data indicated that 5 of the 14 high resolution sediment cores had acceptable Cs-137 profiles, were considered dateable, and were fairly well distributed along the main axis of the river. These five cores were located at RM1.4, RM2.2, RM7.8, RM11.0, and RM12.6. Prior to shipping the sediment samples for organic analysis, the sediment segments were thawed and manually combined – every two intervals, consecutively – to yield approximately 20 samples per core. Organic compound analyses performed on these combined samples included PCDD/F congeners, PCB congeners, PAH compounds, and pesticides. The USEPA 2005 high resolution sediment core dataset can be summarized as follows:

- Correlated radiological and chemical data provide geochemical tools for interpreting historical contaminant loading to the Lower Passaic River.
- Surface sediments represent contaminant concentrations from the 2003 to 2005 time period. The observations from the 5 core sites were further supported and enhanced by the 2007 to 2008 USEPA Supplemental Sediment Programs (Section 2.9).
- Ratios among contaminants within and among cores were used to examine the variations in contaminant loads over time and distance.
- The dated sediment cores chronicle the history of contaminant discharges from the 1940s to the present and from RM1.4 to RM12.6.

Additional high resolution sediment cores were collected in 2007 by Malcolm Pirnie, Inc. from nine locations in the Upper Passaic River between Dundee Dam and the Interstate Route 80 Bridge. Locations were selected based on bathymetric data, historical satellite photographs that showed shoreline development, literature references, and field reconnaissance conducted on December 14, 2006. These data resources were used to identify coring locations with potentially undisturbed silt deposits in continuously

depositional areas that could be used to determine the contaminant load on particle-borne water column solids transported from the Upper Passaic River to the Lower Passaic River.

At each coring location, a geological boring and co-located high resolution sediment core were collected. The geological boring was split longitudinally to examine stratigraphic sequences and identify locations with silt deposits. Four locations were classified as potentially depositional based on the stratigraphic sequence; the corresponding co-located high resolution sediment cores from these four locations were divided into 2-cm (0.8-inch) and 4-cm (1.6-inch) intervals, yielding approximately 20 samples per core. Samples were shipped immediately for analysis of the following parameters: PCDD/F congeners, PCB congeners, PAH compounds, pesticides, metals including mercury and titanium, TOC, particle size distribution, Cs-137, and Be-7 (core top sample only).

As the radiological data were received and interpreted, two cores were eliminated from consideration because the core top was not Be-7 bearing, indicating that the location did not contain recently-deposited sediments. The corresponding chemical analyses for these cores were halted since it was unlikely that the cores could be dated. Chemical analyses were completed on the two remaining cores that possessed a Be-7 bearing core top; however, further evaluation of the Cs-137 data indicated that the radiological profile was discontinuous (suggesting that the sediments had been disturbed and that the core was not representative of a continuously depositional location). The January 2007 Dundee Lake sediment core dataset can be summarized as follows:

- Surface sediment concentrations from one coring location that contained reportable Be-7 levels represented contaminant loading to the Lower Passaic River from the Upper Passaic River in 2006.
- The dataset provided evidence to roughly characterize the scale of historical contaminant loadings to the Lower Passaic River from the Upper Passaic River, based on the presence of Cs-137 in the deeper layers of one core. However, the Cs-137 levels were too low to establish a core chronology.

In addition to the cores obtained by Malcolm Pirnie, Inc., several high resolution sediment cores had been obtained by scientists from Rensselaer Polytechnic Institute (RPI) and Lamont-Doherty Earth Observatory (L-DEO) in September 2005 above the Dundee Dam. These cores were initially segmented and dried to permit long-term storage while awaiting subsequent analysis. Two of the cores were shown to contain Be-7 and were dateable using Cs-137. Segments from these cores were then subject to chemical analysis for the USEPA Lower Passaic River investigation.[5] These 2005 Dundee Lake dated sediment cores provide the following information, satisfying the major goals for the Upper Passaic River coring:

- Surface sediment concentrations from two coring locations that contained reportable Be-7 levels represent contaminant concentrations on suspended matter delivered to the Lower Passaic River from the Upper Passaic River in 2005.
- The dataset provides a dateable Cs-137 sediment core profile documenting historical contaminant loads to the Lower Passaic River from the Upper Passaic River. In particular, the profile provides a basis to estimate the historical loads of major contaminants to the Lower Passaic River going back to the 1960s.

2.8 2006 USEPA Low Resolution Sediment Coring (Nature and Depth of Contamination)

Low resolution sediment cores were collected by Malcolm Pirnie, Inc. on behalf of the USEPA and USACE from 10 locations in the Lower Passaic River (between RM2 and RM7) in January 2006 to re-examine sediment concentrations reported in the TSI 1995 RI dataset. In contrast to the 1995 TSI field program that systematically collected 6-foot cores, the 2006 low resolution cores were designed to penetrate to the sand or red-clay layer (underlying the silt deposits) to assess the nature and depth of contamination for the thickness of contaminated sediment deposited since the channel was dredged.

[5] A separate analysis was conducted to demonstrate the viability of the sample collection and processing procedures used by the RPI and L-DEO scientists. This demonstration was done on a series of separate sediment sample splits that were handled by the USEPA processing procedures (shipping frozen samples) as well as the drying procedures used by RPI and L-DEO. The samples were chemically analyzed following the standard Lower Passaic River procedures, thereby creating sample pairs differing only by the processing procedure. The analysis confirmed that the sample collection and processing procedures used by the RPI and L-DEO scientists were valid.

A low resolution sediment core is defined as a coarsely-segmented core that is analyzed to describe the general chemistry of the river sediments. Typical segmentation of these cores is six inches or greater. In some cases, the cores may provide data to approximate historical contaminant loads on the time scale of decades. The low resolution cores were split lengthwise to examine geologic sequences. Cores were then divided into approximately six slices based on sediment type with the bottom slice characterizing the underlying sand or red-clay sequence. Samples were processed and submitted for the following analyses: Cs-137, PAH compounds, PCB congeners, PCB Aroclors, PCDD/F congeners, pesticides, VOC, SVOC, chlorinated herbicides, TPH, TOC, pH, specific gravity, grain size, and metals including titanium and mercury. The 2006 low resolution sediment core dataset can be summarized as follows:

- Low resolution sediment cores fully characterized the nature and depth of contamination (in silt deposited since the channel was dredged) at the target locations in RM2 to RM7 because they were advanced to fully penetrate the contaminated sediments and characterized the underlying sand or red-clay layer.
- An extensive suite of chemical and physical parameters was analyzed to characterize the silt deposits and the underlying sand and red-clay layers.

2.9 2007 to 2008 USEPA Supplemental Sediment Programs (Characterization of Surface Sediments RM1 to RM14 and Fine-grained Sediment Deposits above RM8)

On behalf of the USEPA and USACE, Malcolm Pirnie, Inc. conducted two supplemental sediment sampling programs in the Lower Passaic River. The first program was designed to characterize recently-deposited surface sediment concentrations (0 to 1 inch) in the Lower Passaic River from RM1 to RM14. These surface sediment samples were collected using an Ekman dredge or by manually collecting the upper 1-inch of sediment and placing it into a sampling tray underwater in shallow areas inaccessible by boat. The second program involved the collection of low resolution cores above RM8 in fine-grained sediment areas to further evaluate the nature and extent of contamination in these deposits.

Surface sediment samples (0 to 1 inch) to characterize recently-deposited sediments were collected from 23 locations in the Lower Passaic River,[6] four locations in the Upper Passaic River, four locations on the Saddle River above the head-of-tide, and two locations on the Third River above the head-of-tide between December 2007 and January 2008. Depositional areas were specifically targeted during this program and were identified using data collected during a field reconnaissance, evaluating existing side scan sonar data, and evaluating 2007 sediment probing data. No samples were collected on Second River or near Ackerman Avenue Bridge (immediately downriver of the Dundee Dam) because fine-grained sediment deposits could not be located during the field reconnaissance. Sediment samples from each location were analyzed for metals including mercury, TOC, grain size distribution, and radiological parameters (including Be-7, the presence of which is interpreted as confirming that the material was deposited in the previous 6 months or less). Nearly all samples were found to contain Be-7. A subset of the Be-7 bearing samples were then further analyzed for PCDD/F congeners, PCB congeners, PAH compounds, and pesticides.

The low resolution cores were collected in January 2008 between RM8.5 and RM14.5 in fine-grained sediment deposits. Coring locations were identified using late 2007 sediment probing data collected during a field reconnaissance as well as existing side scan sonar data on sediment texture. Cores were advanced until refusal and then divided into two segments: 0 to 6 inches and 6 inches to the bottom of the silt layer or to the core bottom (when underlying coarser material was not recovered with the core). Samples were analyzed for metals including mercury, radiological parameters, grain size distribution, PCDD/F congeners, PCB Aroclors, PAH compounds, and pesticides. The two supplemental sediment sampling programs can be summarized as follows:

- Be-7-bearing sediment samples provide a current (2007) representation of recently-deposited surface sediments in the Lower Passaic River (RM1 to RM14).

[6] In the Lower Passaic River, five of the 23 locations re-occupied the successful 2005 high resolution sediment coring locations to build on the chronologies already established for these locations. Refer to Data Evaluation Report No. 3 for more information on high resolution sediment coring.

- Surface sediment samples collected from the Upper Passaic River and above the tributary head-of-tide provide a representation of the current (2007) suspended solids-borne contaminant loading from these external sources to the Lower Passaic River.

2.10 2008 CPG Low Resolution Sediment Coring (Lateral and Vertical Extent of Contamination RM0 to RM17.4)

In 2008, the CPG conducted a low resolution sediment coring program under USEPA oversight, which included the collection of sediment cores along the Lower Passaic River from RM0 to RM17.4 (Dundee Dam) with additional sampling locations positioned in the tributaries and above Dundee Dam. Surface sediment samples were defined as the top 6-inches of the sediment core. The remaining core length was continuously sectioned into 1-foot or 2-foot intervals to the core bottom. Cores were advanced to refusal or presence of the red sand/clay layer. (If necessary, multiple cores were collected to provide enough sediment mass for analysis.) A co-located sediment grab sample was also collected at each coring location for the analysis of Be-7 in the top 1-inch of sediments.

Sediment samples were analyzed for a suite of chemical parameters, including PCDD/F congeners, PCB Aroclors and congeners, PAH compounds, pesticides, SVOC, VOC, herbicides, metals including mercury, methylmercury, TPH, TOC, grain size, and other general chemistry parameters. A finalized report summarizing these data has not been published; however, the dataset is available. Assessment of the usability of the 2008 datasets indicates:

- Based on a comparison of split samples analyses conducted by USEPA and the CPG, the PCDD/F concentrations generated during the 2008 CPG coring program were found to be biased low and have been corrected following recommendations by the USEPA. Correction factors are based on an independent review of the data by Computer Sciences Corporation (CSC) Environmental Solutions, Inc. (CSC and Interface, Inc., 2010, 2011).

- Surface sediment samples (0 to 6 inches) provide a representation of surface sediment conditions across a variety of geomorphological units in the Lower Passaic River (RM0 to RM17.4).
- Surface sediment samples with detectable levels of Be-7 provide additional information on the current (2008) contaminant load on recently-deposited material. However, data usability is constrained by the fact that surface sediment depth interval covered 0 to 6 inches while the Be-7 measurement was completed on a separate 0 to 1-inch grab sample. In some areas of the river and on the tributaries, 0 to 6 inches of sediment does not represent recently-deposited material.
- Low resolution cores provide information on the contaminant inventory in the different geomorphological units of the river, particularly above RM8.
- Some dated down-core profiles provide an estimate of contaminant loading over time.

2.11 2009 - 2010 CPG Benthic and Sediment Program (Taxonomy, Toxicity, and Exposure Characterization)

In 2009 to 2010, the CPG, under USEPA oversight, conducted a sediment sampling program, which was part of a benthic community survey. At each sampling location in the river, multiple sediment grab samples were collected to represent a spatially composited 0 to 6 inches surface sediment sample. These samples were used to support macrobenthic taxonomy classification, laboratory toxicity testing, and sediment chemistry. Sediment sampling locations were positioned in the river to characterize different benthic habitats. A subset of locations was sampled to characterize human health exposure at shallow nearshore locations or places with human access to the river (such as boat clubs, docks, and fishing locations).

Sediment samples were analyzed for a suite of chemical parameters, including PCDD/F congeners, PCB Aroclors and congeners, PAH and alkylated PAH compounds, pesticides, SVOC, VOC, herbicides, metals including mercury, TPH, TOC, grain size, and other general chemistry parameters. A finalized report summarizing these data has

not been published; however, the dataset is available. Assessment of the usability of the 2009-2010 datasets indicates:

- Surface sediment samples (0 to 6 inches) provide a representation of surface sediment conditions across a variety of geomorphological units in the Lower Passaic River (RM0 to RM17.4). The sampling program was designed to satisfy biological data quality objectives; hence, the locations were positioned in the river to characterize different benthic habitats.
- Each sampling location represents a composite of multiple grab samples. These grabs were homogenized, and an aliquot of sediment was analyzed for chemical parameters while the remaining material was used to support toxicity testing.
- Surface sediment samples were not collected on the tributaries or in the Upper Passaic River.
- Due to the biological nature of the program, Be-7 measurements were not incorporated into the program; thus, there is no direct measure of how recently the sediments were deposited in the system.

2.12 2012 CPG Low Resolution Coring Supplemental Sampling Program

In 2012, the CPG, under USEPA oversight, conducted a low resolution coring program to support delineation of the nature and extent of chemical contamination, the parameterization and calibration of the sediment transport and chemical fate and transport models, and delineation of stable and potentially erosional sediments. One set of cores from 86 locations were sampled using low resolution sampling intervals. Samples from the low resolution cores were collected from the 0 to 0.5 foot surface interval (from the core and grab samples), from two 1-foot segments for a total core depth of 2.5 feet at 83 locations and from four 1-foot segments for a total core depth of 4.5 feet within the footprint of the 2005 Environmental Dredging Pilot Study at 3 locations. Under certain conditions, the segmentation scheme was altered to adjust the sampling intervals to account for a stratigraphic change in the sediment sequence (*e.g.*, change in sediment size, obvious depositional boundary or unconformity) that occurs within a segment.

The samples were analyzed for PCDD/Fs, PCB congeners and homologs, PAHs, SVOCs, organochlorine pesticides, butyltins, metals, mercury, TPH-Extractables, cyanide, TOC, grain size, percent moisture, and specific gravity. Sulfide, nutrients (ammonia-nitrogen, phosphorus, and Total Kjeldahl Nitrogen [TKN]) and Acid-Volatile Sulfide/Simultaneously Extracted Metals (AVS/SEM) analyses were performed for surficial samples (grabs) only. Field measurements included salinity measurements of pore water from grab samples and calculation of bulk density.

The surface sediment data were incorporated in the FFS report. The results showed that the 2012 surface sediment concentrations for the parameters examined in the data evaluation reports are comparable to the concentrations from other data collected previously. The median concentration of 2,3,7,8-TCDD is not statistically different than from any other sampling programs (see Data Evaluation Report No. 4).

2.13 2005 and 2007 TSI Newark Bay Study (Contaminant Nature, Extent, and Chronology)

From October through December 2005, TSI, under USEPA oversight, conducted a Phase I field investigation in Newark Bay as part of the RI/FS for the bay. This field investigation included an evaluation of the biologically active zone using sediment profile imagery, bathymetry, sediment coring, and sediment grab sampling. For the sediment component of the investigations, cores were collected using vibracore equipment while co-located grab samples were collected with a Ponar dredge that was lowered into the bay via a winch-operated cable. Cores were collected at 69 locations from a variety of identified geomorphic units. Cores were advanced to varying depths, depending on the geomorphic unit, in an effort to identify the 1940 sediment horizon and to determine contaminant concentrations and gradients. Co-located sediment grab samples were collected immediately adjacent to the coring locations to provide information on sediment characteristics and recent deposition. Cores were divided into segments (generally one 6-inch core top, then 1-foot segments to a depth of 3.5 feet, and 2-foot segments below 3.5 feet) and analyzed for PCDD/F congeners, PCB congeners,

PCB Aroclors, pesticides, TPH, SVOC, herbicides, organotins, metals, cyanide, mercury, titanium, VOC, TOC, grain size, and bulk density.

The pesticide results obtained by this program had a substantive limitation. Approximately 90 percent of the pesticides results were not detected (*i.e.*, flagged with a qualifier containing a "U") due to high method detection limits and matrix interference. The only pesticide regularly detected in Newark Bay as part of this program was Dichlorodiphenyldichloroethylene (DDE). Mean surface sediment concentrations for select contaminants are provided in the Data Evaluation Report No. 2.

In November 2007, TSI conducted Phase II sediment coring activities to continue investigations of the nature and extent of contamination in Newark Bay while also sampling locations proximal to potential sources of contamination on the bay's industrial waterfront. Sediment cores were collected from 50 locations with sampling depths ranging up to 30 feet below the sediment surface in an attempt to capture the circa-1940 depositional horizon. Some Phase I locations where cores were not advanced deep enough to encounter the 1940 horizon were re-sampled during Phase II. Surface sediment samples were collected along with the sediment cores to continue to characterize contaminant concentrations and to determine areas of recent deposition via Be-7 analysis.

The scope of the Phase II sampling programs is described in the Phase II Remedial Investigation Work Plan (RIWP; TSI, 2007). The data generated by the Phase II investigations are presented in the Phase I and Phase II Sediment Investigation Field and Data Report (TSI, 2008). The Phase I and II field investigation in Newark Bay can be summarized as follows:

- Surface sediment concentrations (0 to 6 inches) provide a representation of current (*circa* 2005 and 2007) surface sediment conditions in Newark Bay.
- Be-7 was detected in most sampling locations (0 to 1 inch) located in the navigational channel. Surface samples (0 to 6 inches) from these locations were examined to assess contamination levels in the recently-deposited (*circa* 2005 and 2007) material. It is important to note that the data usability is limited by the fact that surface

sediment depth interval covered 0 to 6 inches while the Be-7 measurement was completed on a separate 0 to 1 inch grab sample. In some areas of the river and on the tributaries, 0 to 6 inches of sediments does not represent recently-deposited material.

3 WATER INVESTIGATIONS

This section describes the water investigations that were conducted in the Lower Passaic River. The water data collected prior to 2005 are limited and do not cover a large temporal and spatial extent. Water investigations datasets are available on the project web site "ourPassaic.org."

3.1 1995 and 1999 Water Investigations in the Lower Passaic River (Modeling Parameters and Water Quality)

Multiple entities conducted water sampling in the Lower Passaic River in the 1990s. In 1995, TSI conducted various surface water characterization efforts (TSI, 2004) for the USEPA. As part of sediment mobility modeling, 1,317 total suspended solids (TSS) samples and measurements of physiochemical parameters, including temperature, pH, and conductivity profiles, were collected from 8 transects during three rounds of sampling. In addition, TSI conducted a surface water characterization investigation to evaluate water quality in relation to the rest of New York/New Jersey Harbor. For this investigation, physiochemical parameters including temperature, pH, and conductivity profiles were collected at each mudflat sampling station between RM1 and RM7.

Adding to the collection of Lower Passaic River water quality data during this period is National Oceanic and Atmospheric Administration's (NOAA) August 1999 water quality monitoring (temperature, dissolved oxygen, salinity, pH, and conductivity) conducted as part of a bivalve mussel deployment in the Lower Passaic River (NOAA, 1999) and two surface water samples collected on behalf of the Diamond Shamrock Chemicals Company during the 80 Lister Avenue Site Investigation for the New Jersey Department of Environmental Protection (NJDEP) [DSCC, 1985].

3.2 2005 Large Volume Water Column Sampling Study (Dissolved versus Suspended Matter Concentrations)

As part of the 2004 to 2006 USEPA hydrodynamic sampling program, Malcolm Pirnie, Inc. collected large volume water column samples from RM2.5 on October 6, 2005 and RM10.5 on October 5, 2005. Samples were collected one meter (3.3 feet) below the water surface to represent freshwater above the salt front at RM2.5 and freshwater at RM10.5 (uninfluenced by saline intrusion); however, only the samples collected at RM2.5 were analyzed. Samples were analyzed for PCB congeners, PCDD/F congeners, pesticides, TSS, dissolved organic carbon (DOC), and particulate organic carbon (POC).

The objective of the study was to evaluate various techniques for large volume water column sampling to separately characterize dissolved phase and suspended phase hydrophobic organic contaminants. The equipment compared in the study included an Infiltrex, Trace Organic Platform Sampler (TOPS), and collection of whole water samples in 20-liter containers for filtering at the laboratory. The Infiltrex is a high efficiency, high volume automatic water sampling system designed for the extraction of trace-level organic contaminants. The Infiltrex consisted of three distinct components: (1) a 1 micrometer (µm) [3.937×10^{-5} inches] glass wound cartridge filter used to remove the majority of particulates from the influent whole river water; (2) a 0.7 µm (2.756×10^{-5} inches) Whatman glass fiber filter used as a polishing step for particulate removal; and (3) a solid phase extraction system used to measure trace quantities of dissolved-phase organic contaminants. The TOPS is an automatic water sampling system that is similar in design and function to the Infiltrex (developed as part of CARP). For the Lower Passaic River sampling events, it consisted of two components: (1) a 0.5 µm glass wound cartridge filter used to remove the majority of particulates from the whole water; and (2) a 0.7 µm Whatman glass fiber filter used as a polishing filtration step. Both TOPS and Infiltrex can operate from any water sampling platform and removes solids and hydrophobic organic compounds/organometals from water samples (in the field) through the use of filters and XAD traps.

Each method was used to collect samples for laboratory analysis followed by comparison of the results. The intent of the study was to compare the efficacy of field processing of water column samples to laboratory processing. The large volume water column sampling study can be summarized as follows:

- Dissolved and suspended phase of the samples provided the partitioning coefficients of the organic contaminants.
- The lab-filtered results were comparable to the field-filtered results.
- The lessons learned from this effort were applied to the design and execution of the Combined Sewer Overflow/Stormwater Outfall (CSO/SWO) program (Section 3.5).

3.3 2005 Small Volume Water Column Sampling Study (Modeling Parameters)

As part of the 2004 to 2006 USEPA hydrodynamic sampling program, Malcolm Pirnie, Inc. collected small volume water column samples from four locations on the Lower Passaic River on November 8, 2005. Additional small volume water column samples were collected at Ackerman Avenue Bridge on the Lower Passaic River and from the head-of-tide on Second River, Third River, and Saddle River on November 10, 2005. These locations were selected to correspond to mooring locations and other water column samples being collected under the hydrodynamic program.

To sample the length of the Lower Passaic River simultaneously, four boats were stationed at RM1.0, RM2.5, RM4.5, and RM10.5. Each boat crew was assigned to collect water samples along a transect perpendicular to the river's axis at the designated location. Each transect included five surface locations positioned 1 meter (3.3 feet) below the water surface (designated as nodes: S1, S2, S3, S4, and S5) and three corresponding bottom locations positioned 1 meter (3.3 feet) above the river bottom (designated as nodes: S2D, S3D, and S4D). The surface water samples were designed to represent freshwater above the salt front, and the deep water samples were designed to represent brackish water in the salt front. Samples were collected during three "passes" generally conducted during the incoming tide.

Tributary sampling was conducted at the head-of-tide of Second River, Third River, and Saddle River, with an additional water column sample collected at Ackerman Avenue Bridge (RM17) to represent water quality and contaminant loads from Dundee Dam (located at RM17.4). For these four locations, samples were only collected at one node (15 centimeters [5.9 inches] below the water surface); consequently, they represent discrete grab samples. Unlike the simultaneous sampling that was conducted at each transect on the Lower Passaic River main stem on November 8, tributary samples were collected consecutively on November 10. Third River was sampled first, then Second River, Ackerman Bridge, and finally Saddle River. Moreover, only one sampling pass was performed at each location regardless of tide.

Depending on the analytes of interest, water column samples were collected as either discrete grab samples to represent a node or as a composite sample to represent all five nodes along the transect. All mercury/methylmercury samples were collected following a clean-hands method outlined in Standard Operating Procedure #20, "Ultra-clean Water Sampling Procedures for Mercury" (Malcolm Pirnie, Inc., 2005b and addenda). Other metals samples were filtered and preserved at a field facility before shipment, whereas the mercury/methylmercury samples were shipped as whole water samples and filtered by the laboratory following a clean-hands method. The samples were analyzed for the following analytes: DOC, mercury, methylmercury, metals (filtered and total), POC, ammonia, Biochemical Oxygen Demand (BOD), chlorinated herbicide, Chlorophyll A, Chemical Oxygen Demand (COD), cyanide, orthophosphate, TKN, total phosphorous, TSS, SVOCs, and VOCs. The small volume water column samples provided preliminary suspended solids metals concentrations in the tributaries. However, these data were subject to analytical issues and did not meet the data quality objectives. As a result, these results were not used for further analyses.

3.4 2005 Semi-Permeable Membrane Device (SPMD) Study (Dissolved Phase Contamination)

As part of the 2004 to 2006 USEPA hydrodynamic sampling program, Malcolm Pirnie, Inc. deployed SPMDs to estimate dissolved phase contamination based on lab-determined partitioning coefficients and sampling rates. The SPMD is a semi-quantitative technique; it does not provide direct measurements of concentration, but it can be used to compare the relative concentration among the stations (assuming turbulence and temperature are uniform). The SPMDs were deployed at RM0, RM2.5, RM4.5, RM10.5, Second River, Third River, Saddle River, and Dundee Dam for duration of 30 to 45 days. However, the SPMD at RM2.5 was lost during the deployment. The SPMDs were analyzed for the following parameters: PCDD/F congeners, PCB congeners, PAH compounds, and pesticides. The SPMD data were not used in any of the analyses due to some disadvantages using SPMDs such as bio-fouling, variations in temperature, and flow-turbulence regime that can affect uptake estimates and back-calculated water concentration.

3.5 2008 USEPA High Flow Storm Event Sampling (External Contaminant Load Inputs)

To characterize the suspended phase contaminant loading to the Lower Passaic River from CSO/SWO discharge points and major tributaries, Malcolm Pirnie, Inc. collected large volume water column suspended solids samples[7] and sediment trap samples during high flow storm events between January 2008 and March 2008 on behalf of the USEPA and USACE. High flow storm events were targeted because they deliver large quantities of suspended matter over a short period of time, thus providing a good opportunity for sampling to integrate a large portion of the solids load. In fact, for CSO discharge, releases to the Lower Passaic River are largely restricted to large rainfall events whereas SWO discharges may occur under any precipitation event.

[7] Dissolved-phase contaminant loading was not investigated because the contaminants being examined are hydrophobic and largely associated with suspended matter.

CSO sampling locations (mainly in Newark, New Jersey) were selected considering both sewer drainage areas and sampling accessibility. SWO sampling locations were focused upriver of the City of Newark in the separately-sewered areas of Nutley, Belleville, Rutherford, and Lyndhurst, New Jersey. Note that SWO outfall pipes are typically positioned below the high-tide mark on the river. It was determined after sampling that river-originating solids were able to flow back into the outfall pipes during high tide events and settle inside. Consequently, solids collected during the storm events represent a mixture of river-originated solids and SWO-originated solids that were flushed out of the system.

Whole-water samples were shipped to the laboratories for filtration. A 20-liter (5.3-gallon) whole-water sample was filtered using a nominal 0.5 micrometers (µm) [1.969 x 10^{-5} inches] glass-fiber cartridge filter and a 0.7 µm (2.756 x 10^{-5} inches) glass-fiber flat filter. The filters, representing the particulate phase, were analyzed for PCDD/F congeners, PCB congeners, pesticides, and PAH compounds. A separate 4-liter (1.1-gallon) whole-water sample was filtered using a Whatman QMA (quartz fiber) filter. The QMA filter, representing the particulate phase, was analyzed for metals and mercury. In addition, a time-integrated TSS sample was analyzed using the QMA filter. The TSS value reported using the QMA filter was then compared to a corresponding time-integrated, TSS sample following USEPA Method 160.1. A time-integrated sample was also analyzed for POC. Lastly, a series of time-integrated whole-water samples were collected for grain size distribution analysis. Solids in these whole-water samples were allowed to settle out of the water over a three day period. Overlying water was decanted, and the remaining settled particles were analyzed for grain size distribution.

In addition to whole water CSO/SWO samples, field filtration of whole water samples collected from tributaries also occurred during the high flow events. Samples were collected from Saddle River, Third River, Second River, and the Lower Passaic River near the Ackermann Avenue Bridge (RM17; representing the Dundee Dam boundary

condition[8]). Suspended matter was collected by pumping water through a glass-fiber cartridge filter with a nominal 1 µm pore size followed by a flat filter with a nominal 0.7 µm pore size. Suspended matter at each station was collected continuously over a period of 1 to 2 hours under high flow conditions. The filters were analyzed for PCDD/F congeners, PCB congeners, PAH compounds, pesticides, and POC.

Solids originating from the tributaries were also characterized with sediment traps. Each trap deployment represented a two week period (with at least one high flow event). Solids from the traps represented solids that were suspended in the water column of the tributary during the two week period. These trapped solids were analyzed for PCDD/F congeners, PCB congeners, PAH compounds, pesticides, metals including mercury, radiological parameters, TOC, and grain size distribution. The 2008 storm event sampling program can be summarized as follows:

- The dataset includes samples that characterize the instantaneous loads of suspended matter-borne contaminants delivered to the Lower Passaic River from the Upper Passaic River, CSO discharge points, and tributaries during individual high flow events.
- The dataset includes sediment trap samples that characterize the integrated of suspended matter-borne contaminants loads delivered to the Lower Passaic River from the Upper Passaic River and tributaries over two week periods, incorporating one or more individual high flow events.
- Suspended matter samples collected from SWO sites were not considered usable because the outfall pipes were located below the high-tide mark. Solids collected during the storm events represent a mixture of river-originated solids and SWO-originated solids that were flushed out of the outfall pipe. Due to the nature of the water collection systems for Second River and Third River (*i.e.*, they are urban streams primarily fed by storm water collection systems), samples collected from these tributaries are considered representative of a typical SWO site.

[8] The area near the Ackermann Avenue Bridge is considered at or above the head-of-tide because of proximity of the bridge to the Dundee Dam and the rapid downstream water flow generally associated with this location.

3.6 2011 CPG Small Volume Chemical Water Column Monitoring (CWCM)

The small volume CWCM program implemented by the CPG under USEPA oversight was intended to characterize changes in chemical concentrations associated with the movement of suspended sediments over a range of tides and flow regimes.

Broadly defined, the goals of the CWCM Data Collection Program were to:

1. Collect data to support the calibration, validation, and sensitivity analysis of the Chemical Fate and Transport (CFT) model developed by the CPG under USEPA oversight. The data provide information to develop the inputs to the model and to characterize the transport of contaminants in the LPRSA and NBSA, including the preliminary calibration of the flux of contaminants from the sediments to the water column through routine monitoring events. Water column contaminant concentration data collected in the LPRSA and NBSA with sufficient spatial coverage and frequency and over a range of flow conditions was used to characterize potential gradients, mixing and general inputs to the system.
2. Collect data to characterize the impacts of storm-related high flow conditions on contaminant sources and transport in which resuspension of contaminants from the sediment bed and subsequent deposition from the water column are expected to dominate over other transport processes. Water column contaminant concentration data collected during high flow conditions were used to assess the potential for increased contaminant loading to the water column from upstream sources and/or through resuspension of existing sediments.
3. Collect data to characterize the transport of contaminants under low flow conditions and maximum tidal excursion, which occurs during low flow conditions at spring tides. Water column contaminant concentration data collected during a combination of low flow and spring tide conditions were used to better assess the up-river transport potential and support the understanding of the fate and transport for the 17-mile LPRSA RI/FS Conceptual Site Model and Lower Passaic River/Newark Bay Model.

4. Estimate average water column concentrations of contaminants in the LPRSA over several seasons and flows for use in exposure point concentration estimation for the 17-mile LPRSA RI/FS Human Health Risk Assessment, Ecological Risk Assessment and Food Web Model (FWM).

These monitoring goals were designed to support the ongoing 17-mile LPRSA RI/FS site characterization and modeling efforts and included the following elements:

- **Routine Events** - Water samples were collected for chemical analysis from seventeen locations in the LPRSA (including the LPRSA tributaries), above Dundee Dam, Newark Bay, and Newark Bay at its confluences with the Hackensack River, Arthur Kill, and Kill van Kull during five routine events spread over winter, spring and summer. The samples included whole water (unfiltered) and filtered water samples, depending on the analyte. Samples were filtered for dissolved metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc), dissolved methyl mercury, hexavalent chromium, and dissolved solids. Organic carbon was analyzed as dissolved, particulate and total (*i.e.*, DOC, POC, and TOC). Samples for chlorophyll a were filtered at the laboratory. All other samples were whole water. The sampling events were conducted during typical medium flows (400 - 3,000 cfs at Dundee Dam) and likely bracketed several flow regimes over the tidal cycle and captured spring and neap tide conditions. Samples were collected from the deepest part of the river (thalweg) and at two depths (3 feet above the bottom and 3 feet below the surface) for the stations from RM 0 to RM17.4 of the Lower Passaic River and the NBSA, and at mid-depth for locations above Dundee Dam and the LPRSA tributaries. These depths were selected with the goal of sampling the relevant layer while avoiding artifacts associated with sampling in close proximity to the sediment bed, the pycnocline (layer with the greatest density gradient), and the water surface. The thalweg was targeted because it was assumed that the denser layer with net inflow was located in the deepest part of the cross section and the collected samples would best represent the dominant flux past that cross-section.
- **High Flow Events -** Water samples were collected for chemical analysis during high flow conditions (>3,000 cfs at Dundee Dam) at seventeen locations in the LPRSA

(including the LPRSA tributaries), above Dundee Dam, Newark Bay, and Newark Bay at its confluences with the Hackensack River, Arthur Kill, and Kill van Kull through two separate high flow events. Stations were generally co-located with stations occupied during the Routine Events and the samples were collected from the same depths and analyzed for the same parameters as described above. Fourteen of the seventeen stations were sampled four times each throughout the predicted storm hydrograph; the station above Dundee Dam was sampled six times throughout the predicted storm hydrograph. The Arthur Kill and Kill van Kull were sampled just before high and low slack tides.

- **Low Flow/Spring Tide Event -** Water samples were collected for chemical analysis during a single event under low flow and spring tide conditions at nine locations in the LPRSA and above Dundee Dam. Stations were generally co-located with Routine Event stations with each station sampled four times during the tidal cycle and the samples were analyzed for the same parameters as described above. Stations in the Lower Passaic River were sampled at two depths; stations above Dundee Dam and in the LPRSA tributaries were sampled from one depth.

4 BATHYMETRIC, GEOPHYSICAL, GEOTECHNICAL, AND HYDRODYNAMICS SURVEYS

4.1 Bathymetric, Geophysical, and Geotechnical Surveys of the Lower Passaic River (Evidence of Erosion and Deposition)

Multiple bathymetric surveys have been conducted on the Lower Passaic River by various organizations (see Table 2-1). The bathymetric survey data obtained for the Lower Passaic River are substantial, covering a period of 23 years (1989 to 2011) from 13 separate surveying events. These data were used to examine long-term and short-term movement of sediments in the Lower Passaic River, and to identify the boundaries of different geomorphological features of the river. Five of these bathymetric surveys were conducted between 1995 and 2001 in the region between RM0.9 and RM7. For these surveys, elevation data were collected along transects that were planned to be co-located. The degree of alignment achieved between these survey events was typically 18 feet or less. Eight bathymetric surveys are available to characterize RM0 to RM8 or RM0 to RM17.4 (see Table 2-1) and consist of the 1989, 2002, 2004, 2005, 2007, 2008, 2010 and 2011 surveys. In 2007, both single-beam and multi-beam surveys were conducted by CPG. The 2007, 2008, 2010 and 2011 surveys used a multi-beam technique, which provides a three-dimensional representation of the river bottom. The level of confidence in the bathymetric data is discussed further in Appendix B along with a detailed discussion on several analyses that used the data and the implications of differences in transect points.

A side scan sonar survey was conducted in 2005 between RM0 and RM14 to characterize the sediment surface in the Lower Passaic River. This survey involved the use of a geophysical acoustic surveying technique capable of discerning sediment classes by acoustic reflectivity. The interpretation of the acoustic reflectivity was then calibrated by the collection of discrete surface samples throughout the Lower Passaic River. Grain size distribution was also analyzed, providing a quantitative sedimentological description as well as a means to “calibrate” the qualitative field classifications.

4.2 Hydrodynamic Surveys

Several hydrodynamic studies were conducted from 1995 to 2010 to characterize how water flows in the Lower Passaic River, Newark Bay, and Kill Van Kull. All of the studies are summarized in Table 2-1.

Most surveys from 1995 to 2005 involved deployment of tide gauges and current meter moorings throughout the river for a period of time to measure tidal water elevations, current velocities, water temperature, and salinity. Boat-based surveys were also done to collect cross-river current velocity profiles, conductivity, temperature, and depth.

Surveys from 2008 to 2011 consisted of Acoustic Doppler Current Profilers (ADCPs) deployed in the river to record vertical profiles of current velocity and sediment flux (through acoustic backscattering), water temperature, and conductivity.

4.2.1 1995-1996 TSI Passaic River Study Area RI/FS (Modeling Parameters)

TSI collected data between 1995 and 1996 in the Lower Passaic River consisting of three bottom moorings that measured tidal currents, water elevations, temperature, and conductivity as well as a series of transect measurements of current velocities using ship-mounted ADCPs and vertical Temperature/Salinity (T/S) casts to obtain snapshots of hydrographic conditions. The 1995 to 1996 TSI data provided tidal stage measurements at three locations on the Lower Passaic River (RM1, RM3, and RM8). The data collection periods extend from mid-April 1995 to mid-June 1996. Water surface elevations were measured at five- and six-minute intervals and the data were used for model calibration for these periods.

4.2.2 2000-2004 Rutgers University Institute of Marine & Coastal Sciences (IMCS) Hydrographic Measurements (Modeling Parameters)

On behalf of NJDOT and USACE, from December 2000 through April 2002, IMCS of Rutgers University collected data which consist of bottom mounted ADCP, pressure, temperature, and conductivity sensors at five locations: Perth Amboy, the Arthur Kill, the Kill van Kull, and two in Newark Bay. However, the instruments were rotated between the locations at different periods so that there are many gaps in the data.

In 2004-2005 IMCS of Rutgers University deployed a set of six moorings, most of them equipped with two probes (an upper and lower probe) between RM1 and RM8. Data are available from these probes for several distinct periods: August to October 2004, November 2004 to January 2005, and July to September 2005. The data set includes high resolution profiles of salinity and TSS, fixed location measurements of salinity, TSS derived from backscatter, and velocity. Field data collected include bottom mounted ADCP and pressure sensors, and surface and bottom mounted T/S sensors in the Lower Passaic River. The data include low and high flow events providing an excellent range of river behavior for evaluation.

The study implemented by Robert Chant at Rutgers University in 2004 and 2005 provides a baseline of water column velocity, salinity, and TSS measurements in the Lower Passaic River focused on better understanding sediment transport in the system. The study is summarized in a 2010 paper (Chant *et al.*, 2010). Longitudinal profiles of salinity and TSS during low and high flow cases illustrate the dominance of estuarine and riverine processes depending on flow.

4.2.3 2004 to 2005 USEPA and NJDOT Hydrodynamic Studies (Modeling Parameters and Salt Front)

Two separate hydrodynamic studies were conducted on the Lower Passaic River to characterize the movement of the salt front in the river, as follows:

- A hydrodynamic study was conducted as part of NJDOT's Environmental Dredging Pilot Study and involved the placement of several salinity probes between RM2.7 and RM3.1. Six probes were placed near the water surface and four near the water column bottom. Data collection occurred over a period of about 10 days in December 2005.
- On behalf of USEPA and USACE, Malcolm Pirnie, Inc. deployed three moorings with probes located in the upper and lower water column. Two moorings (at RM8.6 and RM9.8) successfully measured salinity data between November 2004 and September 2005.

Note that during the evaluation of these hydrodynamic datasets, the quality of portions of the data was called into question. Data quality issues were attributed largely to probe calibration, which is believed to affect the probe response. Many of the probes seemed to lose their calibration during the course of the deployment periods, which was attributed to the large amount of debris carried by the Lower Passaic River. In addition, some probes showed erratic changes that were not replicated in nearby probes or yielded salinity conditions that were highly improbable. Refer to Appendix B, which describes the data problems and the processes used to separate valid data from inaccurate data.

4.2.4 2009 TSI ADCP Moorings Study (Modeling Parameters)

In 2009, TSI, under USEPA oversight, collected data (from RM2.1, RM3.2 and RM4.1) for use in the design of the Phase 1 Removal Action hydrodynamic model. The hydrodynamic assessment data collection consisted of three tasks (TSI, 2009):

1. *Water sampling and monitoring.*
   Current profiling, water samples, and water quality monitoring data were collected along three cross-river transects with three monitoring locations per transect (¼, ½, and ¾ river width) for seven consecutive days. Water samples were collected from mid-water column depth. At the half-river width location, water samples were also collected 3 feet below the water surface and 1.5 feet above the sediment surface.
2. *Water surface elevation monitoring.*

Tidal elevation data was collected using one primary and one backup tide gauge installed across the river from 80 Lister Avenue. The water surface elevation data was collected at 6-minute intervals in accordance with NOAA/National Ocean Service standards (NOAA, 2008). The tide gauge data was collected for 35 consecutive days to capture a full lunar tidal cycle.

3. *In-situ current and water quality monitoring.*

   One ADCP and one co-located water quality probe were deployed along three cross-river transects, at the approximate half-river width location. The water quality probe collected temperature, conductivity, salinity, and turbidity data. The ADCP collected current and acoustic backscatter data. Settling testing was performed approximately once every 6 hours at one location near the river bottom using Sequoia's laser in-situ scattering and tranmissometry instrument-settling test (LISST-ST). Current and water quality data were collected at 12-minute intervals, synchronized with the tide gauge for 35 consecutive days.

4.2.5 2009-2010 CPG Physical Water Column Monitoring (PWCM) Study (Modeling Parameters)

To characterize Lower Passaic River and Newark Bay estuarine dynamics and the movement of suspended sediments, the CPG, under USEPA oversight, deployed five moorings in the fall of 2009 (Lower Passaic River) and the spring and summer of 2010 (Newark Bay). The five stations were located at RM1.4, 4.2, 6.7, 10.2, and 13.5. The moorings were equipped with meters to record water level, temperature, conductivity, salinity, and optical and acoustic backscatter. A wave gauge was also installed in Newark Bay.

Ocean Surveys, Inc. (OSI) collected ADCP current velocity and turbidity data from the moorings during this study, capturing a broad range of flow conditions. Water column profiles of TSS were computed from the ADCP acoustic backscatter (ABS) data, which were used to develop a series of estimated TSS for comparison to model predictions. During mooring deployment, boat-based ADCP surveys were also conducted in the Lower Passaic River and Newark Bay to obtain velocity profiles.

Water column samples analyzed for suspended solids concentration (SSC), DOC, and POC were collected at the time of mooring deployment, at each mooring servicing event, and upon mooring retrieval. Water column samples for SSC analysis were also collected during the ADCP transect surveys in the Lower Passaic River and Newark Bay.

The scope of the PWCM program also included the collection of water samples for laboratory analysis for SSC, POC, and DOC from the Passaic River upstream of Dundee Dam, just downstream of Dundee Dam (Ackerman Avenue Bridge at RM17), and within the major tributaries to the Lower Passaic River under storm-enhanced flow conditions. Tributaries included in the program consisted of the Saddle River, Second River, and Third River. Samples were collected from shore-based stations in the major tributaries to the Lower Passaic River for suspended solids analysis under wet weather conditions. The program included acoustic backscattering measurements at 12-minute intervals, which provided a basis for evaluation of sediment transport behavior on intra-tidal time scales.

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5 ACRONYMS

ABS	Acoustic backscatter
ADCPs	Acoustic Doppler Current Profilers
AVS/SEM	Acid-Volatile Sulfide/Simultaneously Extracted Metals
Be-7	Beryllium-7
BOD	Biochemical Oxygen Demand
CARP	Contaminant Assessment and Reduction Program
cfs	Cubic Feet per Second
CFT	Chemical Fate and Transport
cm	Centimeter
COD	Chemical Oxygen Demand
CPG	Cooperating Parties Group
Cs-137	Cesium-137
CSC	Computer Sciences Corporation
CSO	Combined Sewer Overflow
CWCM	Chemical Water Column Monitoring
DDE	Dichlorodiphenyldichloroethylene
DFIRM	Digital Flood Insurance Rate Map
DOC	Dissolved Organic Carbon
FEMA	Federal Emergency Management Agency
FFS	Focused Feasibility Study
FWM	Food Web Model
HOC	Hydrophobic Organic Constituents
HQI	HydroQual, Inc.
IMCS	Institute of Marine and Coastal Sciences
L-DEO	Lamont-Doherty Earth Observatory
LISST-ST	Laser in-situ scattering and tranmissometry instrument-settling test
LPRSA	Lower Passaic River Study Area
MB	Multi-Beam

MLW	Mean Low Water
NBSA	Newark Bay Study Area
NJDEP	New Jersey Department of Environmental Protection
NJDOT	New Jersey Department of Transportation
NJGS	New Jersey Geological and Water Survey
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Services
NS&T	National Status & Trends
NY/NJ HEP	New York and New Jersey Harbor Estuary Program
NYSDEC	New York State Department of Environmental Conservation
OSI	Ocean Surveys, Inc.
PAH	Polycyclic Aromatic Hydrocarbon
Pb-210	Lead-210
PCB	Polychlorinated Biphenyl
PCDD/F	Polychlorobenzodioxin/furan
POC	Particulate Organic Carbon
PRSA	Passaic River Study Area
PWCM	Physical Water Column Monitoring
QAPP	Quality Assurance Project Plan
RI	Remedial Investigation
RI/FFS	Remedial Investigation and Focused Feasibility Study
RI/FS	Remedial Investigation and Feasibility Study
RIWP	Remedial Investigation Work Plan
RM	River Mile
RPI	Rensselaer Polytechnic Institute
SB	Single-Beam
SEI	Sea Engineering, Inc.
SPMD	Semi-Permeable Membrane Device
SSC	Suspended solids concentration
SVOC	Semi-Volatile Organic Compounds
SWO	Stormwater Outfall

TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
TOPS	Trace Organic Platform Sampler
TPH	Total Petroleum Hydrocarbons
T/S	Temperature/Salinity
TSI	Tierra Solutions, Inc.
TSS	Total Suspended Solids
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compounds
µm	Micrometers

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TABLES

Table 2-1: Historical and Current Datasets Incorporated into the Data Evaluation Reports and the RI/FFS Report

Year	Data Source Name	Approved QAPP or Work Plan	Data Validated
GIS Layers			
1995	Chromate Waste Sites, NJDEP	Not Applicable	Not Applicable
1999	NJDEP Wetlands, NJDEP	Not Applicable	Not Applicable
2001	Habitat, NJDEP Division of Fish and Wildlife	Not Applicable	Not Applicable
2002	Land Use, NJDEP	Not Applicable	Not Applicable
2003	Toxic Release Inventory Facilities, USEPA	Not Applicable	Not Applicable
2004	National Priority List Sites, USEPA	Not Applicable	Not Applicable
2005	Known Contaminated Site List, NJDEP	Not Applicable	Not Applicable
2006	Soils, NRCS and USDA	Not Applicable	Not Applicable
2005-2007	FEMA Flood Zones, FEMA DFIRM Database	Not Applicable	Not Applicable
2007	NWI Wetlands, National Wetland Inventory Dataset	Not Applicable	Not Applicable
2007	Bedrock Geology, NJGS and NJDEP	Not Applicable	Not Applicable
Tissue			
1993	NYSDEC 1993	Unknown	Unknown
1994	NYSDEC 1994	Unknown	Unknown
1995	1995 Biological Sampling Program	Unknown	Yes
1999	1999 Late Summer/Early Fall ESP Sampling Program	Yes	Yes
2000	2000 Spring ESP Sampling Program	Yes	Yes
2005	2005 Sediment Profile Imaging Survey of Sediment and Benthic Habitat Characteristics of the Lower Passaic River	Yes	Yes
2005	2005 Taxonomic Identification of Benthic Invertebrates	Yes	Yes
2009-2010	2009-2010 CPG Benthic and Surface Sediment Program	Yes	Yes
2009-2010	2009-2010 Fish Community and Tissue Collection Surveys	Yes	Yes
2010	2010 CPG Habitat Identification Survey	Yes	Yes
2010	2010 CPG Summer/Fall Avian Community Survey	Yes	Yes
Sediment			
1991	1991 Core Sediment Investigation	Unknown	Yes
1993	NOAA NS&T Hudson-Raritan Phase II- 1993	Unknown	Unknown
1993	1993 Core Sediment Investigation - 01 (March)	Unknown	No
1993	1993 Core Sediment Investigation - 02 (July)	Unknown	No
1994	1994 Surficial Sediment Investigation	Unknown	No
1995	1995 TSI Remedial Investigation Sampling Program	Yes	Yes
1999	1999 Sediment Sampling Program	Yes	No
1999	1999 Late Summer/Early Fall Environmental Sampling Program	Yes	Yes
1999/2000	1999/2000 Minish Park Monitoring Program	Yes	No
2000	2000 Spring Environmental Sampling Program	Yes	Yes
2005	2005 Newark Bay Phase I Remedial Investigation	Yes	Yes
2005	2005 Sedflume Testing	Yes	Yes
2005	2005 Gust Microcosm Testing	Yes	Yes

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Table 2-1: Historical and Current Datasets Incorporated into the Data Evaluation Reports and the RI/FFS Report

Year	Data Source Name	Approved QAPP or Work Plan	Data Validated
2005	2005 USEPA High Resolution Sediment Coring	Yes	Yes
2005	Polytechnic Institute (RPI) and Lamont-Doherty Earth Observatory (L-DEO) Upper Passaic High Resolution Sediment Cores	Unknown	Unknown
2006	2006 USEPA Sampling Program (Malcolm Pirnie, Inc.) Low Resolution Cores	Yes	Yes
2007	2007 USEPA Upper Passaic High Resolution Sediment Coring	Yes	Yes
2007	2007 Newark Bay Phase II Remedial Investigation	Yes	Yes
2007-2008	2007-2008 USEPA Supplemental Sediment Programs	Yes	Yes
2008	2008 USEPA Suspended-Phase High Flow Storm Event Sampling	Yes	Yes
2008	2008 Sedflume Consolidation Testing	Yes	Yes
2008	2008 CPG Low Resolution Sediment Coring	Yes	Yes
2009-2010	2009-2010 CPG Benthic and Surface Sediment Program	Yes	Yes
2012	2012 CPG Low Resolution Coring Supplemental Sampling Program	Yes	Yes
Water Column			
2005	2005 Large Volume Water Column Sampling Study	Yes	Yes
2005	2005 Small Volume Water Column Sampling Study	Yes	Yes
2005	2005 Semi-Permeable Membrane Device Study	Yes	Yes
2005	2005 USEPA High-Flow Water Column Suspended Solids Sampling	Yes	Yes
2005	NJDOT Environmental Dredging Pilot Study	Yes	Yes
2009-2010	2009-2010 CPG Physical Water Column Monitoring	Yes	Yes
2010	CPG High-Flow Water Column Suspended Solids Sampling	Yes	Yes
2011-2012	CPG RI Water Column Monitoring/Small Volume Chemical Data Collection	Yes	Yes
Hydrodynamics			
1995-1996	TSI Passaic River Study Area RI/FS	Yes	Yes
Nov, 2004 to Sep, 2005	November 2004 to September 2005 Malcolm Pirnie, Inc. Survey	Yes	Not Applicable
Aug – Oct 2004	August to October 2004 Rutgers University Survey First Deployment	Yes	Yes
Nov, 2004 to Sep, 2005	November 2004 to January 2005 Rutgers Survey Second Deployment	Yes	Not Applicable
Jul – Sep 2005	July to September 2005 Rutgers Survey Third Deployment	No	Not Applicable
2005	NJDOT Environmental Dredging Pilot Study	Yes	Not Applicable

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Table 2-1: Historical and Current Datasets Incorporated into the Data Evaluation Reports and the RI/FFS Report

Year	Data Source Name		Approved QAPP or Work Plan	Data Validated
2008-2009	Rutgers University and University of Delaware ADCPs Study		Unknown	Unknown
2009	TSI ADCP Mooring Study		Yes	Yes
2010	CPG Physical Water Column Monitoring Program		Yes	Yes
Bathymetry				
1989	November 1989 Topo-Metrics, Inc. for USACE	RM-0.5 to RM14.98	Not Applicable	Not Applicable
1995	March/April 1995 Ocean Surveys, Inc. for TSI	RM0.87 to RM6.97	Not Applicable	Not Applicable
1996	November 1996 Ocean Surveys, Inc. for TSI	RM0.87 to RM6.95	Not Applicable	Not Applicable
1997	April 1997 Ocean Surveys, Inc. for TSI	RM0.87 to RM6.95	Not Applicable	Not Applicable
1999	June 1999 Ocean Surveys, Inc. for TSI	RM0.89 to RM6.97	Not Applicable	Not Applicable
2001	August 2001 Ocean Surveys, Inc. for TSI	RM0.89 to RM6.96	Not Applicable	Not Applicable
2002	July 2002 TVGA Consultants for USACE	RM-0.44 to RM8.01	Not Applicable	Not Applicable
2004	November 2004 Rogers Surveying, Inc. for USACE	RM-0.54 to RM17.42	Not Applicable	Not Applicable
2005	Aqua Survey Inc. Geophysical and Side Scan Sonar Survey	RM0 to RM17	Yes	Not Applicable
2007	CPG - Multi-Beam (MB) and Single-Beam (SB) Bathymetry	RM-0.50 to RM14.45 (MB) RM0.5 to RM8.21 and RM14.38 to RM16.54 (SB)	Not Applicable	Not Applicable
2008	CPG - Multi-Beam and Single-Beam Bathymetry	RM-0.5 to RM14.26	Not Applicable	Not Applicable
2010	CPG - Multi- Beam Bathymetry	RM-0.5 to RM14.27	Not Applicable	Not Applicable
2011	CPG - Bathymetric Survey of Lower 14 Miles of the Passaic River After Hurricane Irene	RM-0.5 to RM14.27	Not Applicable	Not Applicable

a: The original vertical datum for surveys was MLW as defined by the USACE. The transect density for the surveys was approximately 52 transects per mile.

b: The validation status of the historical sediment and tissue datasets was reported in the "Passaic River Study Area RI/FS Database PRSA version 4."

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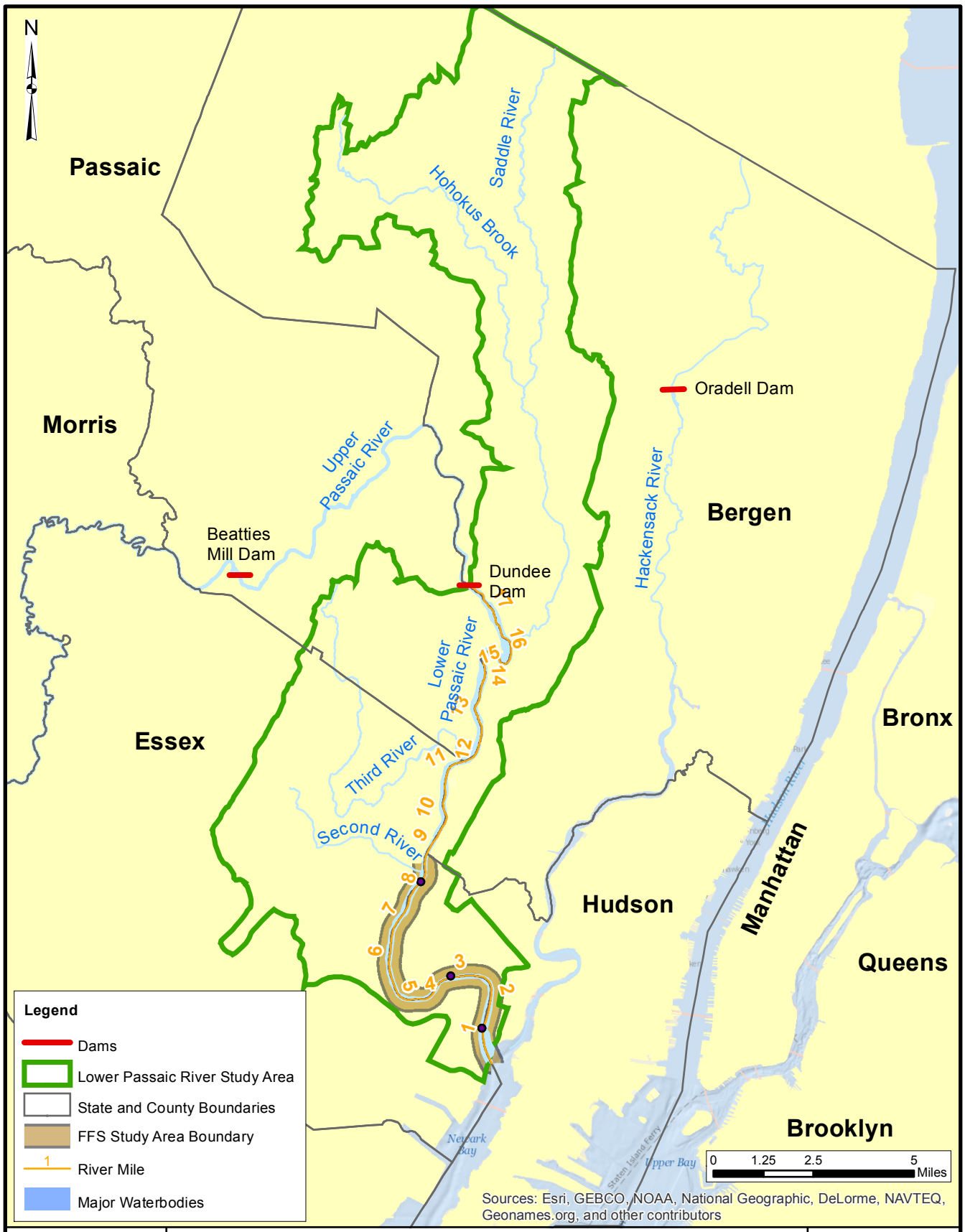
FIGURES



FFS Study Area Location Map

Lower Eight Miles of the Lower Passaic River

Figure 1-1

2014

Path: P:\0285924\Mapping\CSM_MassBalance\sitelocation_CSM_no_logos.mxd

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Data Evaluation Report No. 2:

“Boundary Conditions”

LOWER EIGHT MILES OF THE LOWER PASSAIC RIVER
DATA EVALUATION REPORT NO. 2: BOUNDARY CONDITIONS

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1 INTRODUCTION

This document is part of a series of data evaluation reports describing different aspects of the Lower Passaic River, which were prepared to support the Remedial Investigation (RI) and Focused Feasibility Study (FFS). Where necessary, data evaluation reports are cross-referenced to direct the reader to another report that contains further explanation. Topics discussed in this series include major sediment and water investigations conducted in the river, boundary conditions of the River, hydrodynamics of the system, solids transport in the River, historical sediment contamination, surface sediment contamination, source pattern analyses, contaminant inventory calculations, and biota analysis. This report examines the boundary conditions of the Lower Passaic River, that is, the external contributions of contaminants, solids, and water, as they affect the sediments of the lower eight miles.

1.1 Overview of the FFS Study Area

The FFS Study Area is located within the Lower Passaic River Study Area (LPRSA), which is the 17-mile, tidal portion of the Passaic River from Dundee Dam [located at River Mile (RM[1]) 17.4] to the confluence with Newark Bay at RM0 and the watershed of this river portion, including the Saddle River (RM15.6), Third River (RM11.3) and Second River (RM8.1) [Figure 1-1]. During a comprehensive study of the Lower Passaic River, the sediments of the lower eight miles were found to be a major source of contamination to the rest of the river and Newark Bay. Therefore, the United States Environmental Protection Agency (USEPA) completed the FFS to evaluate alternatives to address those sediments in the lower eight-mile stretch from RM0 to RM8.3, near the border between the City of Newark and Belleville Township. The entire 17-mile Lower Passaic River is the subject of another Remedial Investigation/Feasibility Study (RI/FS)

[1] The FFS uses the "River Mile" (RM) system developed by the United States Army Corps of Engineers (USACE), which follows the navigation channel of the Lower Passaic River. The Data Evaluation Reports (Appendix A), Empirical Mass Balance (Appendix C) and Lower Passaic River-Newark Bay model (Appendix B) were initially developed at the beginning of the 17-mile Remedial Investigation and Feasibility Study (RI/FS), and thus follow a RM system developed for that RI/FS, which follows the geographic centerline of the river. RM0 is defined by an imaginary line between two marker lighthouses at the confluence of the Lower Passaic River and Newark Bay: one in Essex County just offshore of Newark and the other in Hudson County just offshore of Kearny Point. River miles then continue upriver to the Dundee Dam (RM17.4). The two RM systems are about 0.2 miles apart.

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being implemented by the Cooperating Parties Group (CPG; a group of approximately 70 potentially responsible parties who signed an agreement with USEPA in 2007), under USEPA oversight. The Upper Passaic River watershed (the portion of the Passaic River located above the Dundee Dam) contributes solids, water, and contaminants that cross over the head-of-tide, which is represented by the Dundee Dam[2], into the Lower Passaic River.

1.2 Overview of the Boundary Conditions Data Evaluation Report

This report characterizes the boundary conditions for the Lower Passaic River. The report is composed of the following sections in addition to the introduction:

- *Section 2.0, Overview of Boundary Conditions*: provides a brief description of each boundary condition on the Lower Passaic River. Each of the major contributors to the Lower Passaic River is then described in detail in the subsequent sections.
- *Section 3.0, Upper Passaic River Boundary Condition*: characterizes the freshwater discharge from the Upper Passaic River and the associated contaminant loading to the Lower Passaic River.
- *Section 4.0, Newark Bay Boundary Condition*: characterizes the seaward boundary condition at Newark Bay and the tidally driven bidirectional exchange between the Bay and the Lower Passaic River.
- *Section 5.0, Tributary Boundary Conditions*: characterizes the freshwater discharges at the tributaries (Saddle River, Second River, and Third River) and the associated contaminant loading to the Lower Passaic River.
- *Section 6.0, Point Discharge Boundary Conditions*: characterizes the discharges at the Combined Sewer Overflow (CSO) and Stormwater Outfall (SWO) outlets to the River and the associated contaminant loading to the Lower Passaic River.

[2] The Dundee Dam represents a hydraulic boundary. The head-of-tide actual location is downstream of the dam because even though the tides can influence the water level near the dam, the upper-most extent of saltwater (*i.e.*, the salt front) typically stops several miles below the Dundee Dam (refer to Lower Passaic River System Understanding of Sediment Transport [HQI and Sea Engineering Inc, 2011] for further details on the salt front migration).

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- *Section 7.0, Other Boundary Conditions*: discusses miscellaneous boundary conditions (*i.e.*, groundwater and atmospheric inputs) and their negligible impacts to the Lower Passaic River.
- *Section 8.0, Acronyms*: defines the acronyms used in this report.
- *Section 9.0, References*: lists the references used in this report.

1.3 Definition of Boundary Conditions

In order to understand the FFS Study Area, its major external inputs of suspended solids and the contaminants bound to those solids need to be characterized. In this context, "boundary conditions" are defined at locations where flows or contaminants enter (or depart) the main area of interest, and where these flows and fluxes can be readily measured, such as at a dam or discharge point. Boundary conditions are an important input to modeling efforts, defining the conditions and constraints of the inputs to (and outputs from) the system being modeled.

The boundary conditions described in this document were developed for the FFS and the Empirical Mass Balance (EMB) model described in Appendix C of the FFS. Note that boundary conditions developed to support numerical modeling are presented in Appendix B of the FFS. For the purposes of the FFS and the EMB model, the bounded region is the sediment bed and tidally influenced water column within the Lower Passaic River. The major contributions influencing this domain, and therefore the major external sources to the Lower Passaic River, are:

- Upper Passaic River (defined by elevation and a physical barrier) (see Section 3.0);
- Confluence of the Lower Passaic River and Newark Bay (see Section 4.0);
- Heads-of-tide on the Saddle River, Second River, and Third River (defined by elevation or a physical barrier) (see Section 5.0); and
- CSO and SWO discharge pipes (see Section 6.0).

A schematic diagram of the relative locations of the boundary conditions is provided in Figure 1-2.

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The contaminant loads at these major boundaries are inputs to the Lower Passaic River. These inputs must then be quantified to predict their impacts within the confines of the tidally-influenced reaches of the River itself. (Note that atmospheric deposition and groundwater are two other boundary conditions where chemical exchange can occur with the Lower Passaic River. However, it is unlikely that these boundaries yield a significant net transport of the compounds of concern into or out of the River. See Section 7.0 for further discussion). For the RI and the EMB model, contaminant loading estimates were based on direct field measurements and samples collected at the boundaries, in combination with measurements or estimates of annual flow. The samples included water column suspended matter and surface sediment samples collected just outside of the domain at the physical boundaries that separate the source waters and solids from the influence of the Lower Passaic River (*e.g.*, above the head-of-tide or at point source outflow).

Because of the relationship between the Lower Passaic River and the New York-New Jersey Harbor Estuary, contaminated solids originating in the Lower Passaic River are distributed throughout the estuary by tidal action. This phenomenon is reported by Chaky (2003), who identified a tracer of Passaic-contaminated solids, specifically the unique ratio of 2,3,7,8- tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) to Total tetrachlorodibenzo-p-dioxin (Total TCDD). In the Chaky model, Passaic-contaminated solids have a ratio value of approximately 0.7, which represents one end member, while solids originating from sewage, atmospheric deposition, and the Upper Hudson River have a ratio of 0.06 or less, representing the "other" end members. The mixing of solids between these end members is observed throughout the New York-New Jersey Harbor Estuary by the variation of this ratio [Figure 1-3; reprint from Chaky (2003)].

Other studies have reported 2,3,7,8-TCDD/Total TCDD ratios ranging from 0.5 to 0.8 for the Lower Passaic River, which are consistent with Chaky's work (Bopp, *et al.*, 1991, Bopp, *et al.*, 1982). For example, Lower Passaic River surface sediment samples collected in 1995 by Tierra Solutions, Inc. (TSI) exhibited a mean 2,3,7,8-TCDD/Total TCDD ratio of 0.7 [sample size (N) = 97] (see Data Evaluation Report No. 3). Beginning

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near the mouth of the Lower Passaic River, the 2,3,7,8-TCDD/Total TCDD ratio is then observed to steadily decline across Newark Bay, from north to south from a ratio of 0.6 to 0.3 in recently-deposited surface sediments that are located in the channels of the bay (Figure 1-4). The change in this chemical ratio is the result of mixing Passaic-contaminated sediments with solids from other areas.

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2 OVERVIEW OF BOUNDARY CONDITIONS

The following subsections provide a brief description of each boundary condition on the Lower Passaic River, including the Upper Passaic River, Newark Bay, tributaries, point discharges and other boundary conditions (*i.e.*, groundwater and atmospheric inputs). Details describing referenced sampling events are provided in Data Evaluation Report No. 1.

2.1 Overview of Upper Passaic Boundary Condition

The non-tidal Upper Passaic River (which forms the upstream boundary) discharges solids, freshwater, and contaminants to the Lower Passaic River at Dundee Dam (RM17.4) in Garfield/Clifton, New Jersey. Freshwater runoff from roughly 90 percent of the entire Passaic River drainage basin enters the Lower Passaic River at the dam, making the dam the largest freshwater point source to the Lower Passaic River. In addition to freshwater inputs, the Upper Passaic River contributes an estimated annual average solids load of 70,000 cubic yards per year (cy/yr) [40,000 metric tons per year (mt/yr)] at Dundee Dam; representing nearly 90 percent of the upland delivery of solids to the Lower Passaic River (see Section 5.0 of this report). As such, samples collected in the immediate vicinity of Dundee Dam are considered representative of the contaminant load generated by the 810 square-mile Upper Passaic River watershed to the Lower Passaic River. The area immediately downstream of the dam is also considered representative because, although the tides can influence the water level near the dam, the upper-most extent of saltwater (*i.e.*, the salt front) typically stops several miles below the Dundee Dam[3] due to the river bottom ascending above sea level. Hence the head-of-tide is downstream of the dam around RM16.5.

Samples collected in the immediate vicinity of the dam (above and below) to characterize the Upper Passaic River contaminant load included suspended matter in the water

[3] Refer to Lower Passaic River System Understanding of Sediment Transport (HQI and Sea Engineering Inc., 2011) for further details on the salt front migration.

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column, sediment trap samples, and recently-deposited [*i.e.*, beryllium-7 (Be-7) bearing[4]] surface sediments. The contaminant levels detected in these samples (when considered with measured flows) can be used to estimate contaminant loads entering the Lower Passaic River from the entire 810 square-mile Upper Passaic River watershed. The Upper Passaic River boundary condition is further discussed below in Section 3.0, as well as in Appendix C of the FFS, which describes the EMB model.

2.2 Overview of Newark Bay Boundary Condition

Newark Bay represents the downstream or seaward boundary of the Lower Passaic River at RM0. At this boundary, tidal action causes the bi-directional exchange of contaminants, solids, and water between Newark Bay and the Lower Passaic River. The composition of the Newark Bay waters, which enter the Lower Passaic River at the RM0 boundary, is influenced by the bay (proper), major tributaries (including the Lower Passaic River), minor streams entering the bay, and point and non-point source discharges to the bay. Most importantly, water and solids contributions come from the tidal waters of the Hudson River, Upper and Lower New York Harbors, and Raritan Bay through the Kill Van Kull and Arthur Kill waterways. Like the rest of the New York-New Jersey Harbor Estuary, twice-daily tidal mixing causes the re-working of surface sediments and the mixing of solids in the bay with solids derived from other areas. A solids mass balance performed by Lowe *et al.* (2005) indicated that on a net annual basis, Newark Bay was a receiver of solids and that a significant portion of the solids delivered to Newark Bay are removed by maintenance dredging. The net solids input with respect to the Passaic River interface with Newark Bay was estimated to be 30,000 cy/yr (approximately 17,000 mt/yr) by Sommerfield and Chant (2010). This is similar to the figure compiled by Suszkowski (1978), who estimated the gross outflux from the River to the Bay is 71,000 cy/yr (approximately 40,500 mt/yr) and the gross influx from the Bay to the River is 40,000 cy/yr (approximately 22,500 mt/yr), yielding a net flux into the Bay of 31,000 cy/yr (approximately 17,500 mt/yr).

[4] Be-7 is a naturally occurring, particle-reactive radioisotope with a short half-life (53 days). The presence of Be-7 in surface sediments suggests that the associated solids were deposited on the sediment bed within the last 6 months (termed "recently-deposited surface sediments") prior to collection. Refer to Data Evaluation Report No. 4 for further discussion.

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In 2005 and 2007, TSI collected surface sediment samples (0 to 6 inches) throughout the Bay and analyzed them for a suite of chemical parameters. At each sampling location, a co-located sediment grab sample was collected (0 to 1 inch) and analyzed for Be-7 (TSI, 2007, 2008). Recently-deposited solids in Newark Bay were identified by examining the chemical concentrations in these surface sediment samples (0 to 6 inches) at select locations in the navigation channel that contained detectable concentrations of Be-7. The information from these samples was used to develop estimates of the exchanges between Newark Bay and the Lower Passaic River. Based on the observed concentration gradients in the bay, three main sources of solids (*i.e.*, three "end members") to the bay were identified: the Kill Van Kull, the Arthur Kill, and the Lower Passaic River. The mixture of these sources at the northern end of Newark Bay constitutes the Newark Bay boundary condition; that is, the solids that are delivered to the Lower Passaic River from Newark Bay. This is further discussed below, in Section 4.0 "Newark Bay Boundary Condition" as well as in Appendix C of the FFS, which describes the EMB model.

2.3 Overview of the Tributary Boundary Conditions

Three main tributaries discharge freshwater and solids into the Lower Passaic River: the Saddle River, Third River, and Second River. The Saddle River originates in Rockland County, New York and then flows south through Bergen County, New Jersey. This tributary drains a watershed to the east of the main stem of the Lower Passaic River. The confluence of the Saddle River and Lower Passaic River is located at RM15.6. The Third River drains the New Jersey municipalities of Nutley and Clifton to the west of the Lower Passaic River, with its confluence located at RM11.3. The Second River is an urbanized river[5] on the west side of the Lower Passaic River that drains the New Jersey municipalities of Newark, Bloomfield, and Belleville. The confluence of the Second River and the Lower Passaic River is located at RM8.1.

[5] The Second River drainage area is largely urban and much of its banks are hardened or bulkheaded.

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The boundary conditions for these tributaries are defined at locations just upriver of their respective heads-of-tide or at physical dam structures to eliminate any possible influence from the Lower Passaic River on the boundary condition characterization via upriver tidal transport. Unlike the Newark Bay and Upper Passaic River boundary conditions, an extensive data evaluation was not necessary to define the tributary boundary conditions for two reasons. First, samples collected above the head-of-tide represent point sources that are not impacted by tidal mixing or other mechanisms. Second, and more importantly, the combined solids load from the three tributaries (approximately 6,000 cy/yr [approximately 3,300 mt/yr]) represents less than 10 percent of the total solids load to the Lower Passaic River. The tributary boundary conditions are further discussed below, in Section 5.0 "Tributary Boundary Condition" as well as in Appendix C of the FFS Study, which describes the EMB model.

2.4 Overview of CSO and SWO Boundary Conditions

CSO and SWO sites represent the two types of point discharge boundary conditions in the Lower Passaic River. The "capture zone" at each of these point sources is the physical surface area within the city or municipality that drains directly into the piping (and sewage system, where applicable). The characteristics of the solids discharged by CSOs were measured at the regulator-box overflow weir during CSO discharge events. Discharge from CSOs only occurs when rainfall is sufficient and the tide level is sufficiently low, permitting the tide gates to open. The gates and weir are designed to prevent the backflow of river water into the sewerage system. Suspended solids were collected via a surface manhole located between the regulator-box overflow weir and the tide gate, intercepting the water discharging directly to the River.

The boundary condition for each SWO was defined at an accessible location close to or at the discharge point to the River. Unlike CSOs, SWO discharge points do not have tide gates and the storm drains are routinely flooded with river water at high tide. As a result, the measurements of SWO solids are believed to be impacted by solids originating in the Lower Passaic River.

The solids load from the CSO/SWO point discharges (approximately 2,800 cy/yr [approximately 1,600 mt/yr]) contributes less than 3 percent of the total solids load to the Lower Passaic River. The CSO and SWO discharges are further discussed below, in Section 6.0 "CSO and SWO Discharge Boundary Conditions" as well as in Appendix C of the FFS, which describes the EMB model.

2.5 Overview of Other Boundary Conditions

Atmospheric exchange and groundwater transport represent other boundary processes where chemical exchange can occur. Atmospheric delivery of contaminants occurs across the entire watershed of the Passaic River. This delivery is integrated and monitored by the measurements at the confluences of the Upper Passaic River, the tributaries, the CSOs, and the SWOs. Contaminants transported by the wind or rain can be deposited directly to the River's surface, but this is small in comparison to the loads delivered to the watershed. Contaminants can also be transported to the River as dissolved constituents in groundwater that is percolating through the sediment bed. However, as discussed in Section 7.0 "Other Boundary Conditions," it is unlikely that the flux from these boundaries represent a significant net transport of contaminants into or out of the Lower Passaic River when compared to the exchanges that occur at the other boundaries.

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3 UPPER PASSAIC RIVER BOUNDARY CONDITION

The Upper Passaic River drainage basin (810 square miles) enters the Lower Passaic River at Dundee Dam (RM17.4). The non-tidal Upper Passaic River is separated from the tidal Lower Passaic River at the dam, which was built in 1845 and is located between Garfield and Clifton, New Jersey. This section describes the contaminant loading at this boundary to the Lower Passaic River.

3.1 River Flow and Solids Delivery at Dundee Dam

The average annual flow at Dundee Dam was determined by calculating the average annual flow at the United States Geological Survey (USGS) gauging station at Little Falls, New Jersey (period of record: 1956 to 2005, USGS, 2007), located about 12 miles above Dundee Dam, and adjusting the flow rate to account for the additional drainage area between the gauging station and Dundee Dam. The average annual flow rate at the Little Falls USGS gauging station was estimated at 1,100 cubic feet per second (cfs) [31.15 cubic meters per second (m^3/s)]. Based on USGS records, the total drainage area at the Little Falls gauging station is 762 square miles, as compared to the 810 square miles that discharge to Dundee Dam. Using these areas and assuming a linear relationship, the average annual flow at Dundee Dam was estimated at 1,200 cfs (33.98 m^3/s).

Variation in river flow to the Lower Passaic River was characterized by examining the Little Falls gauging station flow data to determine how high and low flow events varied over time. River flow statistics for the Little Falls gauging station are presented in Table 3-1, which provides flow data for a 16-year time period (1995 to 2011) along with flow statistics for the past 55 years (1956 to 2011). This period was selected to examine flows corresponding to the majority of recent studies of the River. Between 1995 and 2011, the annual average river flow varied by a factor of 6 (with minimum and maximum average flows of 450 cfs (13 m^3/s) and 2,600 cfs (74 m^3/s), respectively), while the annual peak river flow varied by a factor of 7 (with minimum and maximum peak flow of 3,100 cfs

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(88 m^3/s) and 21,000 cfs (595 m^3/s), respectively). This shows that the Lower Passaic River experiences significant variations in flow (and thus velocity), which translates to variations in sediment mobilization and deposition in the River. The average annual river flow and annual peak flow between 1995 and 2011 are comparable to the average flow and peak flow over the past 55 years (1956 to 2011; Table 3-1).

With the estimated annual flow established, the corresponding mass of solids delivered annually can be estimated from flow records and measurements of suspended solids obtained by the USGS over time. Based on these records, the annual average solids load from the Upper Passaic River is estimated at 70,000 cy/yr [40,000 mt/yr] based on an integration of the relationship between flow and suspended solids, as described in Appendix B of the FFS. As discussed in further detail in Section 5.0 of this report, this load represents nearly 90 percent of the upland delivery of solids to the Lower Passaic River. Tributaries, CSOs, and SWOs comprise the remaining fraction, approximately 10 percent. The 90 percent load is comparable to the average mass of sediment that accumulates annually in the Lower Passaic River (see Appendix C of the FFS).

These observations provide the basis to estimate the magnitude of contaminant loads delivered by Upper Passaic River solids to the Lower Passaic River and compare them qualitatively to downstream sources. Additionally, these observations provide independent estimates of solids and contaminant loads that will be incorporated in more rigorous analyses (such as a fate and transport model or a mass balance analysis) to quantitatively assess the importance of Upper Passaic River loads relative to all loads to the Lower Passaic River. Table 3-2 summarizes the relative load contribution estimates. Note that the percentages used for the Upper Passaic River loads relative to the Lower Passaic River loads are intended as approximate values.

3.2 Characterization of the Contaminant Burden on Solids Delivered by the Upper Passaic River

Several different measurement approaches were used to characterize the contaminant concentrations of suspended solids delivered to the Lower Passaic River by the Upper Passaic River. Bopp *et al.* (2006) collected high resolution sediment cores in 2005 from the Upper Passaic River. Sediments from their 2005 dateable core (Field ID "PASS8B") provide a record of historical water column suspended matter that was deposited on the sediment bed between approximately 1960 and 2005 (refer to Figures 3-1 to 3-2 and Figures 3-5 to 3-6). In 2007 to 2008, surface sediment samples (0 to 1 inch core tops) and water column suspended matter were collected from above and immediately below Dundee Dam, respectively, by Malcolm Pirnie, Inc. on behalf of the United States Army Corps of Engineers (USACE) and USEPA. The surface sediment samples were analyzed for Be-7 activity. If sufficient concentrations of Be-7 were detected in a sample, the sediments were characterized as recently-deposited (*i.e.*, deposited within the last 6 to 12 months prior to collection). Analytical results for the water column suspended matter samples, recently-deposited (Be-7 bearing) surface sediment samples (0 to 1 inch), and core top slices collected by Bopp *et al.* are provided in Tables 3-3 and 3-4 and discussed below. These samples characterize the solids transported by Upper Passaic River during the 2005 to 2008 period and can be used to provide an estimate on the contaminant load entering the Lower Passaic River. The analysis linking suspended matter and Be-7 bearing sediments is presented in Data Evaluation Report No. 4. The results show close agreement between the two sample types for the Lower Passaic River samples.[6]

3.2.1 2,3,7,8-TCDD in Upper Passaic River Solids

The reported 2,3,7,8-TCDD concentrations for recently-deposited solids originating in the Upper Passaic River are summarized in Tables 3-3 and 3-4. Mean levels of 2,3,7,8-TCDD in the Upper Passaic River [2.3 nanograms per kilograms of sediment (ng/kg)] are

[6]The analysis presented in Data Evaluation Report No. 4 showed that Be-7 bearing sediment samples (0 to 1 inch core tops) could be used to characterize contamination on solids in the water column. Comparison between Be-7 bearing sediments from the Lower Passaic River with suspended matter collected from the water column of the Lower Passaic River showed close agreement between the two sample types for the Lower Passaic River samples.

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more than 2 orders of magnitude lower than the mean concentrations observed in recently-deposited surface sediment from the Lower Passaic River (370 ng/kg) (refer also to Figure 5-1). Historical solids delivered from the Upper Passaic River also had higher levels of 2,3,7,8-TCDD than current solids. For example, the 2,3,7,8-TCDD concentrations reported in the Bopp *et al.* 2006 core (Field ID "PASS8B") for solids dating to 1975 and 1963 were 7.6 ng/kg and 22 ng/kg, respectively (Figure 3-1). However, when compared to solids deposited in the Lower Passaic River during these years, the difference between Upper and Lower Passaic River solids is even greater (*i.e.,* 7.6 to 22 ng/kg for the Upper Passaic River versus concentrations in the range of 1,000 to 20,000 ng/kg for the Lower Passaic River).

As discussed in Data Evaluation Report No. 4, 2,3,7,8-TCDD strongly partitions to solids and thus solids transport is the main means of transport for this compound. Based on this geochemistry and the comparisons described above, it can be concluded that the Upper Passaic River is not and has not been an important source of 2,3,7,8-TCDD to the Lower Passaic River since the early 20th century.

Further support for this conclusion arises from an examination of the ratio of 2,3,7,8-TCDD to Total TCDD in sediments. The supporting discussion for the application of this ratio is described in detail in Data Evaluation Report No. 3. In the Upper Passaic River, this ratio is less than 0.05 for recently-deposited material as well as historical water column suspended matter (as recorded in the Bopp 2005 core; Figure 3-1). The low ratio observed in the Upper Passaic River is consistent with that observed in atmospheric deposition or CSO effluent (Chaky, 2003). Conversely, sediments in the Lower Passaic River are fingerprinted with a markedly higher 2,3,7,8-TCDD/Total TCDD ratio of 0.7, associated with the industrial discharges to the Lower Passaic River. The clear difference in this diagnostic ratio as well as the orders-of-magnitude difference in concentration indicate that the Upper Passaic River is not an important source of 2,3,7,8-TCDD to the Lower Passaic River.

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3.2.2 Total PAHs in Upper Passaic River Solids

In contrast to the findings for 2,3,7,8-TCDD, the Upper Passaic River is an important source of Polycyclic Aromatic Hydrocarbons (PAHs) to the Lower Passaic River. Based on the samples summarized in Tables 3-3 and 3-4, the solids from the Upper Passaic River contain PAH concentrations greater than those observed in recently-deposited sediments in the Lower Passaic River. Specifically, the mean Total PAH concentration on solids delivered by the Upper Passaic River is 70 milligrams per kilograms of sediment (mg/kg), based on suspended solids from USEPA/Malcolm Pirnie, Inc. 2007 to 2008 samples and recently-deposited sediments from Bopp 2005 core tops. This mean concentration is higher than observed in recently-deposited surface sediments samples collected from the Lower Passaic River, which have a mean Total PAH concentration of 39 mg/kg (refer also to Figure 5-2). The mean Total PAH concentration in the Upper Passaic River (*i.e.*, 70 mg/kg) is also higher than measured Total PAH concentrations for water column suspended matter deposited on the sediment bed in 1990 [30 mg/kg; refer to Bopp 2005 data (Field ID "PASS8B") in Figure 3-2]. Given the large volume of solids which originate in the Upper Passaic River and the notably higher concentrations observed on the solids, it can be concluded that the Upper Passaic River is likely the dominant source of Total PAHs to the Lower Passaic River.

3.2.3 Evaluation of PCBs in Upper Passaic River Solids

Conditions for Polychlorinated Biphenyls (PCBs) fall between those of 2,3,7,8-TCDD and Total PAHs. Based on the samples collected (Tables 3-3 and 3-4), solids originating in the Upper Passaic River are somewhat less contaminated than those depositing in the Lower Passaic River, but not by a great amount. Specifically, solids delivered by the Upper Passaic River have an average Total PCB concentration of about 500 µg/kg, whereas solids accumulating in the Lower Passaic River have average concentrations around 1,000 µg/kg (refer also to Figure 5-3). This is about a factor of two, in contrast to the two orders of magnitude difference (factor of 100) observed for 2,3,7,8-TCDD. The results indicate that the Upper Passaic River contributes a PCB load that is important but smaller than that originating downstream.

To evaluate this observation further, the PCB congener pattern in Upper Passaic River surface sediments was compared to the corresponding PCB pattern in Lower Passaic River sediments. If the only source of PCB congeners to the Lower Passaic River were the Upper Passaic River contaminant load, then the two PCB patterns would be similar. Figure 3-3 shows the normalized PCB congener patterns for the Upper Passaic River and Lower Passaic River surface sediments (all samples presented in Figure 3-3 represent recently-deposited material from core tops). Note that instead of comparing absolute PCB concentrations, the individual congeners and co-eluting groups were normalized to the PCB congener 2,2',5,5'-tetrachlorobiphenyl, also known as Ballschmiter and Zell number 52 (BZ52), to enable a comparison of the relative proportions of each congener in the samples. Note that the Upper Passaic River solids, as represented by the Dundee Lake core top, have lower ratios than nearly all the other results for low molecular weight congeners (below BZ70, 'x' symbol at the bottom for each congener), but have notably higher ratios for the higher molecular weight congeners (above BZ70, 'x' symbol at the top for each congener). The larger percentage of high molecular weight (HMW) PCB congeners in the Upper Passaic River samples suggests that the Upper Passaic River sediments contain higher fractions of Aroclors 1254 and 1260 relative to the sediments of the Lower Passaic River. The difference in the PCB patterns suggests that while the Upper Passaic River solids supply a significant contaminant load of HMW PCB congeners to the Lower Passaic River, other PCB sources add a significant quantity of low molecular weight (LMW) PCB congeners to the Lower Passaic River.[7]

To further explore the PCB distribution in the Lower Passaic River, the PCB congener data from Upper Passaic River, Lower Passaic River, and selected locations from the southern portion of Newark Bay were compared. (Refer to Section 4.2 for further discussion on PCB correlations in northern and southern Newark Bay locations). Because

[7] The change in PCB congener pattern in the Dundee Dam samples to the Lower Passaic River samples may be partially due to a change in PCB sediment-water partitioning that occurs as the salinity changes from freshwater to saltwater, which causes PCB congeners to partition more strongly to solids. However, the change in PCB pattern is accompanied by a 2-fold increase in concentration, so it is unlikely that the partitioning effect alone could be responsible for the observed pattern shift. Thus, this evidence indicates the likely presence of a LMW PCB source downriver of the Dundee Dam.

PCB congener analyses for the Newark Bay investigation (TSI, 2007) were performed by a different laboratory (relative to the Upper Passaic River and Lower Passaic River samples), the reported PCB co-elutions differed between the datasets; consequently, a direct comparison of data as initially reported was not possible. To address this issue, single and co-eluting congeners were combined to form a series of co-elution groups common to both laboratories. The reported concentrations for all congeners placed in each group were then summed to produce a value for the group that could be directly compared.

Once the co-eluting congeners were addressed, the concentrations for individual congeners and co-eluting groups were normalized to PCB congener BZ52. These normalized concentrations were then compared in a series of scatter plots (called a "correlation matrix") to assess the correlations of PCB congeners among the different water bodies (Figure 3-4). Each point on each graph represents a congener pair, that is the normalized concentration for congener x in sample 1 versus the normalized concentration for the same congener in sample 2. Thus, samples that have similar congener patterns will have similar normalized concentrations and plot tightly along a 45 degree line.

The correlation matrix shows that Lower Passaic River recently-deposited (Be-7 bearing) surface sediment samples are well correlated with one another, which supports the observation that tidal action has mixed these solids over a long distance (between RM1.4 and RM12.6). Southern Newark Bay samples are also fairly well correlated with one another, indicating that suspended solids in this 1.6 mile section are also being well mixed prior to deposition. The data also suggest that the Upper Passaic River PCB congener pattern is more closely correlated with the Lower Passaic River congener pattern [with correlation coefficients (R) values ranging from 0.93 to 0.96] than the Newark Bay congener pattern (with R values ranging from 0.75 to 0.8). These results, combined with observed Total PCB concentration gradients from the Lower Passaic River to Newark Bay (see Figure 5-3 and refer to Data Evaluation Report No. 4 for additional details of the analysis), suggest that the Upper Passaic River has a stronger impact on the Lower Passaic River PCB contaminant load than does Newark Bay, and

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that the Lower Passaic River is likely contributing some portion of the PCB contaminant burden to the bay.

Moreover, Total PCB concentrations in the Upper Passaic River have been relatively constant since 1990, at approximately 500 µg/kg with Total PCB concentrations ranging from 280 to 710 µg/kg in post-1990 deposition (see Figure 3-5 and Table 3-3). The lack of contaminant concentration decline in the Upper Passaic River since 1990 suggests that the sediments transported over the Dundee Dam will continue to provide contaminated solids that will influence sediment PCB concentrations in the Lower Passaic River.

3.2.4 Pesticides in Upper Passaic River Solids

Based on the samples of suspended solids and recently-deposited sediment as summarized in Tables 3-3 and 3-4, the Upper Passaic River is an important potential source to the Lower Passaic River for some pesticides, but not for others (refer also to Figure 5-4 series). Like 2,3,7,8-TCDD, these compounds are very particle-reactive, so that most of their transport occurs via solids transport. Thus, similar or greater concentrations on recently-deposited sediments relative to the Lower Passaic River indicate a major role for contributions of certain pesticides from the Upper Passaic River. Concentrations on Upper Passaic River solids that are less than 25 percent of the values observed in the Lower Passaic River would indicate a minor or minimal contribution from the Upper Passaic for others. For example, the mean dieldrin concentration in the Upper Passaic River [10 micrograms per kilograms of sediment (µg/kg)] is comparable to the mean Lower Passaic River (recently-deposited) surface sediment concentration (13 µg/kg). Likewise, the mean aldrin concentration in the Upper Passaic River (1.3 µg/kg) is comparable to the mean Lower Passaic River (recently-deposited) surface sediment concentration (1 µg/kg). In both instances, it is likely that the Upper Passaic River solids play a major role in determining the surface concentration of these contaminants in recently-deposited Lower Passaic River sediments.

Conversely, the mean concentrations of 4,4’-dichlorodiphenyldichloroethane (DDD), 4,4’-dichlorodiphenyldichloroethylene (DDE), and 4,4’-dichlorodiphenyltrichloroethane

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(DDT) in the Upper Passaic River are less than half the concentrations detected in the Lower Passaic River recently-deposited surface sediments. Total DDx concentrations (the sum of 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT) in the Lower Passaic River had an average concentration of about 110 µg/kg, which is approximately 2 times higher than the corresponding average concentration measured in the Upper Passaic River (54 µg/kg). This indicates that most of the Total DDx contamination in the Lower Passaic River originates downstream, but, like Total PCBs, the Upper Passaic River load represents an important contribution.

3.2.5 Metals in Upper Passaic River Solids

For most metals of concern, the Upper Passaic River is typically a minor contributor, with solids originating in the Upper Passaic River having lower concentrations than recently-deposited sediments in the Lower Passaic River (see Tables 3-3 and 3-4; also refer to the Figure 5-5 series). For example, the mean chromium concentration in recently-deposited solids in the Upper Passaic River was 41 mg/kg (Table 3-4) whereas the corresponding mean chromium concentration in Lower Passaic River recently-deposited surface sediments (RM0 to RM12) was approximately 100 mg/kg.[8] Similar differences between Upper Passaic River solids and recently-deposited sediments in the Lower Passaic River were observed for cadmium, copper, lead, and mercury, indicating that the Upper Passaic River is an important contributor for each of these metals but in each case represents less than half of the total load, which means that resuspension of contaminated legacy sediments in the Lower Passaic River is the most important contributor of metals to the recently-deposited sediments in the Lower Passaic River. Further detail on the relative concentrations is presented in Section 5.0 of this report.

Further evidence supporting the Upper Passaic River's important but subordinate role is obtained by examining normalized concentrations of these metals. Heavy metals (like mercury, cadmium, and copper) tend to be sorbed to and transported by fine-grained

[8] The value of 100 mg/kg represents an approximate average concentration based on an area-weighting of the RM0 to RM8 and RM8 to RM12 values provided in Table 5-3. Concentrations for RM0 to RM12 for other metals discussed in this section were estimated in the same way.

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materials (silts and clay). In a given sediment sample dataset, metal concentrations will vary from one sample to another simply by the proportion of fine-grained material relative to the sand present in the sample matrix. To minimize this variance, a sample set can be normalized to the proportion of fine-grained material by normalizing metals concentrations to an indicator of the fine-grained sediment content such as iron, aluminum, or lead. This same normalized concentration then becomes a signature of the origin of the fine-grained solids, since the ratios will not vary greatly from place to place unless an additional source exists that has a different ratio or a source exists that contributes additional mass of one metal relative to the other.

In this evaluation, the ratios of cadmium/lead, copper/lead, and mercury/lead in recently-deposited (Be-7 bearing) surface sediments from the Lower Passaic River and Upper Passaic River were examined (Table 3-5). Because of their particle affinities, the ratio of these metals are not expected to change from location to location unless other sources of metals or solids are introduced that have different concentrations and ratios of these metals. Changes in these ratios are considered indicative of the occurrence of sources. Because of the particle affinities of these metals, ratio analysis provides a more sensitive and definitive indication of the presence or absence of such sources.

The cadmium/lead ratio does not vary widely in the surface sediments of the Lower Passaic River (approximately 0.017) and is similar to the cadmium/lead ratio (0.015) measured in the Upper Passaic River. On a cursory examination, the similar cadmium/lead ratio in the two water bodies suggests that the Upper Passaic River may be a source of cadmium to the Lower Passaic River. In this instance, however, the large concentration difference between Upper and Lower Passaic River sediments (roughly 2 versus 4 mg/kg, see Tables 3-4 and 5-3, respectively and Figure 5-5c) rules out this possibility. Like Total PCBs and Total DDx, the Upper Passaic River has an important but subordinate role for cadmium contamination in the Lower Passaic River. The copper/lead ratio is also fairly constant across the Lower Passaic River (approximately 0.7 with a narrow range of 0.63 to 0.76). Given the narrow range, it is likely that this ratio is substantively different than the corresponding ratio measured in the Upper Passaic

River (0.56). The change in the copper/lead ratio indicates that a second source of copper must be present in the Lower Passaic River. Based on these ratios alone, the copper concentration relative to lead concentration increases by 25 percent ([0.7-0.56]/0.56) in the Lower Passaic River. To produce this change, the Lower Passaic River source must either contribute copper directly or contribute fine-grained solids with a ratio greater than that observed in either the Upper or Lower Passaic River recently-deposited sediments. Given the change in concentration between Upper and Lower Passaic River solids (approximately 89 versus 130 mg/kg, respectively), the Lower Passaic River source must contribute substantially more copper than the Upper Passaic River.

The ratio of mercury to lead varies by a factor of two from 0.005 to 0.011 in the Lower Passaic River, with the lowest ratio reported near the Dundee Dam and the highest ratio reported near the confluence with Newark Bay, although no consistency in the variation of this ratio is seen in between. However, the ratio of mercury to lead in the Upper Passaic River recently-deposited sediments is 0.0045, about 50 percent less than the average ratio in Lower Passaic River sediments of 0.008. This substantive change in the ratio indicates that the Upper Passaic River cannot be the dominant source of mercury to the Lower Passaic River. This is supported by the absolute change in mercury concentrations; the mean mercury concentration in recently-deposited solids in the Upper Passaic River was 0.70 mg/kg whereas the corresponding mean mercury concentration in Lower Passaic River (recently-deposited) surface sediment was approximately 1.5 mg/kg (Table 3-4 and Table 5-3). These two lines of evidence identify the Upper Passaic River as an important but subordinate contributor of mercury relative to the large Lower Passaic River source.

Notably, mercury concentrations in the Upper Passaic River have been relatively constant since about 1990 (Figure 3-6; Bopp 2005 sediment core, Field ID "PASS8B"), indicating that the Upper Passaic River has been an important but subordinate source of mercury to the Lower Passaic River from the present to 1990, and likely prior to that as well.

3.3 Defining an Upper Passaic River Boundary Condition

An evaluation of the contaminant concentrations, flow, and solids loads of the Upper Passaic River relative to observations of recently-deposited sediments in the Lower Passaic River rules out the Upper Passaic River as a substantive source of contamination for many of the compounds of concern. In particular, the Upper Passaic River can be assigned at most a minimal role with respect to 2,3,7,8-TCDD and an important but subordinate role to other sources for contaminants like PCBs, DDT, several pesticides, and the metals cadmium, chromium, copper, lead, and mercury. Among these, PCB contamination originating in the Upper Passaic River plays a relatively more important role than for the other contaminants. For Total PAHs, the greater concentrations observed in the Upper Passaic River relative to the Lower Passaic River indicate that the Upper River is the current dominant source of these contaminants and any recovery of PAH concentrations in recently-deposited sediments of the Lower Passaic River will only occur in response to a decline in the Upper River source. This evaluation of the contaminant contributions by the Upper Passaic River is further explored and better quantified as part of the empirical mass balance model described in Appendix C of the FFS. This characterization of the importance of the Upper Passaic River as a source of the various contaminants of potential concern (COPCs) and contaminants of potential ecological concern (COPECs) also does not account for their importance as risk drivers (*e.g.*, PAHs are not risk drivers for human health risk and are only minor risk drivers for certain ecological receptors, whereas PCBs contribute substantially to the overall human health and ecological risks), which is discussed in Appendix D.

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4 NEWARK BAY BOUNDARY CONDITION

Newark Bay is the downstream or seaward boundary of the Lower Passaic River at RM0 (Figure 4-1). At this boundary, freshwater flow and tidal action causes bi-directional exchange of water, solids, and contaminants between the Lower Passaic River and Newark Bay. The composition of Newark Bay waters, that enter the Lower Passaic River at the RM0 boundary, is influenced by the bay (proper), major tributaries (including the Hackensack River and the Lower Passaic River itself), minor streams entering the bay, and point and non-point source discharges to the bay. Newark Bay is part of the New York-New Jersey Harbor Estuary system and is subject to twice-daily tidal mixing of water, salinity, and transported constituents that can originate from the Hudson River, Upper and Lower New York Harbors, and Raritan Bay through Kill Van Kull and Arthur Kill. This hydrodynamic transport influences sediment and contaminant transport within the bay and across the downstream boundary for the LPRSA. A solids mass balance analysis performed by Lowe *et al.* (2005) indicated that there is net accumulation of solids in Newark Bay on an annual average basis and that a significant portion of the solids delivered to the bay are periodically removed by navigation channel dredging. Dredging has altered bathymetry, impacted flow patterns in the bay, and influenced sediment and contaminant transport patterns over time, thereby affecting the potential return transport of sediments and contaminants from the bay and into the Lower Passaic River.

Because mass transport across the RM0 boundary with Newark Bay is bi-directional, it is important to recognize that contaminants entering the river from the bay are influenced by previous contaminant transport from the Lower Passaic River. Consequently, concentrations of contaminants associated with Newark Bay solids transported across the Lower Passaic River boundary are expected to vary over time in response to changes in sediment and contaminant loads leaving the Lower Passaic River.

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This section considers hydrodynamic, sediment, and chemical transport processes that control the magnitude and nature of bi-directional mass transfers across the Newark Bay boundary with the Lower Passaic River. The descriptions of these processes, as provided in this section, are meant to illustrate how Newark Bay affects the Lower Passaic River.

4.1 Hydrodynamic Transport in Newark Bay

Newark Bay is the downstream or seaward boundary of the Lower Passaic River and connects to the Kill van Kull and Arthur Kill at its downstream end. It also connects to the Hackensack River at its northeastern end. The bay is about 6 miles long and its width varies from 0.6 to 1.2 miles. Its shoreline and bathymetry have been modified extensively since the mid-1800s by dredging and filling. In general, the western part of the bay has navigation channels over 50 ft (15 m) deep and the eastern half of the Bay is shallow with depths less than 10 ft (3 m). Predominant hydrodynamic processes occurring in Newark Bay are tidal and estuarine. The tidal range in the bay is about 1.5 m (5 ft) and predominantly semi-diurnal. Peak tidal currents in the bay are about 0.5 meters per second (m/s)[1.64 ft/s]. Newark Bay receives freshwater inflows from two rivers at its north end (the Passaic and Hackensack Rivers) and saltwater inflow via tidal straits at its south end. In near shore, subtidal flats, wind-induced shear stresses can have a significant impact on local currents and result in near shore waves.

An important bathymetric feature of the Bay is the relatively deep, dredged navigation (or shipping) channel, which crosses the Bay from its northern end at the mouth of the Passaic River to its southern end where it connects with the Kills. Much of this shipping channel (from Port Newark south) is dredged as part of an ongoing operation. It has been progressively deepened over the previous 60 years or longer. Another notable feature of Newark Bay is the subtidal flat region, primarily situated east of the navigational channel and, to a lesser extent, along the west side. Each of the preceding features influences hydrodynamic transport (as well as sediment and chemical transport) within Newark Bay and across its boundary with the Passaic River.

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Newark Bay has been the subject of extensive hydrodynamic (and water quality) investigations in recent years. Investigations by Pence *et al.* (2005), Sommerfield and Chant (2010), and HDR|HydroQual (2011) provide information relevant to hydrodynamic processes in the bay and how bay water interacts with the River. Pence *et al.* (2005) used the monitoring data obtained in the Newark Bay and the Kills between 2000 and 2002 to validate a 3-dimensional hydrodynamic model (ECOMSED) and discussed detailed estuarine circulation patterns occurring in the bay.

Sommerfield and Chant (2010) focused on mechanisms of seasonal and long-term sediment accumulation in Newark Bay and included moored observations of hydrodynamic flow. This study provides information relevant to hydrodynamics within the bay and exchange with the Lower Passaic River. Twelve months of hydrodynamic (and sediment transport) data were collected at six mooring sites on the Lower Passaic River, Hackensack River, Newark Bay, Arthur Kill, and Kill van Kull. Surface salinity at the Newark Bay navigation channel mooring location was more variable than bottom salinity. This was attributed to advection of fresh water from the Passaic River during ebb tides. Stratification in the Bay is persistent under most flow conditions and tends to increase during ebb tides, even during conditions of extremely low freshwater inflow.

One unexpected finding of these investigations was an apparent increase over time in non-tidal exchange flows via the Kill van Kull. Exchange flows (*i.e.*, mean flow from New York Harbor to Newark Bay) approximately doubled from the 1997 to 1998 period to the 2008 to 2009 period (Sommerfield and Chant, 2010). This change in flow was attributed to bathymetric changes associated with actions to deepen the shipping channel and has important implications to the magnitude of suspended sediment delivery to Newark Bay from New York Harbor (Sommerfield and Chant, 2010). Sediment transport results from this study are discussed in the next section of this report.

The bathymetry of Newark Bay has undergone considerable changes over time, primarily related to dredging operations performed to maintain the depth of the shipping channel and also to increase its depth to allow passage of larger ships over time. Hydrodynamic

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simulations performed by HDR|HydroQual (see Appendix B of the FFS) demonstrate how changes in bathymetry may have influenced the strength of tidal currents, residual currents, salinity intrusion, and sedimentation (Figure 4-2). Simulation results indicate that the magnitude of residual currents decreased as channel depth and cross-sectional area increased. The degree of salinity intrusion has also increased. Although changes in the bathymetry of subtidal flats are less pronounced, increased salinity intrusion associated with navigation channel dredging has led to a higher salinity in the shallow flats as well. These results provide a quantitative estimate of how changes in bathymetry influenced the degree of exchange that occurs at the Passaic River boundary with Newark Bay.

4.2 Sediment Transport in Newark Bay

Several studies detail sediment transport processes and sediment budgets for Newark Bay, including Suszkowski (1978), Lowe *et al.* (2005), and Sommerfield and Chant (2010). Sommerfield and Chant (2010) examined mechanisms of seasonal and long-term sediment accumulation in Newark Bay. The study was intended to address sources of fine-grained sediments to the system and the influence that deepening of the navigation (shipping) channel (between dashed lines on Figure 4-1) has had on sediment transport in the system. In addition to 12 months of hydrodynamic and sediment transport data at six mooring locations, the study also included a Bay-wide bathymetric survey, grab samples of sediment from 126 sites (for analysis of sediment physical properties), quarterly seabed coring (10 sites) and vibracoring (7 sites), and a review of historical bathymetry data (1934 to 2008).

Sommerfield and Chant (2010) determined a solids budget for Newark Bay and estimated net inputs of solids of approximately 245,000 cy/yr (approximately 140,000 mt/yr) from Kill van Kull, 30,000 cy/yr (approximately 17,000 mt/yr) from the Lower Passaic River, and approximately 8,750 cy/yr (approximately 5,000 mt/yr) from the Hackensack River. These net solids inputs represent the difference between the flux of solids entering and exiting the bay over time. A net output of approximately 35,000 cy/yr (approximately 20,000 mt/yr) of solids from the bay was estimated to occur via Arthur Kill. In the bay,

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Sommerfield and Chant (2010) reported that the net flux of solids to the north shipping channel (*i.e.*, north of the NB channel station) was approximately 38,500 cy/yr (approximately 22,000 mt/yr). This is much less than the net solids flux of approximately 245,000 cy/yr (approximately140,000 mt/yr) entering the bay from the Kill van Kull and suggests that most of the net sediment input from Kill van Kull does not reach northern Newark Bay. Lowe *et al.* (2005) estimated that the bay sediment budget also includes a small contribution from atmospheric deposition of approximately 300 cy/yr (approximately 170 mt/yr).

With respect to the Lower Passaic River interface with the bay, Sommerfield and Chant (2010) estimated the net solids input as 30,000 cy/yr (approximately 17,000 mt/yr). However, it is important to note that the magnitudes of gross solids fluxes into and out of the Lower Passaic River will control long-term contaminant transport at the River-Bay boundary. Suszkowski (1978) estimated the gross outflux from the River to the Bay to be approximately 72,000 cy/yr (approximately 41,000 mt/yr) and the gross influx from the Bay to the River to be approximately 41,000 cy/yr (approximately 23,000 mt/yr), yielding a net flux into the bay of approximately 31,000 cy/yr (approximately 18,000 mt/yr). This is similar to the net flux of approximately 30,000 cy/yr (approximately 17,000 mt/yr) estimated by Sommerfield and Chant (2010), in spite of the large increases in solids flux at the southern end of the bay during the intervening period, as noted above. As such, it is inferred that the gross flux amounts estimated by Suszkowski (1978) continue to be valid.

As described by Sommerfield and Chant (2010), salinity stratification is relatively persistent in Newark Bay and the degree of stratification tends to increase during ebb tides. This has implications for sediment transport because a high degree of stratification tends to reduce resuspension and resulting sediment transport by currents. Intensification of stratification during ebb tides also promotes trapping of sediment in the northern reaches of Newark Bay. The trapped sediment originates from various sources, including material transported into the Bay from the Passaic River and Kill van Kull.

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Hydrodynamic and sediment transport simulations performed by HDR|HydroQual (see Appendix B of the FFS) also provide information regarding how shear stresses may have changed in response to changes in Newark Bay bathymetry over time. A comparison of simulated shear stresses corresponding to 1949, 1976, and 2008 bathymetry is presented in Figure 4-3 (left to right panels, respectively). As indicated on the 1949 panel, velocities were relatively high because the navigation channel was relatively shallow at that time. Under those conditions, bottom shear stresses of about 5 to 8 Dynes per square centimeter (dynes/cm^2) occur in the navigation channel across the length of the Bay. This may be compared to bottom shear stresses that were typically less than 6 dynes/cm^2 for 1976 bathymetry and less than 4 dynes/cm^2 for 2008 bathymetry. This reduction is likely responsible for an increasing rate of net sediment accumulation and an increased need for maintenance dredging over time. Although bottom shear stress also responds to changes in the magnitude of freshwater inflows to the Bay, bathymetric changes are believed to have had a greater impact on bottom shear stress and sediment transport than year-to-year differences in freshwater inputs. Importantly, it should also be recognized that these analyses did not include the effects of wind-induced shear stresses, which can be significant in shallow-water areas such as nearshore, subtidal flats.

Typical sizes of particles comprising the sediment bed vary across the Bay. Figure 4-4 presents grain size data, expressed as percent sand, for surficial sediments analyzed during the TSI Newark Bay Study, Phases I and II sediment sampling programs (TSI, 2007 and 2008). Areas with relatively high sand contents (*i.e.*, greater than 60 percent) generally occur in shallow tidal flats, such as the northeastern region of the Bay and the area northwest of Shooters Island. Other areas of the Bay typically have lower sand fractions, in the range of 10 to 50 percent. It should be noted that Total Organic Carbon (TOC) tends to vary with grain size. Finer sediments tend to have higher TOC content than coarser sediments. This is important because many contaminants tend to be associated with finer sediments having a relatively high TOC content. Sediment bed composition and other physical characteristics such as TOC are also important factors related to the erosion potential of bed sediments. Spatial patterns in bed characteristics and erosion potentials are expected to influence exchange of sediments (and

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contaminants) between the Passaic River and Newark Bay. Surficial sediments found in the northwest portion of Newark Bay near the mouth of the Passaic River tend to be relatively fine-grained.

4.3 Chemical Characterization of Contaminated Solids in the Bay

Sediment chemistry in Newark Bay was characterized in 2005 and 2007 during low resolution coring programs, conducted under the Phase I and II RI/FS of Newark Bay (TSI, 2007 and 2008). For these programs, cores were collected from 119 locations with the core tops (or "surface sediments") representing 0 to 6 inches of sediment. The chemical data associated with these samples indicate that relatively strong concentration gradients exist longitudinally across Newark Bay for some chemicals (*e.g.*, 2,3,7,8-TCDD and PAHs), from north to south, as contaminated sediments from the Lower Passaic River were mixed with relatively less-contaminated sediment entering Newark Bay from the Kills. These concentration gradients are most apparent in the navigation channels, where maintenance dredging has created deep, quiescent zones that provide an ideal environment for rapid sediment deposition, and where sediment concentrations are less affected by local inputs. Other chemicals (*e.g.*, for mercury and Total PCB) have distributions with local maxima near the intersection of Port Newark Channel and the main channel of Newark Bay as well as at the mouth of the Arthur Kill.

To define the Newark Bay boundary condition, it was necessary to differentiate surface sediment samples that were located in areas defined as recently depositional from sediments that were in non-depositional locations, based on reported activities of Be-7 in the top few centimeters of the samples (Figure 4-5). Locations were characterized as "likely recently-depositional" if the reported Be-7 level was greater than 0.5 picocuries per gram of sediment (pCi/g). This criterion was based on the Be-7 sample detection limits in the TSI Phase I Newark Bay dataset, which ranged from approximately 0.1 to 0.5 pCi/g. Based on this criterion, only 67 of the 119 sampling locations in Newark Bay were classified as Be-7 bearing and represented sites that were likely recently depositional. These depositional locations were located both in the channel and on the

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adjacent shoal areas. The remaining 52 locations were defined as not Be-7 bearing and represented sites that were non-depositional or were experiencing minimal deposition.

Furthermore, a Be-7 limit of 1.0 pCi/g was used to infer conditions representing sites "highly likely" to have recent deposition. Forty-one (41) samples had Be-7 concentrations above the 1.0 pCi/g threshold. In general, samples with the highest Be-7 concentrations were collected from areas within or immediately adjacent to Newark Bay navigation channels. The latter classification is particularly relevant due to the expected relationship that chemical concentrations on Be-7 bearing bottom sediments are comparable to concentrations on suspended sediment.[9] This expected relationship was confirmed by a study of Be-7 bearing sediments and suspended matter for the Lower Passaic River. Descriptions of concentrations and longitudinal gradients for each of the preceding constituents are presented in the following subsections.

4.3.1 TOC

TOC is typically a sorbent to which many contaminants partition. TOC concentrations in bay sediments are presented in Figure 4-6. Locations circled in black (on this and subsequent maps) are judged to be "highly-likely recent depositional locations" (based on Be-7 > 1.0 pCi/g). These locations tend to be situated within the dredged shipping channel. Longitudinal plots of the Be-7 data as a function of distance from the Lower Passaic River mouth (RM0) are presented in Figures 4-7. Distances in the bay away (south) from the River as measured along the axis of the navigation channels are indicated as negative values (*e.g.*, -4.0 is four miles south of the River mouth as measured along the channel). In depositional areas where Be-7 activity is greater than 1.0 pCi/g, TOC concentrations typically range from approximately 1 to 5 percent, with higher concentrations occurring between 6 and 8 miles south of the Lower Passaic River mouth, in the Arthur Kill.

[9] For example, 2,3,7,8-TCDD concentrations on suspended sediment in the Lower Passaic River range from 0.2 to 0.4 µg/kg for most samples and 2,3,7,8-TCDD concentrations in Newark Bay suspended sediments were generally in the range of 0.04 to 0.2 µg/kg. These values are comparable to 2,3,7,8-TCDD concentrations in beryllium-bearing sediments which ranged from 0.2 to 0.5 µg/kg in the Lower Passaic River (MPI, 2008 dataset) and from 0.1 to 0.2 µg/kg in the navigation channel and side slopes in north Newark Bay (TSI, 2005/2007 datasets).

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4.3.2 2,3,7,8-TCDD, PAHs, and PCBs

Spatial distributions of 2,3,7,8-TCDD concentrations in Newark Bay sediments as measured at Phase I and Phase I sampling locations are presented in Figure 4-8. Longitudinal plots of these data as a function of distance from the Lower Passaic River mouth are presented in Figure 4-9. Measurements from depositional areas where Be-7 activity is greater than 1.0 pCi/g (lower left panel) exhibit a strong gradient from the Lower Passaic River mouth through the area 5 miles south of the Lower Passaic River mouth. In the area from 5 to 8 miles south of the River (RM5 to RM8), concentrations are more variable, with higher 2,3,7,8-TCDD concentrations in this area co-occurring with higher TOC concentrations (Figure 4-7). A more extended gradient is evident when concentrations in Lower Passaic River sediments are considered (Figure 4-10). The steepest portion of the gradient extends from RM2 to RM5. Above RM2, a much shallower gradient extends to RM11. Peak 2,3,7,8-TCDD concentrations occur approximately 11 miles upstream of the Lower Passaic River mouth. TOC-normalized 2,3,7,8-TCDD concentrations are presented in Figure 4-11. When TOC-normalized, 2,3,7,8-TCDD concentrations show a gradient of decreasing concentration from the Lower Passaic River mouth through the area 5 miles south of the River. In the reach from 5 to 8 miles south of the River, TOC-normalized 2,3,7,8-TCDD concentrations generally vary in the range of 0.5 to 1.5 ng/g_{oc}. Concentrations from this region (RM5 to RM8), which were elevated relative to concentrations between RM4 and RM5 when displayed on a dry weight basis (Figure 4-9, lower left) are now, with one exception, comparable on a carbon-normalized basis. The relative uniformity of carbon-normalized 2,3,7,8-TCDD concentrations means that the variations in absolute 2,3,7,8-TCDD concentrations are related to variations in the amount of organic carbon in the sediments, not to changes in the level of contamination in the sediments.

Patterns and gradients for 2,3,7,8-TCDD in Newark Bay sediments are qualitatively similar to those that occur for other organic chemicals of interest, including benzo[a]pyrene (BaP; Figures 4-12 through 4-15), LMW PAHs (Figures 4-16 and 4-17), and HMW PAHs (Figures 4-18 and 4-19). As presented in Figure 4-13 and 4-14, benzo[a]pyrene concentrations in depositional areas of Newark Bay sediments generally

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vary in the range of 3,000 to 8,000 µg/kg, decrease to about 3,000 µg/kg just beyond the Lower Passaic River mouth and further decrease to roughly 300 to 400 µg/kg at a point roughly 5 miles south of the Lower Passaic River. In the area from 5 to 8 miles south of the Lower Passaic River, benzo[a]pyrene concentrations appear to increase again from 500 to 1,500 µg/kg, co-occurring with more variable TOC concentrations in this region. Carbon-normalization yields a much more uniform profile between RM3 and RM8 (Figure 4-14, lower left panel). Like 2,3,7,8-TCDD and BaP, LMW PAH (Figures 4-16 and 4-17) and HMW PAH (Figures 4-18 and 4-19) concentrations tend to be higher near the Lower Passaic River mouth and decrease with distance to the area roughly 5 miles south of the Lower Passaic River mouth, the confluence of the Kill Van Kull and the Arthur Kill, then increase in the region with relatively high sediment TOC concentrations in the upper portion of the Arthur Kill.

Total PCB concentrations and longitudinal gradients in Newark Bay sediments are presented in Figures 4-20 through 4-23. Like dioxin and PAHs, PCB concentrations in areas with Be-7 activity greater than 1.0 pCi/g generally tend to decrease with distance south of the Lower Passaic River mouth. However, when these data are TOC-normalized, PCB concentrations tend to be more uniform throughout the Bay. One exception to this general trend occurs around Port Newark. TOC-normalized PCB concentrations from sites within the Port Newark navigation channel are noticeably higher in concentration than samples from other parts of the bay (Figure 4-23, lower left panel).

4.3.3 Pesticides

As a consequence of analytical problems and high detection limits, DDE was the only pesticide consistently detected in surface sediments from the Phase I dataset. Phase II pesticide data do not have the same issues as the Phase I dataset. From this limited number of measurements, no clear concentration gradients are evident within the Bay. However, the Phase I and II data presented on Figure 4-24 indicate that concentrations in the southern part of the Bay are relatively high. The reason for this pattern remains to be evaluated in detail in the on-going Newark Bay Study Area RI/FS.

4.3.4 Metals

Spatial distributions of mercury concentrations in Newark Bay sediments as measured at Phase I and Phase II sampling locations are presented in Figures 4-25 through 4-27. Surficial mercury concentrations in samples from depositional areas (based on Be-7 activity greater than 1 pCi/g) exhibit a gradual decrease in concentration from approximately 2 mg/kg upstream of RM10 in the Lower Passaic River to somewhat less than 1 mg/kg in the southern bay near RM-5. This concentration gradient is less pronounced than the gradients associated with some of the other organic chemicals presented previously. Notably elevated mercury concentrations also occur in the vicinity of the Port Newark channel and in the southern Bay near the Arthur Kill (Figure 4-27, green data symbols). Metals sorb to both mineral phases and to organic matter, and data for mercury concentrations in the bay indicate a reasonably clear correlation of mercury with the TOC content of surficial sediments (Figure 4-28).

The spatial profile for surficial sediment cadmium concentrations within the bay is qualitatively similar to the pattern for mercury. In contrast to these metals, the spatial profile for lead is relatively uniform across the bay (about 100 mg/kg), with somewhat elevated concentrations evident in Port Newark Channel and south of RM-5 in Newark Bay (approximately 180 - 350 mg/kg) (see RI Report for diagrams of cadmium and lead).

4.4 Effect of Mixing on the Newark Bay End Member

Section 4.3 describes the distribution of contamination in Newark Bay and notes the concentration gradient from the northern to southern end of the Bay. In this discussion, the Bay is described as having two end members; that is, two extremes of contaminant concentrations located at each end of the Bay, but not within the Bay itself. However, Newark Bay is not a significant net source of solids to Lower Passaic River and, as noted previously, the Bay serves to accumulate solids originating externally, along with any contamination these solids carry. Thus, a more complete description of Newark Bay needs to consider the factors that determine its contaminant distribution; that is, the solids contribution of the Lower Passaic River, the Kill van Kull, and the Arthur Kill. In the

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analysis that follows, these external areas are considered as end members for Newark Bay. As will be further discussed below, this analysis indicates that the Newark Bay end member to the Lower Passaic River is strongly influenced by the outflow from the Lower Passaic, unlike contributions from the Upper Passaic River, tributaries, CSOs, and SWOs. Note that this model can be applied only to those contaminants that exhibit a single gradient between the Lower Passaic River and the southern end of Newark Bay (*i.e.,* 2,3,7,8-TCDD, Total TCDD, and Total PAHs). The distribution of contaminants such as mercury and PCBs indicate a more complicated source pattern, suggesting at least a three end-member mixing scheme, which is beyond the scope of this analysis. The discussion below considers only 2,3,7,8-TCDD and Total TCDD in the identification of end members to Newark Bay. However, the conclusions regarding the processes that govern contaminant concentrations in recently-deposited sediments in the main channel of the Bay will be applicable to any contaminant whose gradient parallels that of 2,3,7,8-TCDD.

4.4.1 2,3,7,8-TCDD Gradients in the Bay

The 2,3,7,8-TCDD surface sediment concentration scatter plot indicates a north-to-south decreasing gradient in Newark Bay at depositional locations both in the channel and on the shoals (Figure 4-29a). A decreasing 2,3,7,8-TCDD concentration gradient was earlier suggested by Bopp *et al.* (1991), who also showed that this gradient continued through the Kill Van Kull, with the lowest levels of 2,3,7,8-TCDD measured in New York Harbor. Their data indicated that the likely source of the 2,3,7,8-TCDD contamination was the Lower Passaic River.

A similar gradient is observed when examining the 2,3,7,8-TCDD/Total TCDD ratio in surface sediments. This ratio decreases from approximately 0.6 in the northern end of the Bay to 0.3 in the southern end of the Bay (Figure 4-29b). The change in ratio reflects the mixing of highly contaminated Lower Passaic River sediment (having a signature ratio value of 0.7) with relatively less-contaminated sediments (with respect to 2,3,7,8-TCDD) originating from the Upper and Lower New York Bays. The relatively cleaner sediments have a 2,3,7,8-TCDD/Total TCDD ratio more consistent with sewage-based sources and 2,3,7,8-TCDD concentration levels orders of magnitude below the concentrations

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observed in the Lower Passaic River. Elevated surface sediment concentrations observed at the heads of the port channels for other contaminants (*e.g.*, Total PCB and metals) are not observed for 2,3,7,8-TCDD, indicating that, unlike some other contaminants, no major 2,3,7,8-TCDD source exists to Newark Bay other than the Lower Passaic River. Based on absolute concentration and the 2,3,7,8-TCDD/Total TCDD ratio, the distribution of 2,3,7,8-TCDD in Newark Bay can be explained by the mixing of the sediments measured in the source areas located at each end of the bay.

Newark Bay has no large internal source of solids, but rather solids enter from the north (primarily from the Lower Passaic River) and south (mainly from the Kill Van Kull and Arthur Kill) and accumulate within the Bay (Lowe *et al.,* 2005). Given the oblong configuration of the bay and the fact that solids originate at the extreme ends of the bay, a two end-member mixing model provides a useful basis to explain the concentration gradients observed in the recently-deposited surface sediments in the main channel of the bay and better define the Newark Bay/Lower Passaic River boundary condition. To further explore this hypothesis, a numerical two end-member mixing model was formulated using, as end members, the Be-7 bearing surface sediment concentrations measured in samples collected at the extreme southern end of the Bay (representing solids entering from Lower New York Harbor) and the Lower Passaic River.

Because of the strong gradient observed in the absolute 2,3,7,8-TCDD concentration as well as the change in the 2,3,7,8-TCDD/Total TCDD ratio, these compounds form ideal parameters to apply a two end-member mixing model. Moreover, the ratio allows for the tracking of 2,3,7,8-TCDD and Total TCDD simultaneously. Since the geochemistries of these two analytes are essentially identical with respect to sediment-water partitioning, solubility, and persistence in the environment, changes in the 2,3,7,8-TCDD/Total TCDD ratio over distance can only occur by mixing one source with another. Simple dilution with a dioxin-free sediment would only decrease the absolute concentration of both 2,3,7,8-TCDD and Total TCDD simultaneously, leaving the ratio unchanged.

4.4.2 Two End-Member Mixing Model Formulation

The two end-member mixing model for a single constituent is given by a simple algebraic expression based on the fraction of each end member in any given mixture of the two, as follows:

$$C_{mix} = (C_1 \times f_1) + (C_2 \times f_2) \qquad \text{Equation 4-1}$$

where: C_{mix} = contaminant concentration in the final mixture

C_i = contaminant concentration in end member *i*

f_i = fraction of end member *i* in the mixture. (For our purposes here, f_i is assumed to equal the solids mass from end member *i* divided by the total solids mass in a sample.)

Equation 4-1 describes a simple linear relationship between the two end members, such that values for C_{mix} fall on a straight line when plotting concentration against the fraction of one end member in the mixture. When tracking the ratio of two contaminants in a mixture ($R_{A/B}$; such as the ratio of 2,3,7,8-TCDD/Total TCDD), Equation 4-2 is applied to describe the two end-member mixing model:

$$R_{\frac{A}{B}} = \frac{C_A}{C_B} = \frac{(C_{A1} \times f_1) + (C_{A2} \times f_2)}{(C_{B1} \times f_1) + (C_{B2} \times f_2)} \qquad \text{Equation 4-2}$$

Where C_A and C_B refer to the concentrations of contaminant A and B in the two end-members and the subscript numbers refer to the two end-members.

Equation 4-2 is not linear unless the ratio of contaminant A to contaminant B in each end member is identical. In a diagram plotting the ratio ($R_{A/B}$) against the fraction of one end member, the equation describes a curve that depends on the difference in the concentrations and the difference in the ratios. An example is given in Figure 4-30, with end-member concentrations and ratios similar to those observed in Newark Bay. An alternate means of displaying this mixing curve is to plot the ratio ($R_{A/B}$) against the reciprocal of the concentration of one of the contaminants, as shown in Figure 4-31. In

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this alternative presentation, the nearly horizontal and vertical regions of the curve seen in Figure 4-30 are avoided, enabling a better view of the relationship between data and the model. Note that for a true two end-member mixing system where the end-member concentrations and ratios are fixed, there is one unique concentration for each constituent for a given ratio. In the example above, shown in Figure 4-32, a 2,3,7,8-TCDD/Total TCDD ratio of 0.31 uniquely defines a 2,3,7,8-TCDD concentration of 67 µg/kg.

Note that the surface sediments in Newark Bay and the Lower Passaic River have varying grain size distributions. Since the contaminants are associated with the fine-grained material in the sediment, the addition or subtraction of coarser grained material in a sample will dilute or concentrate the fine-grained particles and the contaminants associated with them. To correct individual samples for varying levels of fine-grained sediments, the 2,3,7,8-TCDD concentrations were normalized to iron (which provides an indicator of the fine-grained content in the sediment) prior to use in the mixing model.

4.4.3 2,3,7,8-TCDD/Total TCDD Mixing Model in the Bay

A two end-member mixing model was constructed using Equation 4-2 and the 2,3,7,8-TCDD and Total TCDD values reported in recently-deposited surface sediments in the main portion of the Lower Passaic River (RM2 to RM12) and at the southern end of the Bay. These data yield the dashed model mixing curve shown in Figure 4-32. With the reciprocal of the 2,3,7,8-TCDD/iron ratio (or iron/2,3,7,8-TCDD ratio) plotted on a log scale, a regression on the 2,3,7,8-TCDD/Total TCDD ratio yields a nearly linear relationship, with a linear regression coefficient (R^2) of 0.96. The mixing line extends from Newark Bay to the surface sediment samples that define the Lower Passaic River, using the data from the Lower Passaic River locations as an end member for the system. At the other end of the mixing line are the Newark Bay samples that are located farthest from the Lower Passaic River (or closest to the Kill Van Kull). These samples are used to define the other end member for the mixing curve. Notably the regression line and the mixing curve are quite disparate.

The lack of agreement between the model mixing curve (dashed line in Figure 4-32) and the reported data regression (solid line in Figure 4-32) shows that Newark Bay is not a simple linear mix of the two end members, since the data show a straight line and not a curve between the two end members. Rather, the data indicate a more complex mixing regime of multiple, more localized, mixing curves. Close adherence to a straight line in this diagram is consistent with solids that are mixed over short distances prior to temporarily being deposited, only to be resuspended on an ensuing tide. In this scenario, the end members for any given mixture would have fairly similar 2,3,7,8-TCDD/Total TCDD ratios, describing shorter mixing curves as shown in Figure 4-33. As shown in this figure, three mixing curves approximate the trend observed by the data: two in Newark Bay and one between Newark Bay and the Lower Passaic River. A shorter distance of 1 to 2 miles is covered by the proposed Newark Bay mixing curves, as opposed to 6 miles covered by the single mixing curve for the Lower Passaic River (RM1 to RM7). While the exact mechanism behind these observations has not been confirmed, these mixing lengths appear to coincide with the tidal displacements in the Bay and in the River. (Refer to Appendix B of the FFS for a discussion on the tidal displacement for the Lower Passaic River.)

Also evident in Figure 4-32 (where samples are labeled by their river mile location) is that a large degree of separation exists among the Newark Bay samples, reflecting the long gradient across the Bay. On the other hand, the Lower Passaic River samples are more tightly clustered, while still consistent with the line, reflecting the greatly reduced concentration gradient in the Lower Passaic River relative to Newark Bay.

4.5 Defining a Newark Bay Boundary Condition

The results of the analyses described above are used to identify the Newark Bay boundary condition for the Lower Passaic River, not only for 2,3,7,8-TCDD but for other contaminants as well. While recently-deposited sediment mixtures in Newark Bay appear to be the result of a multistep mixing process that ultimately blends sediments from the Lower Passaic River with southern Newark Bay or Lower New York Harbor, this process takes a relatively long time to move solids northward in the Bay, on the scale of months

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to a year (*i.e.,* the age of the Be-7 bearing sediments). As a result, the sediments that are available day-to-day to mix into the Lower Passaic River are those solids located in the northern portion of the bay, not the solids located in the southern basin of Newark Bay. The southern sediments will likely be deposited and resuspended many times before reaching the mouth of the Lower Passaic River, with incremental changes in chemical character along the way.

Thus, at any given point in time, it is the sediments at the northern end the bay, which have already been transported up through the bay by tidal action to the mouth of the Lower Passaic River, that represent the Newark Bay boundary condition. However, since these sediments represent the mixing of Lower Passaic River and southern Newark Bay solids, they do not constitute a large reservoir of contaminated sediments that can be expected to impact the Lower Passaic River over time. Rather, the contaminant concentrations of this northern Newark Bay end member are tied to the contaminant levels delivered by the Lower Passaic River, particularly for 2,3,7,8-TCDD and Total PAHs, and would be expected to decline to the levels observed in southern Newark Bay in the absence of a Lower Passaic River source. Even contaminant concentrations for mercury and PCBs, which appear to have a Newark Bay source other than the Lower Passaic River, will still be impacted to some degree by what transpires in the Lower Passaic River. The close relationship between concentrations in recently-deposited Lower Passaic River sediments and northern Newark Bay sediments (Figure 4-32) leads to a further conclusion: The contaminant concentrations in northern Newark Bay sediments are expected to decline in parallel to any recovery in the Lower Passaic River.

5 TRIBUTARY BOUNDARY CONDITIONS

The Lower Passaic River receives water and solids from three major tributaries: the Saddle River, the Second River, and the Third River. The boundaries of the Lower Passaic River at the confluences with the tributaries were selected to be at the head-of-tide on each tributary to assure that tidal exchanges of contaminants from the Lower Passaic River did not influence estimates of the tributaries' contributions. On the Saddle River, the properties of solids delivered to the Lower Passaic River were determined at the active USGS gauge station located near the dam in Lodi, New Jersey (3.2 miles upstream of its confluence with the Lower Passaic River). The properties for solids delivered by the Third River were measured at the former USGS gauge station located in Bloomfield, New Jersey (2 miles upstream of its confluence with the Lower Passaic River). This former gauge is positioned upriver of the head-of-tide. On the Second River, the properties for solids were determined near the former USGS gauge station in Belleville, New Jersey, which was located upriver of a low dam, 1.4 miles upstream of its confluence with the Lower Passaic River.

5.1 Solids Load on Tributaries

In the following discussion, estimates of the annual solids load from each of the tributaries are made based on literature values that are adjusted based on drainage basin area. The estimated annual solids loads for the Lower Passaic River tributaries, CSOs, SWOs, and the Upper Passaic River are summarized in Table 5-1.

5.1.1 Saddle River Solids Load

Saddle River is the largest of the tributaries to the Lower Passaic River, with its confluence located at RM15.6. The Saddle River originates in Rockland County, New York, flowing south through the New Jersey municipalities of Lodi, Garfield, and Wallington. Lowe *et al.* (2005) estimated that the solids load carried by Saddle River at Lodi, New Jersey (USGS gauging station 01391500) was approximately 3,700 cy/yr (approximately 2,100 mt/yr). Since this gauging station only accounts for 90 percent of

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the Saddle River watershed (60.4 square miles; USGS, 2007), the solids load was adjusted for the additional watershed area (5.8 square miles) between Lodi, New Jersey and the Lower Passaic River, yielding a solids load of 4,100 cy/yr (approximately 2,300 mt/yr).

5.1.2 Third River Solids Load

The Third River's confluence with the Lower Passaic River is located at RM11.3. The Third River extends through the New Jersey municipalities of Nutley and Clifton. Since no active USGS gauging stations exist on Third River, the solids load was estimated assuming that the solids yield on Third River was similar to the solids yield on Saddle River (68 cubic yards of solids per square mile per year). This assumption is based on the similar settings of the two watersheds. Both rivers drain urban and suburban areas, and would be expected to yield similar amounts of solids per unit area. Based on a watershed of 12.5 square miles [New Jersey Department of Environmental Protection (NJDEP) Hydrologic Unit Code (HUC) database], the Third River yields a solids load of 850 cy/yr (approximately 500 mt/yr; Table 5-1).

5.1.3 Second River Solids Load

The Second River's confluence with the Lower Passaic River is located at RM8.1. The Second River flows through the New Jersey municipalities of Newark, Bloomfield, and Belleville. Like Third River, no active USGS gauging station is located on Second River; hence, the solids load for Second River was estimated considering the solids yield on Saddle River (68 cubic yards of solids per square mile per year). Based on a watershed area of 14.6 square miles (NJDEP HUC database), the Second River yields a solids load of 990 cy/yr (approximately 560 mt/yr; Table 5-1).

5.2 Characterization of Contaminated Solids in Tributaries

The same sampling methods used to characterize the contaminant load for the Upper Passaic River were applied to the three tributaries. These techniques allow for the characterization of tributary solids during three distinct periods of resuspension and

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deposition. Water column sampling provides direct characterization of suspended matter prior to deposition; collection of sediment trap samples with detectable Be-7 concentrations confirms deposition over the past 2 to 4 weeks; and collection of surface sediment samples with detectable Be-7 concentrations confirms deposition within the prior several months. All samples were collected just upriver of the head-of-tide in each tributary to assure that tidal exchanges of contaminants from the Lower Passaic River did not influence estimates of the tributaries' contributions. Refer to Table 5-2 for compilation of tributary data collected during the USEPA/Malcolm Pirnie, Inc. 2007 to 2008 sampling event.

The following section describes the contaminated solids collected at the tributary heads-of-tide, which define the tributary boundary condition. Note that unlike samples collected in Newark Bay, an extensive data evaluation was not necessary for the tributaries since samples collected above head-of-tide represent point sources that are not impacted by tidal mixing or other mechanisms. Moreover, the solids load from the three tributaries (approximately 6,000 cy/yr [approximately 3,300 mt/yr]; Table 5-1) contributes less than 10 percent of the total solids load to the Lower Passaic River. Consequently, following a logic thread similar to that described in Section 3.1 for the Upper Passaic River, contaminant loads from the tributaries can only be important if the mean contaminant concentration is at least an order of magnitude greater than the observed concentration on recently-deposited sediment of the Lower Passaic River. This is because solids loads from the individual tributaries are at least an order of magnitude smaller than the solids load delivered by the Upper Passaic River. The empirical mass balance analysis for the Lower Passaic River, described in Appendix B, confirms this premise. In the following sections, contaminant concentrations from the tributaries (shown in Table 5-2) are compared to concentrations from the Lower Passaic River Be-7 bearing surface sediment (shown in Table 5-3).

5.2.1 2,3,7,8-TCDD in the Tributaries

The 2,3,7,8-TCDD concentrations detected in water column suspended matter, sediment traps, and surface sediments from Saddle River, Second River, and Third River are

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significantly lower than recently-deposited surface sediment concentrations observed in the Lower Passaic River and in Newark Bay (Table 5-2). Figure 5-1 presents the concentrations for the tributaries as well as for the CSOs, SWOs, Newark Bay, Upper Passaic, and Lower Passaic River. The figure series 5-2 through 5-5 provide a similar presentation for the other contaminants described below. The average 2,3,7,8-TCDD concentration for all three tributaries is 3.1 ng/kg, which is more than two orders of magnitude lower than concentrations of 250 ng/kg measured in Lower Passaic River (recently-deposited) surface sediment. Consequently, it can be concluded that the tributaries are not a substantive source of 2,3,7,8-TCDD to the River.

5.2.2 Total PAH in the Tributaries

Total PAH concentrations in water column suspended matter from the tributaries during a storm event ranged from 29 to 600 mg/kg, with measured Total PAH concentrations reaching 790 mg/kg in two samples (Figure 5-2; Table 5-2). Total PAH levels detected in these water column samples are significantly higher than Total PAH concentrations observed in recently-deposited surface sediments of the tributaries, Newark Bay, and the Lower Passaic River. The elevated Total PAH concentrations detected in the water column samples are most likely due to the increased runoff from roads and sewers during the storm event and may not be reflective of the longer-term average concentrations capture by the other two sampling techniques. Therefore, the water column suspended matter samples, which represent solids loads at specific points of time, must be considered accordingly. The mean tributary Total PAH concentration is 150 mg/kg when the water column suspended matter samples are included, which is greater than the recently-deposited surface sediment mean concentrations measured in the Lower Passaic River of 38 mg/kg. However, the mean Total PAH concentration is 52 mg/kg for the tributaries when only the surface sediment and sediment trap samples are included. Given the small amount of solids delivered by the combined tributaries, it is unlikely that they represent a substantive load of PAHs to the Lower Passaic River.

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5.2.3 Total PCB in the Tributaries

Total PCB concentrations ranged from 52 to 1,400 µg/kg for the tributaries (Figure 5-3 and Table 5-2). The mean concentration for all three tributaries was 910 µg/kg (when all samples were considered), which is comparable to the Lower Passaic River Total PCB (recently-deposited) surface sediment concentration (1,000 µg/kg). Similar to observations in the Total PAH data, high-flow, rain-driven sampling events provided the highest recorded Total PCB concentration. When only the surface sediment and sediment trap samples are considered, the mean Total PCB concentration is 52 µg/kg for the tributaries. Like the PAHs, given the small amount of solids delivered by the combined tributaries, it is unlikely that they represent a substantive load of PCBs to the Lower Passaic River.

5.2.4 Pesticides in the Tributaries

For pesticides, depending on the compound, contaminant concentrations measured at the head-of-tide were comparable or higher relative to concentrations reported in recently-deposited surface sediment of the Lower Passaic River (Figure 5-4 series and Table 5-2). For example, the mean dieldrin concentration for all three tributaries (42 µg/kg) was higher than surface sediment concentrations measured in the Lower Passaic River (9 µg/kg). Similarly, the mean aldrin concentration for all three tributaries was slightly higher than Lower Passaic River surface sediment concentrations (2.0 µg/kg versus 1 µg/kg). Conversely, the Total DDx mean concentrations in the tributaries were comparable to the mean recently-deposited surface sediment concentrations in the Lower Passaic River (270 µg/kg versus 110 µg/kg). Because of the small amount of solids delivered by the combined tributaries, and the fact that the pesticides concentrations are not orders of magnitude greater than the Lower Passaic River, it is unlikely that they represent a substantive load of pesticides to the Lower Passaic River.

5.2.5 Metals in the Tributaries

The comparison of metals concentrations collected at the heads-of-tide in the tributaries relative to Lower Passaic River (recently-deposited) surface sediments showed that the

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tributaries do not provide a metals solids load that is sufficient to generate the levels observed in the Lower Passaic River (Figure 5-5 series and Table 5-2). For example, the mean mercury concentration for all three tributaries was 0.44 mg/kg compared to the mean mercury concentration measured in the (recently-deposited) surface sediments in the Lower Passaic River of approximately 2 mg/kg. The mean chromium concentration for all three tributaries was 44 mg/kg while mean chromium concentration in the Lower Passaic River recently-deposited surface sediment concentration was 110 mg/kg.

5.3 Defining Tributary Boundary Conditions

The head-of-tide data collected during the USEPA/Malcolm Pirnie, Inc. 2007 to 2008 sampling event suggest that the tributaries are not a significant source of contaminated solids to the Lower Passaic River for most contaminants. For example, tributary solids concentration for 2,3,7,8-TCDD and metals were lower than recently-deposited surface sediment concentrations measured in the Lower Passaic River. Although Total PAH, aldrin, and dieldrin on the suspended matter collected during the high flow storm event were detected at higher levels than those concentrations measured in the Lower Passaic River, the Total PAH results suggest that long-term average concentrations are closer to those of the Lower Passaic River, indicating the tributaries are not an important source, despite the few high suspended sediment sample results. Since the solids loads from all three tributaries (approximately 6,000 cy/yr [approximately 3,300 mt/yr]; Table 5-1) contribute less than 10 percent of the total solids load to the Lower Passaic River, concentrations on tributary suspended solids would need to be much greater in order for the tributaries to represent a substantive source of PAHs, pesticides, 2,3,7,8-TCDD, and metals. Notably, measured contaminant concentrations for nearly all contaminants were similar among the three tributaries, indicating that for most contaminants in all three watersheds, contaminants loads represent the integration of urban surface and sources, and not industry-related point discharges, which would impact one tributary but not all to the same degree. Consequently, the tributary boundary conditions are defined as the average contaminant concentrations from all three tributaries.

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6 CSO AND SWO DISCHARGE BOUNDARY CONDITIONS

CSO and SWO discharges contribute water, solids load, and contaminant mass to the Lower Passaic River. Leakage or backflow from the River may influence these discharges under certain circumstances, confounding the measurements of contamination and the associated estimates of load. The following section describes the flow and solids flux along with the solids-borne contamination at CSO and SWO discharge points and the subsequent contaminant loading to the water and sediment of the Lower Passaic River.

6.1 Overview of CSO and SWO Discharges

6.1.1 Description of CSO Sampling Locations

CSO systems are designed to collect and convey stormwater, domestic sewage, and industrial wastewater. Under base flow or non-rain conditions, Lower Passaic River CSOs transport primarily domestic and industrial wastewater through the sewerage system to interceptor lines that are connected to the Passaic Valley Sewerage Commission sewage treatment plant (STP) in Newark, where the sewage is treated and then discharged to New York Bay. However, during periods of heavy rainfall or snowmelt, the wastewater volume in the CSO system can exceed the capacity of the STP. CSO systems are designed to overflow under these high volume conditions and discharge the excess flow directly to the River (Figure 6-1). CSO discharges contain not only stormwater but also untreated human and industrial waste and debris. CSO sites along the Lower Passaic River are presented in Figure 6-2.

Five CSO locations (located in Newark, New Jersey between RM3.9 and RM7.8) were sampled during the 2007 to 2008 USEPA/Malcolm Pirnie, Inc. field effort [Figure 6-3 (green circles) and Table 6-1]. These five CSO locations were chosen from the larger group of CSO sites based on the total area contained in the "sewer-shed" (*i.e.,* the size of the sewage drainage area) for a particular CSO. The five selected CSO sites had the largest drainage areas that discharge directly to the Lower Passaic River.

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6.1.2 Description of SWO Sampling Locations

SWO discharges are generated by runoff from land and impervious areas such as paved streets, parking lots, and building rooftops during rainfall and snowmelt events. SWO discharges may also include other contamination sources when associated with illegal connections or spills that may cause other wastewater to enter the system.

SWO sampling locations were selected based on the criterion that the SWO site must discharge directly to the Lower Passaic River and by comparing the size of the SWO drainage area relative to the total acreage of the Lower Passaic River drainage area. Eight SWO locations, covering Newark and Lyndhurst, New Jersey (between RM2.6 and RM11.1), were sampled during the 2007 to 2008 USEPA/Malcolm Pirnie, Inc. field effort [Figure 6-4 (green circles) and Table 6-2].

Since the SWO discharge locations are located below the high tide elevation of the Lower Passaic River, water, and solids from the Lower Passaic River enter these SWO collection systems twice daily during the high tide. Therefore, an effort was made to collect SWO samples during a storm with a coincident low tide event to ensure that water within the SWO piping would be discharging to the River. However, the associated sampling locations selected were apparently below the high tide elevation as well and the solids collected during the 2007 to 2008 sampling event represent a mixture of river-originated solids and SWO-originated solids. (Evidence for this conclusion is discussed below in Section 6.2.1.) Therefore, the SWO samples were not usable for defining contamination on solids originating from the SWOs. The results themselves are still discussed below since, despite this influence, the concentrations are still too low to have any significant impact to the Lower Passaic River. However, for the purposes of modeling, these potentially biased results were rejected in favor of those obtained for the suspended solids from the Second River. Due to the nature of the Second River watershed, which is an urban stream fed primarily by SWO discharge, solids from Second River are considered representative of typical SWO solids and were used to estimate the loads from these outfalls.

6.2 Characterization of Contaminated Solids at CSO and SWO Discharges

The following section describes the CSO and SWO solids and contaminant discharges to the Lower Passaic River. Unlike the evaluation presented for Newark Bay, an extensive data evaluation was not necessary for the CSO and SWO samples because (like the tributaries) they are generally not impacted by tidal mixing or other mechanisms and represent a point discharge.[10] Moreover, the combined solids load from CSO/SWO sites (approximately 2,800 cy/yr[approximately 1,600 mt/yr]; Table 5-1) contributes less than 3 percent of the total solids load to the Lower Passaic River. Given the small solids contribution from these point discharges, and following the same logic as described in Section 3.1 for the Upper Passaic River and Section 5.2 for the tributaries, contaminant loads from the CSOs and SWOs can only be important if the mean contaminant concentration is roughly 25 times greater than the observed concentration on recently-deposited sediment of the Lower Passaic River. This is because the combined solids loads from the CSOs and SWOs are at least 25 times smaller than the solids load delivered by the Upper Passaic River. The empirical mass balance model for the Lower Passaic River, described in Appendix B of the FFS, confirms this premise. As will be discussed below, the CSOs and SWOs represent only minimal discharges for the entire suite of contaminants. In the following sections, contaminant concentrations from the CSOs and SWOs (shown in Tables 6-3 and 6-4) are compared to concentrations from the Lower Passaic River (shown in Table 5-3).

6.2.1 2,3,7,8-TCDD at CSO and SWO Discharges

The mean 2,3,7,8-TCDD concentration measured on suspended solids in CSO samples is approximately 4.1 ng/kg (Table 6-3 and refer also to Figure 5-1), which is approximately two orders of magnitude lower than the mean concentration measured in (recently-deposited) surface sediments in the Lower Passaic River (250 ng/kg). The mean ratio of

[10] While this condition was expected for the SWOs, the sampling locations were not selected so as to avoid the influence of the Lower Passaic River. Although the evidence (discussed later in this section) for estuarine impacts on the SWO samples is clear, the associated concentrations are still not sufficient to constitute a significant source to the Lower Passaic River for any contaminant, as discussed at length below.

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2,3,7,8-TCDD/Total TCDD in the CSO samples was approximately 0.1. This ratio is low compared to the corresponding ratio that was measured for Lower Passaic River sediments (approximately 0.7). Moreover, the ratio measured in Lower Passaic River CSO samples is consistent with Chaky's observation (ratio 0.05) for the Newtown Creek CSO discharge, which is a New York City sewage treatment plant unaffected by Passaic River contamination (Chaky, 2003).

The mean 2,3,7,8-TCDD concentration measured on suspended solids in SWO samples was approximately 20 ng/kg (Table 6-4), which is about one order of magnitude lower than the mean concentration measured in recently-deposited surface sediments in the Lower Passaic River (250 ng/kg). The 2,3,7,8-TCDD concentrations in SWO samples were comparable to concentrations reported in the tributaries (ranging from 0.16 to 12 ng/kg; refer to Section 5.2.1 "2,3,7,8-TCDD in the Tributaries"). However, the 2,3,7,8-TCDD/Total TCDD ratio in SWO samples ranged from 0.1 to 0.8 with a mean of about 0.4 while the ratio in the tributaries ranged from 0.0021 to 0.32 with a mean ratio of 0.1. The measured 2,3,7,8-TCDD/Total TCDD ratio in the SWO samples appeared anomalous because the ratio was expected to be similar to the ratio observed in the tributaries since the drainage areas are similar in nature (*i.e.,* relatively impervious urban areas). As noted earlier in this section, it is likely that most of the SWO samples (collected during the 2007 to 2008 USEPA/Malcolm Pirnie, Inc. field effort) were collected from locations in the pipes below the high tide elevation in the Lower Passaic River and, therefore, were affected by residual solids from tidal exchange. This exchange transported estuarine solids labeled with the River's unique 2,3,7,8-TCDD/Total TCDD ratio into the SWO system. Consequently, the SWO samples actually represent a blend of SWO discharge and Lower Passaic River material. The observations that nearly all SWO samples, regardless of location or river bank (left and right bank), had evidence of the Lower Passaic River ratio and were markedly different from the ratios observed in the tributaries are considered strong evidence of this influence.

Given the small solids loads delivered from the CSO and SWO discharges and the low levels of 2,3,7,8-TCDD on the suspended solids, these discharges are considered minimal sources of 2,3,7,8-TCDD to the Lower Passaic River.

6.2.2 PAH Compounds at CSO and SWO Discharges

The mean concentrations of the LMW PAH, HMW PAH, and Total PAH for the CSO samples are comparable to concentrations measured in recently-deposited surface sediments in the Lower Passaic River (Table 6-3; Figure 5-2). In contrast, the corresponding mean concentrations detected on solids from the SWO samples are about four times higher than surface sediment concentrations measured in the Lower Passaic River (Table 6-4). These concentrations are still much lower than the estimated threshold for a potentially significant load originating with the CSOs and SWOs of 25 times the concentration of recently-deposited Lower Passaic River sediments. Given that the amount of solids discharged from SWO or CSO sites is very small, it is unlikely that the SWOs or CSOs contribute more than a minimal load of PAHs to the surface sediments of the Lower Passaic River.

6.2.3 Total PCB at CSO and SWO Discharges

The mean Total PCB concentrations detected in CSO and SWO samples were about 360 and 670 µg/kg, respectively (Tables 6-3 and 6-4; Figure 5-3). Compared to recently-deposited surface sediments in the Lower Passaic River, which had a mean Total PCB concentration of approximately 1,000 µg/kg, the CSO and SWO Total PCB concentrations were about 30 and 56 percent of the main stem concentrations, respectively. Therefore, the load contribution is negligible.

6.2.4 Pesticides at CSO and SWO Discharges

The pesticide levels on the solids in CSO and SWO discharges are comparable or somewhat greater than to the pesticide levels measured in recently-deposited surface sediment of the Lower Passaic River, depending on the contaminant. For example, the dieldrin mean concentration in the CSO samples (11 µg/kg) is comparable to that of the

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Lower Passaic River (9 µg/kg), but the mean dieldrin concentration in the SWO samples (55 µg/kg) was six times higher than the Lower Passaic River concentration (9 µg/kg). Meanwhile, the mean Total DDx concentration in the Lower Passaic River is approximately 110 µg/kg, compared to 95 µg/kg at CSO sites and 240 at SWO sites (Tables 6-3 and 6-4). Like PAHs, despite the fact that concentrations on these solids are often higher than concentrations measured on recently-deposited surface sediments in the Lower Passaic River, these concentrations are not sufficiently high as to represent a significant contribution. Like the results for the three previous compound classes described above, CSO, and SWO discharges are only minimal sources of pesticides to the Lower Passaic River.

6.2.5 Metals at CSO and SWO Discharges

Metals contamination of CSO and SWO solids fails to meet the threshold for a potentially significant load for all metals. The mean mercury concentrations detected in CSO and SWO samples were about 1.0 and 0.6 mg/kg, respectively. This is about 50 percent lower than the mean mercury concentration on recently-deposited surface sediments in the Lower Passaic River (approximately 2 mg/kg). A similar observation was noted for cadmium, where the mean concentration in recently-deposited surface sediments in the Lower Passaic River (approximately 2 mg/kg) was comparable to the CSO and SWO cadmium concentrations (approximately 2.1 and 1.5 mg/kg, respectively). The mean chromium and lead concentrations in the CSO/SWO samples were comparable to concentrations measured in recently-deposited surface sediments in the Lower Passaic River (Tables 6-3 and 6-4). Like all of the previous contaminants, it is unlikely that the SWOs or CSOs contribute more than a minimal load of metals to the surface sediments of the Lower Passaic River.

6.3 Defining CSO and SWO Discharge Boundary Conditions

Based on the evaluation of the mean contaminant concentrations (from the 2007 to 2008 USEPA/Malcolm Pirnie, Inc. CSO/SWO dataset), CSO and SWO discharges are not a significant source of contamination to the Lower Passaic River. While the CSO and SWO

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discharges are not free of contamination, the volume of contaminated solids and their associated contaminant concentrations are sufficiently low that these discharges can only represent a minimal contribution in comparison to the much larger ones currently driving Lower Passaic River surface sediment contamination. This conclusion contradicts findings of Iannuzzi *et al.* (1996), who concluded that CSO discharges were a source of 2,3,7,8-TCDD to the River. This discrepancy in the characterization of CSO contaminant loads to the River is likely related to the sampling locations chosen by Iannuzzi *et al.* (1996), which failed to properly characterize the CSO contributions. In that study, three CSO sites were sampled that discharged directly to the Lower Passaic River. A fourth CSO site (Ivy Street CSO) that was sampled discharged into a small creek above the head-of-tide.

For the three CSO sites that discharged directly to the River, samples consisted of Lower Passaic River sediments collected near the discharge points rather than sampling suspended solids directly from the CSO. Notably, the contaminant patterns reported for these three CSO sites were similar to the contaminant patterns observed in the surface sediments for the rest of the Lower Passaic River. This observation is not unexpected, since the tidal currents would be expected to disperse the relatively small solids loads from the CSO and deposit Passaic-like solids in the area. (Indeed, the SWO samples obtained by the USEPA/Malcolm Pirnie, Inc. were similarly influenced). Conversely, solids obtained by Iannuzzi *et al.* in the creek near the Ivy Street CSO were not affected by the Lower Passaic River's tidal influence (*i.e.*, they are above the head-of-tide). Data from the Ivy Street CSO, the only site that characterized contaminants coming from a CSO rather than the Lower Passaic River ambient conditions, showed that the Ivy Street CSO was not a significant source of contamination to the River. Based on these observations, the conclusions from Iannuzzi *et al.* regarding the contaminant burden of the CSO discharges are considered incorrect.

6.4 Comparison of the USEPA 2007 to 2008 CSO/SWO Data and 2001 to 2004 CARP Data

Data obtained as part of the Contaminant Assessment and Reduction Program (CARP)[11] were examined to further support the characterization of the contaminant burden from CSO and SWO discharges. These data characterized CSO and SWO point discharges located throughout the Lower Passaic River and Hackensack River during the period 2001 to 2004. Nine CSO locations were sampled during the CARP program. Of these nine locations, five CSO locations are located in the Lower Passaic River watershed, but only one of these five CSO sites discharges directly to the Lower Passaic River. Data from these five CSO sites were used in the subsequent data evaluations (Table 6-5; Figure 6-3). Of the nine original CSO CARP locations, the other four CSO sites discharge into the Hackensack River. Data from these sites were incorporated into the subsequent data evaluation with the assumption that CSO discharges to the Hackensack River would be similar to CSO discharges to the Lower Passaic River, since the drainage areas are characterized by similar levels of industrial, commercial, and residential development. Three SWO discharge points (which are located along the Lower Passaic River) were also sampled during the CARP program (Table 6-5; Figure 6-4).

Contaminant concentration data were received from NJDEP as contaminant mass per liter for whole water. Whole water sample results were then converted to contaminant mass per suspended solids by dividing the whole water sample concentrations by the corresponding total suspended solids (TSS) concentrations. This conversion was considered a conservative approximation of the contaminant concentration per unit mass of suspended solids since a preliminary evaluation using literature partitioning coefficient (K_d) values indicated that the majority of the contaminant mass would be associated with the suspended solids. Thus the detected concentration in a whole water sample was assumed to be approximately equal to the suspended solids-borne fraction. Dividing this result by the TSS concentration provides an upper bound contaminant concentration

[11] CARP is a comprehensive sampling and modeling program sponsored by the Port Authority of New York-New Jersey (and other federal, state, and local agencies, as well as non-governmental groups) to better understand the nature and extent of sediment contamination in the New York-New Jersey Harbor Estuary.

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estimate per unit mass of suspended matter. Analyte results that were reported as non-detect were excluded from this analysis.

The 2001 to 2004 CARP CSO/SWO data were visually compared to the 2007 to 2008 USEPA/Malcolm Pirnie, Inc. CSO/SWO data using box-and-whisker plots for the different contaminants to assess the similarity of the results from the two programs (refer to Figures 6-6 and 6-7). In CSO samples, for all contaminants except Total PCB, the mean concentrations reported in the 2007 to 2008 USEPA/Malcolm Pirnie, Inc. samples were lower than the corresponding concentration reported in the CARP program (Figure 6-5).

A statistical test [Tukey-Kramer Honestly Significant Difference (HSD)] was then performed on the two CSO/SWO datasets to determine if the mean concentrations were significantly different. (Results of the Tukey-Kramer HSD test are provided in Attachment A of Data Evaluation Report No. 4). Based on this statistical test, the mean contaminant concentrations reported in the 2007 to 2008 USEPA/Malcolm Pirnie, Inc. and CARP datasets are not significantly different at the 95th percentile, except for chlordane and the metals. However, for 2,3,7,8-TCDD and PAH compounds in CSO samples, the mean concentrations are significantly different at the 90th percentile. In the SWO samples, no consistent bias was observed between the mean contaminant concentration in the 2007 to 2008 USEPA/Malcolm Pirnie, Inc. samples and the CARP samples (Figure 6-6. Unlike the CSO samples, the mean concentrations in the SWO samples from the two datasets are about the same, except for metals. The Tukey-Kramer HSD test showed that all contaminants, except chlordane and metals, were not statistically different at either the 90th or 95th percentile.

The results show that for the SWO results, the USEPA/Malcolm Pirnie, Inc. and the CARP data are in reasonably good agreement, especially considering the uncertainties introduced by the conversion of the CARP data to a concentration per unit mass of suspended solids. The CSO data do not show the same level of agreement between the two programs. For nearly all contaminants, the CARP data are notably and sometimes

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statistically significantly higher. This may reflect differences in media (whole water versus suspended solids) being measured or analytical differences, such as in the determination of TSS. The comparison is particularly sensitive to this parameter, since all concentrations are divided by it. Alternatively, the difference may reflect the inclusion of non-Passaic River CSO discharges, which may have different contaminant burdens relative to the Lower Passaic River. Only one of the four CSOs sampled under CARP actually discharges to the Lower Passaic River. Nonetheless, the upper-bound concentrations suggested by the CARP data are typically only about 2 to 3 times greater than those for the USEPA/Malcolm Pirnie, Inc. results. In nearly all instances, these concentrations would still not be sufficient to exceed the estimated threshold for a potentially significant load originating with the CSOs and SWOs of 25 times the concentration of recently-deposited Lower Passaic River sediments. While the USEPA/Malcolm Pirnie, Inc. results are more representative (they represent nearly 3,000 acres of Lower Passaic River sewer-shed versus only approximately 800 acres for CARP) and were collected more recently, the conclusions regarding the importance of CSO and SWO discharges remain the same with either data set. CSO and SWO discharges constitute only minimal loads of contaminants to the surface sediments of the Lower Passaic River.

7 OTHER BOUNDARY CONDITIONS

The following section describes the atmosphere and groundwater media as boundary conditions where chemical exchange can occur with the Lower Passaic River. In both cases, a literature and model-based approach is taken to approximate these loads, since direct field measurements are not available. In both instances, the estimated load of contaminants into of the Lower Passaic River at these boundaries is expected to be minimal.

7.1 Groundwater Boundary Condition

In addition to surface water flow, the Lower Passaic River receives groundwater contribution, which is known as "base flow." When precipitation falls within a river's drainage area (or watershed), the majority of the water evaporates, is removed by plants via transpiration, or flows overland to the river. Some water, however, infiltrates to the groundwater table and flows underground until the water enters the river through the sediment bed. Because underground flow encounters greater resistance than overland flow, groundwater moves more slowly. Consequently, surges in base flow from storm events are damped out before they reach the river, and base flow in many rivers is generally constant. While base flow does experience some variations due to seasonal changes and drought conditions, these variations are small compared to the variations observed in the overland flow.

Groundwater discharge to the Lower Passaic River could not be estimated directly because the River is tidal and its net discharge flow cannot be gauged accurately. For this reason, groundwater discharge to the neighboring Elizabeth River, which has a long record of flow gauging and is in the same hydro-geographical setting (*i.e.*, same geology, climate, and urban character), was used as an analogue. The Elizabeth River begins at the border between Union and Essex counties in Hillside, New Jersey. The River flows through Hillside parallel to Morris Avenue and enters the city of Elizabeth, ultimately flowing into the Arthur Kill. Groundwater discharge was estimated by subtracting the

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permitted upland discharge flows from Elizabeth River low flows under dry weather conditions. This estimated base flow discharge was then divided by the Elizabeth River watershed area to estimate a groundwater recharge rate. This Elizabeth River recharge rate was then compared to recharge rates that were calculated for the Second River and Third River using the available short gauging record.[12] This comparison showed that the recharge rates for the three rivers were similar. The groundwater recharge rate determined from the Elizabeth River watershed was then multiplied by the area of the Lower Passaic River's watershed to estimate the groundwater discharge to the Lower Passaic River. The groundwater contribution to the Lower Passaic River, or base flow, was calculated to be about 20 cfs, which is less than 2 percent of the average river flow of 1,200 cfs over the Dundee Dam.

7.2 Estimating Groundwater Contaminant Loads to the Lower Passaic River

7.2.1 Overview of the Estimation Approach Using the Reible Model

An important consideration is whether groundwater that is passing through contaminated sediments contributes a significant contaminant load to the Lower Passaic River water column. Potential groundwater contaminant loads were evaluated using a model described in an appendix to the USEPA document "Guidance for In-Situ Subaqueous Capping of Contaminated Sediments" (Palermo *et al.*, 1998), written by Dr. Danny Reible (known as the "Reible model"). The appendix describes Mathcad formulas used to analyze the pore water (or groundwater) passing through sediment and a sand cap. The same formulas were used to evaluate groundwater contaminant loads to the Lower Passaic River, assuming a non-capped scenario. The report clearly explained all equations and calculations, making it straightforward to convert the Mathcad formulas to a Microsoft Excel spreadsheet. The spreadsheet was validated with input values provided as an example in the Reible model appendix.

[12] Gauging records for Second River and Third River are too short and occurred too long ago to be used as a robust analogue for the Lower Passaic River. Moreover, Saddle River crosses over different hydro-geographic areas, so it is not completely analogous to the Lower Passaic River.

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Since much of the site-specific data necessary for the Reible model were not available for the Lower Passaic River, a Monte Carlo approach was used to estimate the probability of certain outcomes. The Microsoft Excel spreadsheet was placed inside a Monte Carlo engine built using @RISK, an add-on to Microsoft Excel. Data for the model parameters were collected from the existing Lower Passaic River database and from the literature. Where data were not available, professional judgment was used to estimate parameter values. Although some of the parameter ranges could be debated, the model is highly conservative overall. Consequently, minor changes in a specific parameter do not significantly affect the model outcome. The uncertainty in the parameter values is the reason for running a Monte Carlo analysis, which provides a mechanism for converting uncertainty in the input parameters to uncertainty in the outcome.

A Monte Carlo simulation selects random values for each parameter, based on their range and distribution, and then runs the model. This analysis is repeated multiple times, generating 5,000 simulations with equally probable results (based on the reliability of the input data), which can then be used to determine the likelihood of occurrence of a given condition or event. In this analysis, the model results were used to determine the likelihood that groundwater would contribute more than 2 percent, 3 percent, 5 percent, and 10 percent of the River's contaminant load. For example, instead of saying unequivocally that groundwater contributes 2 percent of a given contaminant load, the Monte Carlo approach allows the modeler to report, for example, that there is a 90 percent chance that groundwater contributes less than 2 percent of a given contaminant. This output is based on the percentage of "equally probable" model runs (from random parameter generation) which meet a given condition.

7.2.2 Adjustments to the Reible Model

The following additional changes were made to the Reible model to simulate a non-capped scenario, which was used to model groundwater contributions to the Lower Passaic water column (*i.e.*, to determine whether groundwater passing through contaminated sediments contributes a significant contaminant load to the water column):

- User definition of the time-steps was allowed. The Reible model requires the user to specify the times at which the solution will be calculated. However, when running the model inside a Monte Carlo engine, specifying a time-step is not feasible. Additional user input included the initial time-step size and a multiplier to allow the time-step size to increase with time.
- The steady state condition was defined as the time when the pore water concentration at the sediment-water interface reached 95 percent of the maximum value (*i.e.*, initial pore water concentration in the sediment). The Reible model simply calculated the pore water concentration and flux at any given time. In order to use the Monte Carlo engine, a single number was needed as an output. The Microsoft Excel model calculates the percentage of the initial pore water concentration reaching the sediment-water interface at each time-step. When the percentage reaches 95 percent, the model assumes that a steady state has been reached and prints out a single result for the pore water concentration at the top of the sediment column and the contaminant flux.
- The percent contribution to the river contaminant load was calculated. The Reible model does not calculate a "percent contribution." To assess the load to the River from the sediment column, the steady state contaminant flux was divided by the Lower Passaic River contaminant load to determine its relative importance.[13] This percentage was then reported as an output of the model.

7.2.3 Results of the Reible Model Application and Analysis of Groundwater Contributions

The results of the Reible model, which evaluated the significance of groundwater contribution to Lower Passaic River water column contamination are presented in Table 7-1. These results show that for almost all contaminants, there is virtually no chance that groundwater (or pore water) will contribute more than about 2 percent of the river's contaminant load. The exception is DDE, which was estimated to have less than a 0.1

[13] Although the calculations are not presented here, a rough estimate of the annual solids-borne contaminant load to the Lower Passaic River was prepared by dividing the annual solids solids-borne contaminant load from the Upper Passaic River by the percent contribution from the empirical mass balance model (See Appendix C).

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percent chance that the groundwater could contribute 2 percent or more of the river's contaminant load. It is important to note that this analysis was conducted without the benefit of any site-specific pore water data or seepage velocity measurements. However, because the contaminant loads from other sources are so substantial, even with a conservative approach, the Reible model showed that groundwater is a relatively insignificant source of contamination.

7.3 Atmospheric Boundary Condition

Atmospheric dry and wet deposition and volatilization are not expected to be substantial transport mechanisms for most contaminants, due to the relatively low concentrations associated with atmospheric particles as compared to Lower Passaic River solids concentrations. For example, atmospheric deposition (based on the data available at the New Jersey Atmospheric Deposition Network) cannot yield the observed metals concentrations in the Lower Passaic River (Reinfelder *et al.*, 2004). That is, atmospheric dust does not contain metals at the concentrations observed in the Lower Passaic River recently-deposited sediments.

Atmospheric deposition to the Passaic River watershed would be captured and integrated by the monitoring of loads at the head-of-tide for the tributaries and Upper Passaic River. The additional deposition that takes place directly to the surface of the Lower Passaic River itself is small, by comparison. The drainage area of the Upper Passaic River alone is 810 square miles whereas the surface area of the entire 17.4 miles of the Lower Passaic River is 940 acres or about 1.5 square miles.

Estimated contaminant concentrations associated with atmospheric deposition at Dundee Dam are presented in Table 7-2 for various analytes. The percentage of atmospheric flux relative to contaminant concentrations measured on solids being transported over Dundee Dam from the Upper Passaic River shows that atmospheric deposition is not a substantial source of contamination to the Lower Passaic River since the percentages for nearly all contaminants with literature data were below 2 percent. Only Total PCB, trans-chlordane, and dieldrin had higher contributions at 14, 13, and 7 percent, respectively. While this

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calculation could not be done for 2,3,7,8-TCDD, the work conducted by Chaky (2003) rules this pathway out. In Chaky's work, the 2,3,7,8-TCDD/Total TCDD ratio for atmospheric deposition was reported to be less than 0.06. Lower Passaic River sediment samples possessing these low ratios were observed in pre-1940s sediment deposits, and corresponding absolute concentrations of 2,3,7,8-TCDD were orders of magnitude lower than the post-1940s sediment deposits. Additionally, Chaky reported that recently-deposited sediments (mid-1990s) in a lake in Central Park in Manhattan had concentrations of 2,3,7,8-TCDD of 11 ng/kg. Since this lake has little water shed, the 2,3,7,8-TCDD contamination is considered entirely atmospherically derived. It would be expected that concentrations in Lower Passaic River sediments could not exceed this level if atmospheric deposition were the only flux of this contaminant. These observations all indicate that atmospheric deposition is a minimal source of contamination to the Lower Passaic River relative to the other contributors.

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8 ACRONYMS

2,3,7,8-TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
BaP	Benzo[a]pyrene
Be-7	Beryllium-7
BZ	Ballschmiter and Zell
CARP	Contaminant Assessment and Reduction Program
cfs	cubic feet per second
COPCs	Contaminants of Potential Concern
COPEC	Contaminants of Potential Ecological Concern
CPG	Cooperating Parties Group
CSO	Combined Sewer Overflow
cy/yr	cubic yards/year
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
DDx	The sum of 4,4'DDD, 4,4'-DDE, and 4,4'-DDT
Dynes/cm^2	Dynes per square centimeter
FFS	Focused Feasibility Study
ft	feet
HMW	High Molecular Weight
HSD	Honestly Significant Difference
HUC	Hydrologic Unit Code
K_d	Partitioning Coefficient
KVK	Kill Van Kull
LMW	Low Molecular Weight
LPRSA	Lower Passaic River Study Area
m/s	meter per second
mg/kg	milligrams per kilograms of sediment
mt/yr	metric tons/year
ng/kg	nanograms per kilograms of sediment

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NJDEP	New Jersey Department of Environmental Protection
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
pCi/g	picocuries per gram of sediment
R	Correlation Coefficients
R^2	Linear Regression Coefficient
RI	Remedial Investigation
RI/FS	Remedial Investigation and Feasibility Study
RM	River Mile
STP	Sewage Treatment Plant
SWO	Stormwater Outfall
TOC	Total Organic Carbon
Total TCDD	Total Tetrachlorodibenzo-p-dioxin
TSI	Tierra Solutions, Inc.
TSS	Total Suspended Solids
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
µg/kg	micrograms per kilograms of sediment
yr	Year

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TABLES

Table 3-1: Flow Statistics for the Little Falls USGS Gauging Station

Year[a]	Annual Average River Flow (cfs)[b]	Annual Peak River Flow (cfs)[b]
1995	660	4,900
1996	1,800	9,300
1997	840	4,900
1998	1,100	8,800
1999	830	11,000
2000	900	3,400
2001	700	4,500
2002	450	3,100
2003	1,900	7,200
2004	1,200	4,100
2005	1,400	12,000
2006	1,400	6,300
2007	1,200	16,000
2008	1,300	7,500
2009	1,100	5,400
2010	1,300	16,000
2011	2,600	21,000
Average from 1995 to 2011	1,200	8,500
Average from 1956 to 2011	1,100	7,500
Minimum from 1956 to 2011	270	3,100
Maximum from 1956 to 2011	2,600	21,000

a: Annual average data is calculated from January 1 to December 30.

b: Data source: USGS National Water Information System (http://waterdata.usgs.gov/nwis/dv/?referred_module=sw. Site last accessed February 2, 2007). The site is 01389500 Passaic River (Little Falls, New Jersey).

Table 3-2: Qualitative Assessment of the Relative Importance of Upper Passaic River Loads based on Solids–Borne Contaminant Concentrations

Contaminant Concentrations in Recently-Deposited Sediments of the Upper and Lower Passaic River	Relative Contaminant Contribution of Upper Passaic River to the Lower Passaic River Annual Sediment Contaminant Burden	Scenario	Example Contaminant
[UPR] << [LPR]	Minimal contributor.	Upper Passaic River solids have a negligible load and serve largely to dilute solids contaminant burden originating elsewhere.	2,3,7,8-TCDD
[UPR] is >10% of [LPR] value but <25% of [LPR] value	Minor contributor, probably less than 25 percent of the total contaminant load.	Upper Passaic River solids deliver a meaningful load but the majority of the Lower Passaic River loading originates elsewhere.	None identified
[UPR] is >25% of [LPR] value but <75% of [LPR] value	Important contributor.	Upper Passaic represents a load that is substantive in comparison to the contributions originating downstream.	PCBs, cadmium, chromium, copper, lead, mercury, some pesticides
[UPR] is >75% of the [LPR] value but less than 125% of the LPR value	Major contributor.	Upper Passaic River load is probably the greatest load of the contaminant to the Lower Passaic River. Other sources may be important but no individual load is likely to be greater. Further analysis of other sources is needed to refine the relative contributions.	Some pesticides
[UPR] is >125% of the [LPR] value	Dominant contributor.	Upper Passaic River load represents the single largest contribution of the contaminant. Other sources of solids to the Lower Passaic River serve to dilute the solids burden delivered by the Upper Passaic River.	PAHs

Note: [UPR] = Upper Passaic River concentration, [LPR] = Lower Passaic River concentration.

Table 3-3: Upper Passaic River Be-7 Bearing Surface Sediment Contaminant Concentrations (0-1inch)

Sampler	Sample ID	Field Name	2,3,7,8-TCDD	Total TCDD	Aldrin	Dieldrin	Total Chlordane (cis & trans)	Trans Chlordane	Total DDT (DDD, DDE, and DDT)	DDE	Total Endrin (Endrin Ketone, Endrin, and Endrin aldehyde)	Benzo[a]pyrene
USEPA	LPRP-LVCG-DDL-000004	Water Column Suspended Matter (Field ID: Ackerman Bridge)	0.0046	0.0517	3.0	50	130	120	130	38	1.3	11,000
USEPA	LPRP-LVCG-DDL-000006	Water Column Suspended Matter (Field ID: Ackerman Bridge)	0.0040	0.0156	2.7	0	120	120	120	29	1.7	7,900
USEPA	LPRP-SCSH-DDL-000018	Dundee Lake Core Top (Field ID: Dundee Core 2)	0.0020	0.0734	1.7	4.3	92	47		26		7,100
USEPA	LPRP-SCSH-DDL-000068	Dundee Lake Core Top (Field ID: Dundee Core 6)	0.0019	0.0369	0.83	3.2	42	21		14		3,500
USEPA	LPRP-SCSH-PSR-001579	Surface Sediment (Field ID: SurSed Dundee-2)										
USEPA	LPRP-SCSH-PSR-001589	Surface Sediment (Field ID: SurSed Dundee-4)										
USEPA	LPRP-SCSH-PSR-001590	Surface Sediment (Field ID: SurSed Dundee-3)	0.0029	0.0552	0.92	4.3	41	19	30	13	0.031	5,900
USEPA	LPRP-SCSH-PSR-001602	Surface Sediment (Field ID: SurSed Dundee-1)	0.0014	0.0305	0.73	3.3	29	14	25	8.9	0.051	4,700
USEPA	LPRP-SCSH-PSR-001604	Surface Sediment (Field ID: SurSed Dundee-1 Dup)	0.0028	0.0617	1.2	6.0	52	25	40	16	0.074	10,000
USEPA	LPRP-SCSH-PSR-001607	Sediment Trap (Field ID: PSR SedTrap#1)	0.0016	0.0312	0.72	11	52	24	39	11	0.30	5,200
USEPA	LPRP-SCSH-PSR-001663	Sediment Trap (Field ID: PSR SedTrap#2)	0.0016	0.0260	0.54	12	55	26	35	9.3	0.39	3,700
Bopp	LPRP-SCSH-DDL-000143	Dundee Lake Core Top (Field ID: Bopp PASS8B)	0.0010	0.0275	0.44	3.8	31	15	22	7.5	0.062	5,100
Bopp	LPRP-SCSH-DDL-000153	Dundee Lake Core Top (Field ID: Bopp PASS8BP)	0.0016	0.0337	1.5	3.1	39	19	25	10	0.032	5,800
Average			**0.0023**	**0.0403**	**1.3**	**10**	**62**	**41**	**54**	**17**	**0.4**	**6,300**

Sampler	Sample ID	Field Name	Chrysene	Fluoranthene	Pyrene	HMW PAH	LMW PAH	Total PAH	Total PCB	Aluminum	Arsenic	Cadmium
USEPA	LPRP-LVCG-DDL-000004	Water Column Suspended Matter (Field ID: Ackerman Bridge)	14,000	20,000	17,000	110,000	12,000	130,000	540	49,000,000	13,000	2,900
USEPA	LPRP-LVCG-DDL-000006	Water Column Suspended Matter (Field ID: Ackerman Bridge)	11,000	16,000	14,200	90,000	9,500	100,000	370	37,000,000	18,000	4,500
USEPA	LPRP-SCSH-DDL-000018	Dundee Lake Core Top (Field ID: Dundee Core 2)	8,200	11,000	11,200	65,000	9,400	74,000	1,500	7,900,000	4,300	2,200
USEPA	LPRP-SCSH-DDL-000068	Dundee Lake Core Top (Field ID: Dundee Core 6)	4,000	7,000	6,600	36,000	5,200	41,000	590	6,400,000	2,000	1,800
USEPA	LPRP-SCSH-PSR-001579	Surface Sediment (Field ID: SurSed Dundee-2)								8,500,000	2,900	1,500
USEPA	LPRP-SCSH-PSR-001589	Surface Sediment (Field ID: SurSed Dundee-4)								6,400,000	2,300	1,100
USEPA	LPRP-SCSH-PSR-001590	Surface Sediment (Field ID: SurSed Dundee-3)	6,800	8,300	8,700	52,000	6,000	58,000	430	7,300,000	2,500	1,300
USEPA	LPRP-SCSH-PSR-001602	Surface Sediment (Field ID: SurSed Dundee-1)	5,200	7,600	7,500	43,000	7,200	51,000	240	6,900,000	2,400	1,000
USEPA	LPRP-SCSH-PSR-001604	Surface Sediment (Field ID: SurSed Dundee-1 Dup)	10,000	16,000	15,000	87,000	17,000	100,000	520	6,100,000	3,200	1,000
USEPA	LPRP-SCSH-PSR-001607	Sediment Trap (Field ID: PSR SedTrap#1)	6,000	8,000	8,300	49,000	7,200	56,000	260	8,700,000	3,600	1,600
USEPA	LPRP-SCSH-PSR-001663	Sediment Trap (Field ID: PSR SedTrap#2)	4,400	6,000	6,200	36,000	5,700	41,000	220	6,200,000	2,300	1,700
Bopp	LPRP-SCSH-DDL-000143	Dundee Lake Core Top (Field ID: Bopp PASS8B)	6,000	9,000	8,800	53,000	7,100	60,000	280		2,700	1,400
Bopp	LPRP-SCSH-DDL-000153	Dundee Lake Core Top (Field ID: Bopp PASS8BP)	6,300	9,000	8,900	58,000	6,400	64,000	710		3,800	1,900
Average			**7,500**	**11,000**	**10,000**	**62,000**	**8,400**	**70,000**	**510**	**14,000,000**	**4,800**	**1,800**

Sampler	Sample ID	Field Name	Chromium	Copper	Iron	Lead	Mercury	Nickel
USEPA	LPRP-LVCG-DDL-000004	Water Column Suspended Matter (Field ID: Ackerman Bridge)	100,000	200,000	53,000,000	330,000	700	57,000
USEPA	LPRP-LVCG-DDL-000006	Water Column Suspended Matter (Field ID: Ackerman Bridge)	90,000	260,000	51,000,000	390,000	460	53,000
USEPA	LPRP-SCSH-DDL-000018	Dundee Lake Core Top (Field ID: Dundee Core 2)	34,000	80,000	18,000,000	140,000	720	21,000
USEPA	LPRP-SCSH-DDL-000068	Dundee Lake Core Top (Field ID: Dundee Core 6)	23,000	68,000	17,000,000	160,000	1,000	19,000
USEPA	LPRP-SCSH-PSR-001579	Surface Sediment (Field ID: SurSed Dundee-2)	31,000	70,000	15,000,000	140,000	660	20,000
USEPA	LPRP-SCSH-PSR-001589	Surface Sediment (Field ID: SurSed Dundee-4)	25,000	59,000	13,000,000	110,000	460	15,000
USEPA	LPRP-SCSH-PSR-001590	Surface Sediment (Field ID: SurSed Dundee-3)	25,000	55,000	13,000,000	120,000	740	16,000
USEPA	LPRP-SCSH-PSR-001602	Surface Sediment (Field ID: SurSed Dundee-1)	22,000	44,000	13,000,000	87,000	500	14,000
USEPA	LPRP-SCSH-PSR-001604	Surface Sediment (Field ID: SurSed Dundee-1 Dup)	21,000	49,000	12,000,000	100,000	430	18,000
USEPA	LPRP-SCSH-PSR-001607	Sediment Trap (Field ID: PSR SedTrap#1)	31,000	70,000	17,000,000	150,000	1,800	19,000
USEPA	LPRP-SCSH-PSR-001663	Sediment Trap (Field ID: PSR SedTrap#2)	31,000	56,000	14,000,000	140,000	470	15,000
Bopp	LPRP-SCSH-DDL-000143	Dundee Lake Core Top (Field ID: Bopp PASS8B)	46,000	62,000	23,000,000	140,000	590	22,000
Bopp	LPRP-SCSH-DDL-000153	Dundee Lake Core Top (Field ID: Bopp PASS8BP)	51,000	79,000	23,000,000	140,000	570	27,000
Average			**41,000**	**89,000**	**22,000,000**	**170,000**	**700**	**24,000**

Notes:
- All units are in micrograms per kilogram (ug/kg).
- It is recognized that contaminants with more than a minor contribution to the Lower Passaic River pose the prospect of recontamination after an early action remedy for the lower 8 miles is implemented. This issue is addressed in detail in Appendix C (Mass Balance Modeling Analysis) and Appendix B (Modeling) of the FFS.

Table 3-4: Summary Statistics for Upper Passaic River Contaminant Concentrations (0-1 inch)

Analysis Columns	Unit	Count	Minimum	Maximum	Mean	Median	Standard Deviation	Covariance (%)
2,3,7,8-TCDD	ng/kg	11	1.0	4.6	2.3	1.9	1.1	50
Total TCDD	ng/kg	11	16	73	40	34	18	44
Ratio 2,3,7,8-TCDD/Total-TCDD	unitless	11	0.027	0.25	0.069	0.050	0.063	91
PCB 24+27	ug/kg	11	0.32	13	2.0	0.68	3.7	188
PCB 31	ug/kg	11	3.3	31	9.5	7.0	8.2	85
PCB 50+53	ug/kg	11	1.0	9.2	2.7	1.8	2.4	88
PCB 52+69	ug/kg	11	6.5	49	15	12	12	84
PCB 61+70+74+76+66	ug/kg	11	9.0	113	29	19	29	103
PCB 83+99	ug/kg	11	4.5	31	9.9	7.8	7.6	77
PCB 90+101+113	ug/kg	11	7.6	51	18	14	12	70
PCB 93+95+98+100+102	ug/kg	11	6.2	45	15	12	11	74
PCB 110+115+111	ug/kg	11	9.3	53	20	18	12	61
PCB 129+138+158+160+163+164	ug/kg	11	12	67	27	25	16	61
PCB 139+140+149+147	ug/kg	11	8.1	50	18	16	12	68
PCB 170	ug/kg	11	2.4	16	5.7	4.5	4.0	71
PCB 180+193	ug/kg	11	5.5	41	14	11	10	76
PCB 196+203	ug/kg	11	2.1	14	5.1	5.1	3.4	67
Total PCB	ug/kg	11	220	1,500	510	430	360	70
Acenaphthene	mg/kg	11	0.26	0.91	0.47	0.40	0.20	43
Acenaphthylene	mg/kg	11	0.27	1.3	0.70	0.69	0.29	42
Anthracene	mg/kg	11	0.68	2.4	1.1	0.98	0.46	40
Fluorene	mg/kg	11	0.23	0.80	0.37	0.36	0.16	44
Naphthalene	mg/kg	10	0.29	1.1	0.56	0.49	0.23	40
Phenanthrene	mg/kg	11	3.2	10	5.2	4.4	2.2	42
Benz[a]anthracene	mg/kg	11	3.0	8.5	4.9	4.7	1.6	33
Benzo[a]pyrene	mg/kg	11	3.5	11	6.3	5.8	2.4	37
Benzo[g,h,i]perylene	mg/kg	11	2.2	9.4	4.4	3.5	2.3	52
Benzo[j,k]fluoranthene	mg/kg	11	3.3	13	6.2	5.0	3.0	49
Benzo[j]fluoranthene	mg/kg	11	3.0	12	6.5	5.9	3.1	48
Chrysene	mg/kg	11	4.0	14	7.5	6.3	3.1	42
Dibenz[a,h]anthracene	mg/kg	11	0.66	1.5	1.0	0.98	0.31	29
Fluoranthene	mg/kg	11	6.0	19	11	8.6	4.3	41
Indeno[1,2,3-c,d]-pyrene	mg/kg	11	2.3	9.3	4.4	3.6	2.2	50
Pyrene	mg/kg	11	6.2	17	10	8.8	3.7	36
LMW PAH	mg/kg	11	5.2	17	8.4	7.2	3.4	40
HMW PAH	mg/kg	11	36	110	62	53	25	40
Total PAH	mg/kg	11	41	130	70	60	28	39
DDD	ug/kg	11	11	59	22	17	15	66
DDE	ug/kg	11	7.5	38	17	13	10	61
DDT	ug/kg	11	2.8	62	16	5.5	22	140
Total DDT	ug/kg	11	22	133	54	37	41	75
Aldrin	ug/kg	11	0.44	3.0	1.3	0.92	0.85	66
Dieldrin	ug/kg	10	3.1	50	10	4.3	14	140
Trans-Chlordane	ug/kg	11	14	120	41	24	40	98
Arsenic	mg/kg	13	2.0	18	4.8	2.9	4.9	100
Cadmium	mg/kg	13	0.95	4.5	1.8	1.6	0.95	52
Chromium	mg/kg	13	21	100	41	31	26	64
Cobalt	mg/kg	13	6.0	17	9.9	8.7	3.3	33
Copper	mg/kg	13	44	260	89	68	65	73
Iron	mg/kg	13	12,400	53,000	22,000	17,000	14,000	64
Lead	mg/kg	13	87	390	170	140	91	55
Mercury	mg/kg	13	0.43	1.8	0.70	0.59	0.37	52
Nickel	mg/kg	13	14	57	24	19	14	57
Zinc	mg/kg	11	210	800	370	270	200	55
Total Organic Carbon	mg/kg	11	24,000	160,000	58,000	37,000	49,000	85

Note:
Data associated with a laboratory qualifier containing a "U" were considered to be not detected and were set equal to half of method detection limit and incorporated into statistics.

Table 3-5: Metals Ratios in Surface Sediments for Upper Passaic River and Lower Passaic River

River Location		Mercury/Lead	Cadmium/Lead	Copper/Lead
Lower Passaic River	RM1.4	0.011	0.017	0.73
	RM2.2	0.007	0.016	0.63
	RM7.8	0.010	0.017	0.73
	RM11	0.009	0.019	0.76
	RM12.6	0.005	0.015	0.67
	Mean	0.0084	0.017	0.70
Upper Passaic River	~RM17.4	0.0045	0.015	0.56

Table 5-1: Estimated Solids Load and Corresponding Watershed Area for the Lower Passaic River Boundary Conditions

Source to the Lower Passaic River	Solids Load (cubic yards/year)	Watershed Area (square miles)
Upper Passaic River	73,000	810
Saddle River	4,100	60
Third River	850	13
Second River	990	15
CSO plus SWO (ungauged)	2,800	43

Values were rounded to two significant figures.

Table 5-2: Summary Statistics for Tributary Contaminant Concentrations

Analytes	Unit	Third River						
		Count	Minimum	Maximum	Mean	Median	Standard Deviation	Covariance (%)
2,3,7,8-TCDD	ng/kg	6	1.7	5.0	2.8	2.2	1.3	48
Total PCB[a]	ug/kg	6	850	1,400	1,100	1,100	170	16
Total PAH[a]	mg/kg	6	47	320	110	59	110	97
DDD	ug/kg	6	46	130	97	99	32	33
DDE	ug/kg	6	35	120	67	54	34	51
DDT	ug/kg	6	28	220	120	130	84	70
Aldrin	ug/kg	6	0.59	2.5	1.5	1.4	0.65	44
Dieldrin	ug/kg	6	7.7	100	46	41	38	82
Chromium	mg/kg	6	27	72	47	39	19	42
Mercury	mg/kg	6	0.29	1.8	0.79	0.64	0.57	73

Note: Data was collected in 2007-2008

Table 5-3. Summary Statistics for 1995, 2007-2008 USEPA and 2008 CPG Surface Sediments from Be-7 Bearing Locations

Program	River Mile		RM0 to RM8							RM8 to RM12							RM12 to RM17.4						
	Chemical Parameters	Unit	Count	Min	Max	Mean	Median	Std Dev	Std Err	Count	Min	Max	Mean	Median	Std Dev	Std Err	Count	Min	Max	Mean	Median	Std Dev	Std Err
1995 TSI 0-6 inch samples with Be-7 at the surface (0-2 in)	2,3,7,8-TCDD	pg/g	14	25.0	1,580	387	303	368	98.5														
	Total TCDD	pg/g	14	28.4	1,660	482	410	378	101														
	Total PCBs	ug/kg	14	94.5	2,566	938	857	663	177														
	Aldrin	ug/kg	12	0.99	2.8	2.1	2.2	0.54	0.16														
	Dieldrin	ug/kg	13	1.9	44.4	18.9	19.3	12.8	3.6														
	4,4'-DDD	ug/kg	13	18.2	76.4	47.7	39.4	18.7	5.2														
	4,4'-DDE	ug/kg	14	6.7	93.9	45.3	35.5	25.6	6.8														
	4,4'-DDT	ug/kg	14	1.9	111	39.2	30.2	31.6	8.5														
	Total DDx	ug/kg	14	6.8	353	165	150	91.3	24.4														
	Total Chlordane	ug/kg	10	2.2	80.0	37.8	41.3	25.6	8.1														
	HMW PAH	mg/kg	14	6.8	22.1	14.4	15.2	5.5	1.5														
	LMW PAH	mg/kg	14	0.50	2.5	1.4	1.5	0.74	0.20														
	Total PAHs	mg/kg	14	6.8	24.6	15.7	16.9	6.4	1.7														
	Aluminum	mg/kg	14	3,590	22,100	13,574	13,600	5,263	1,406														
	Cadmium	mg/kg	14	0.29	6.8	4.2	4.1	1.5	0.39														
	Chromium	mg/kg	14	20.6	207	130	131	43.3	11.6														
	Copper	mg/kg	14	35.8	275	184	184	57.3	15.3														
	Iron	mg/kg	14	14,900	36,900	27,393	27,600	6,169	1,649														
	Lead	mg/kg	13	218	665	342	304	121	33.7														
	Mercury	mg/kg	14	0.34	4.4	2.8	2.8	0.99	0.27														
2007-2008 EPA Be-7 Bearing Samples (0-1 in)	2,3,7,8-TCDD	pg/g	7	175	360	249	248	68.5	25.9	2	461	543	502	502	58.0	41.0	2	10.0	127	68.5	68.5	82.7	58.5
	Total TCDD	pg/g	7	274	525	375	383	92.3	34.9	2	628	701	665	665	51.6	36.5	2	40.6	186	113	113	103	72.7
	Total PCBs	ug/kg	7	755	1,300	1,024	1,010	197	74.5	2	1,420	1,590	1,505	1,505	120	85.0	2	555	560	558	558	3.5	2.5
	Aldrin	ug/kg	7	0.42	1.2	0.82	0.84	0.29	0.11	2	1.8	1.9	1.9	1.9	0.04	0.03	2	1.1	1.4	1.2	1.2	0.18	0.13
	Dieldrin	ug/kg	7	5.2	13.8	9.1	8.4	2.7	1.0	2	17.2	18.0	17.6	17.6	0.57	0.40	2	10.3	22.1	16.2	16.2	8.3	5.9
	4,4'-DDD	ug/kg	7	30.3	81.4	46.7	43.8	16.9	6.4	2	52.0	54.9	53.5	53.5	2.1	1.5	2	12.7	22.2	17.5	17.5	6.7	4.8
	4,4'-DDE	ug/kg	7	36.5	60.2	45.1	44.7	8.7	3.3	2	59.6	61.4	60.5	60.5	1.3	0.90	2	12.1	22.8	17.5	17.5	7.6	5.4
	4,4'-DDT	ug/kg	7	6.8	36.2	17.7	14.6	11.2	4.2	2	20.5	24.5	22.5	22.5	2.8	2.0	2	8.1	9.6	8.8	8.8	1.0	0.73
	Total DDx	ug/kg	7	81.8	178	109	103	32.4	12.2	2	132	141	136	136	6.2	4.4	2	32.9	54.6	43.7	43.7	15.3	10.8
	Total Chlordane	ug/kg	7	43.6	84.2	64.3	63.5	15.2	5.7	2	109	122	116	116	9.3	6.6	2	54.4	63.5	59.0	59.0	6.4	4.6
	HMW PAH	mg/kg	7	27.2	48.3	33.2	30.4	7.3	2.7	2	32.0	44.1	38.0	38.0	8.5	6.0	2	29.7	36.6	33.2	33.2	4.9	3.4
	LMW PAH	mg/kg	7	3.8	6.3	4.6	4.4	0.88	0.33	2	4.2	5.7	4.9	4.9	1.0	0.74	2	3.8	5.4	4.6	4.6	1.1	0.79
	Total PAHs	mg/kg	7	31.0	54.6	37.8	34.7	8.1	3.1	2	36.2	49.7	43.0	43.0	9.6	6.8	2	33.6	42.0	37.8	37.8	6.0	4.2
	Aluminum	mg/kg	21	3,750	20,600	12,777	12,600	4,156	907	5	14,300	19,200	16,360	16,100	1,905	852	5	5,300	17,200	9,074	7,000	4,796	2,145
	Cadmium	mg/kg	21	0.22	4.4	2.4	2.5	1.1	0.23	5	3.6	4.4	4.1	4.2	0.34	0.15	5	0.80	4.1	1.9	1.3	1.3	0.59
	Chromium	mg/kg	21	0.02	148	83.3	85.5	35.2	7.7	5	103	138	123	127	13.5	6.0	5	22.3	118	53.3	33.9	39.1	17.5
	Copper	mg/kg	21	0.21	205	110	121	55.6	12.1	5	160	198	186	191	14.9	6.7	5	41.1	179	87.2	61.7	56.0	25.1
	Iron	mg/kg	21	0.19	30,800	20,188	22,100	8,818	1,924	5	26,300	31,300	29,040	30,100	2,498	1,117	5	11,700	28,600	17,520	13,700	6,919	3,094
	Lead	mg/kg	21	62.8	222	161	168	43.7	9.5	5	204	255	221	216	20.4	9.1	5	92.5	227	142	119	56.0	25.1
	Mercury	mg/kg	21	0.36	2.3	1.5	1.5	0.51	0.11	5	0.07	2.5	1.7	2.0	0.97	0.43	5	0.27	1.8	0.74	0.46	0.62	0.28
2008 CPG 0-6 inch samples with Be-7 at the surface (0-2 in)	2,3,7,8-TCDD	pg/g	45	40.9	13,453	783	311	2,007	299	13	19.1	6,491	943	309	1,731	480	13	0.07	585	109	22.8	173	47.9
	Total PCBs	ug/kg	45	73.0	7,760	1,002	770	1,229	183	14	59.0	6,531	905	480	1,637	438	13	21.0	600	242	200	181	50.2
	Aldrin	ug/kg	45	0.01	8.4	0.92	0.30	1.7	0.26	13	0.20	4.0	1.2	0.77	1.1	0.31	13	0.07	3.8	0.68	0.42	0.98	0.27
	Dieldrin	ug/kg	45	0.41	152	12.6	3.8	28.9	4.3	13	2.0	25.0	8.4	6.0	6.7	1.9	13	0.02	43.0	5.8	2.3	11.3	3.1
	4,4'-DDD	ug/kg	45	4.4	220	48.9	31.0	48.5	7.2	13	7.7	300	80.1	54.0	81.9	22.7	13	4.0	410	45.8	11.0	110	30.6
	4,4'-DDE	ug/kg	45	7.1	630	56.5	32.0	95.8	14.3	13	4.1	590	107	46.0	165	45.8	13	1.6	96.0	21.6	9.7	28.5	7.9
	4,4'-DDT	ug/kg	45	0.56	220	20.2	5.5	39.8	5.9	13	0.05	115	19.4	6.4	31.0	8.6	13	0.31	62.0	8.2	2.9	16.5	4.6
	Total DDx	ug/kg	45	12.1	817	126	70.8	149	22.2	13	12.8	930	207	114	253	70.3	13	5.9	568	75.5	22.8	151	41.8
	Total Chlordane	ug/kg	45	4.4	254	59.1	39.0	55.6	8.3	13	15.9	147	74.8	66.0	46.1	12.8	13	4.6	330	54.1	33.0	85.6	23.7
	HMW PAH	mg/kg	45	5.1	266	34.4	23.6	42.0	6.3	14	0.63	56.8	30.3	30.4	20.1	5.4	13	4.0	209	44.8	18.1	63.2	17.5
	LMW PAH	mg/kg	45	0.85	258	12.8	4.3	39.6	5.9	14	0.15	17.0	6.7	6.5	4.8	1.3	13	0.77	74.7	16.2	4.3	25.4	7.1
	Total PAHs	mg/kg	45	6.1	524	47.3	28.2	79.7	11.9	14	0.78	73.8	37.0	35.4	24.3	6.5	13	4.8	242	60.9	22.4	81.9	22.7
	Aluminum	mg/kg	45	5,920	18,000	11,792	12,300	2,920	435	14	2,780	17,800	10,788	11,800	4,800	1,283	13	2,970	15,900	6,256	4,310	4,432	1,229
	Cadmium	mg/kg	45	1.4	29.9	4.3	3.2	4.8	0.72	14	0.31	13.2	4.9	3.5	3.8	1.0	13	0.26	5.5	1.4	0.66	1.6	0.44
	Chromium	mg/kg	45	55.4	1,140	146	115	167	24.8	14	10.0	299	125	109	86.2	23.1	13	12.6	151	45.6	24.6	45.8	12.7
	Copper	mg/kg	45	88.6	577	174	150	87.1	13.0	14	17.2	460	174	165	115	30.8	13	21.8	382	87.9	52.0	103	28.5
	Iron	mg/kg	45	13,400	33,800	26,562	27,300	4,615	688	14	8,520	39,100	23,416	23,850	8,157	2,180	13	8,430	31,300	14,482	11,400	7,625	2,115
	Lead	mg/kg	44	105	763	254	221	122	18.4	14	33.3	458	275	260	118	31.5	13	31.4	641	172	118	154	42.8
	Mercury	mg/kg	45	0.62	13.4	2.3	2.0	1.9	0.29	14	0.02	9.3	2.8	2.3	2.9	0.78	13	0.17	3.2	1.0	0.43	1.2	0.32

Table 5-3. Summary Statistics for 1995, 2007-2008 USEPA and 2008 CPG Surface Sediments from Be-7 Bearing Locations

Program	River Mile		RM0 to RM8							RM8 to RM12							RM12 to RM17.4						
	Chemical Parameters	Unit	Count	Min	Max	Mean	Median	Std Dev	Std Err	Count	Min	Max	Mean	Median	Std Dev	Std Err	Count	Min	Max	Mean	Median	Std Dev	Std Err
1995 TSI & 2008 CPG 0-6 inch samples with Be-7 at the surface (0-2 in)	2,3,7,8-TCDD	pg/g	59	25.0	13,453	689	311	1,765	230	13	19.1	6,491	943	309	1,731	480	13	0.07	585	109	22.8	173	47.9
	Total TCDD	pg/g	14	28.4	1,660	482	410	378	101														
	Total PCBs	ug/kg	59	73.0	7,760	987	810	1,116	145	14	59.0	6,531	905	480	1,637	438	13	21.0	600	242	200	181	50.2
	Aldrin	ug/kg	57	0.01	8.4	1.2	0.50	1.6	0.22	13	0.20	4.0	1.2	0.77	1.1	0.31	13	0.07	3.8	0.68	0.42	0.98	0.27
	Dieldrin	ug/kg	58	0.41	152	14.0	5.0	26.2	3.4	13	2.0	25.0	8.4	6.0	6.7	1.9	13	0.02	43.0	5.8	2.3	11.3	3.1
	4,4'-DDD	ug/kg	58	4.4	220	48.6	35.0	43.5	5.7	13	7.7	300	80.1	54.0	81.9	22.7	13	4.0	410	45.8	11.0	110	30.6
	4,4'-DDE	ug/kg	59	6.7	630	53.8	34.1	84.5	11.0	13	4.1	590	107	46.0	165	45.8	13	1.6	96.0	21.6	9.7	28.5	7.9
	4,4'-DDT	ug/kg	59	0.56	220	24.7	8.7	38.6	5.0	13	0.05	115	19.4	6.4	31.0	8.6	13	0.31	62.0	8.2	2.9	16.5	4.6
	Total DDx	ug/kg	59	6.8	817	135	98.7	138	18.0	13	12.8	930	207	114	253	70.3	13	5.9	568	75.5	22.8	151	41.8
	Total Chlordane	ug/kg	55	2.2	254	55.2	39.3	51.9	7.0	13	15.9	147	74.8	66.0	46.1	12.8	13	4.6	330	54.1	33.0	85.6	23.7
	HMW PAH	mg/kg	59	5.1	266	29.7	19.2	37.7	4.9	14	0.63	56.8	30.3	30.4	20.1	5.4	13	4.0	209	44.8	18.1	63.2	17.5
	LMW PAH	mg/kg	59	0.50	258	10.1	2.9	34.9	4.5	14	0.15	17.0	6.7	6.5	4.8	1.3	13	0.77	74.7	16.2	4.3	25.4	7.1
	Total PAHs	mg/kg	59	6.1	524	39.8	21.4	70.8	9.2	14	0.78	73.8	37.0	35.4	24.3	6.5	13	4.8	242	60.9	22.4	81.9	22.7
	Aluminum	mg/kg	59	3,590	22,100	12,215	12,600	3,641	474	14	2,780	17,800	10,788	11,800	4,800	1,283	13	2,970	15,900	6,256	4,310	4,432	1,229
	Cadmium	mg/kg	59	0.29	29.9	4.3	3.6	4.3	0.55	14	0.31	13.2	4.9	3.5	3.8	1.0	13	0.26	5.5	1.4	0.66	1.6	0.44
	Chromium	mg/kg	59	20.6	1,140	142	118	147	19.1	14	10.0	299	125	109	86.2	23.1	13	12.6	151	45.6	24.6	45.8	12.7
	Copper	mg/kg	59	35.8	577	176	168	80.7	10.5	14	17.2	460	174	165	115	30.8	13	21.8	382	87.9	52.0	103	28.5
	Iron	mg/kg	59	13,400	36,900	26,759	27,300	4,981	648	14	8,520	39,100	23,416	23,850	8,157	2,180	13	8,430	31,300	14,482	11,400	7,625	2,115
	Lead	mg/kg	57	105	763	274	239	127	16.8	14	33.3	458	275	260	118	31.5	13	31.4	641	172	118	154	42.8
	Mercury	mg/kg	59	0.34	13.4	2.4	2.1	1.8	0.23	14	0.02	9.3	2.8	2.3	2.9	0.78	13	0.17	3.2	1.0	0.43	1.2	0.32

Notes:
1) 1995 Total DDx data were adjusted to high resolution method using the following equation
C(HRGC/HRMS)=0.87795*[C(GC/ECD)]^1.0767 (see Data Evaluation Report No. 4)
2) 2,3,7,8-TCDD concentrations generated during the 2008 CPG coring program were biased low and have been corrected by applying a factor of 1.89, which was provided in November 2010 CSC Environmental Solutions, In
3) 2008 CPG Total TCDD data were not used due to analytical issues that resulted in under reporting of Total TCDD concentrations
4) 2008 EPA river mile 0-1 Total PCBs data were calculated as sum of 209 congeners.
5) 2008 CPG Total TCDD data were not used because the correction factor was not developed
6) All non-detects were set equal to 1/2 the sample-specific method detection limit
7) 1995 individual DDx isomers were not adjusted to high resolution method
8) CPG did not collect Be-7 bearing sediments in 2012.

Table 6-1: CSO Locations Sampled during 2007-2008 USEPA/Malcolm Pirnie, Inc. Program

City	Location	River Mile	Total Acres	Percentage of Land Use			
				Residential	Open Space	Industrial	Commercial
Newark	Freeman Street CSO	3.9	120	42		58	
Newark	Saybrook Place/Rector Street CSO	5.2	420	28	2	12	58
Newark	Clay Street CSO	5.8	1,700	50	19	6	24
Newark	Fourth Avenue CSO	6.2	200	51	4	10	35
Newark	Verona Ave CSO	7.8	370	57		21	14

Source: Information provided by Passaic Valley Sewerage Commission "City of Newark Land Use Distribution."

Table 6-2: SWO Locations Sampled during 2007-2008 USEPA/Malcolm Pirnie, Inc. Program

City	Location	River Mile
Newark[a]	Blanchard Street SWO	2.7
Kearny	Johnston Avenue SWO	6.1
Belleville	Little Street and Davidson Street SWO	9.2
North Arlington	River Road and Crystal Street SWO	9.3
Lyndhurst	Riverside County Park SWO	9.6
Lyndhurst	Copeland and Riverside Avenue SWO	10.3
Nutley	Park Avenue Bridge SWO	10.4
Lyndhurst	Tontine & Riverside Avenue SWO	11.2

a: Blanchard Street SWO sampled during USEPA/Malcolm Pirnie, Inc. Program and CARP Program.

Table 6-3: Summary Statistics of CSO Contaminant Concentration for Samples Collected in 2007-2008 USEPA/Malcolm Pirnie, Inc. Program

Analyte	Unit	Count	Minimum	Maximum	Mean	Median	Standard Deviation	Covariance (%)
2,3,7,8-TCDD	ng/kg	14	0.31	24	4.1	2.3	6.2	150
Total TCDD	ng/kg	14	2.0	530	68	16	140	210
PCB 24+27	ug/kg	14	0.0020	2.0	0.67	0.027	0.91	140
PCB 31	ug/kg	14	0.023	30	10	0.41	14	140
PCB 50+53	ug/kg	14	0.006	7.9	2.2	0.058	3.1	150
PCB 52+69	ug/kg	14	0.044	43	12	0.49	17	140
PCB 61+70+74+76+66	ug/kg	14	0.076	119	27	1.1	41	150
PCB 83+99	ug/kg	14	0.036	38	7.7	0.31	12	160
PCB 90+101+113	ug/kg	14	0.064	51	12	0.61	17	150
PCB 93+95+98+100+102	ug/kg	14	0.056	36	9.3	0.49	14	150
PCB 110+115+111	ug/kg	14	0.077	52	12	0.81	18	150
PCB 129+138+158+160+163+164	ug/kg	14	0.088	59	15	1.1	21	140
PCB 139+140+149+147	ug/kg	14	0.058	46	11	0.54	17	150
PCB 170	ug/kg	14	0.015	11	3.4	0.24	4.8	140
PCB 180+193	ug/kg	14	0.037	27	8.0	0.60	11	140
PCB 196+203	ug/kg	14	0.012	9.5	2.9	0.23	4.0	130
Total PCB	ug/kg	14	1.5	1,400	360	20	510	140
Acenaphthene	mg/kg	14	0.0027	0.74	0.26	0.24	0.22	85
Acenaphthylene	mg/kg	14	0.0017	0.41	0.17	0.17	0.13	75
Anthracene	mg/kg	14	0.0033	1.8	0.48	0.53	0.46	96
Fluorene	mg/kg	14	0.020	2.2	0.53	0.42	0.56	110
Naphthalene	mg/kg	14	0.0052	0.95	0.33	0.36	0.28	86
Phenanthrene	mg/kg	14	0.0033	11	3.1	2.8	3.2	100
Benz[a]anthracene	mg/kg	14	0.23	4.9	1.7	1.7	1.3	76
Benzo[a]pyrene	mg/kg	14	0.20	4.7	2.0	2.1	1.4	71
Benzo[g,h,i]perylene	mg/kg	14	0.23	4.4	2.2	2.5	1.5	68
Benzo[j,k]fluoranthene	mg/kg	14	0.20	4.7	2.4	2.7	1.7	70
Benzo[j]fluoranthene	mg/kg	14	0.29	6.5	2.9	3.3	2.0	70
Chrysene	mg/kg	14	0.42	8.4	3.6	4.0	2.6	72
Dibenz[a,h]anthracene	mg/kg	14	0.04	0.93	0.43	0.47	0.30	69
Fluoranthene	mg/kg	14	0.69	14	5.4	6.0	4.0	75
Indeno[1,2,3-c,d]-pyrene	mg/kg	14	0.22	3.9	2.0	2.3	1.3	65
Pyrene	mg/kg	14	0.69	15	5.2	5.3	4.0	76
LMW PAH	mg/kg	14	0.037	17	4.9	4.3	4.6	94
HMW PAH	mg/kg	14	3.5	67	28	31	20	71
Total PAH	mg/kg	14	3.7	84	33	35	24	74
DDD	ug/kg	14	1.7	24	13	12	8.4	64
DDE	ug/kg	14	5.6	52	24	21	14	60
DDT	ug/kg	13	10	160	58	45	41	70
Aldrin	ug/kg	14	0.015	0.88	0.28	0.17	0.27	96
Dieldrin	ug/kg	14	3.5	32	11	11	8.3	73
Trans-Chlordane	ug/kg	13	7.0	74	31	26	21	69
Arsenic	mg/kg	12	4.3	11	7.4	6.8	2.1	28
Cadmium	mg/kg	13	0.37	8.7	2.1	1.2	2.4	110
Chromium	mg/kg	12	8.4	230	67	59	57	85
Cobalt	mg/kg	13	1.3	22	8.4	6.9	5.7	68
Copper	mg/kg	13	110	860	320	280	180	58
Iron	mg/kg	13	4,800	53,000	22,000	19,000	13,000	59
Lead	mg/kg	13	80	1,400	380	350	340	89
Mercury	mg/kg	14	0.30	3.3	1.0	0.92	0.72	71
Nickel	mg/kg	13	9.4	200	50	42	48	97
Zinc	mg/kg	13	280	2,400	870	850	530	60

Note:
Data associated with a laboratory qualifier containing a "U" were considered to be not detected and were set equal to half of method detection limit and incorporated into statistics.

Table 6-4: Summary Statistics of SWO Contaminant Concentration for Samples Collected in 2007-2008 in the USEPA/Malcolm Pirnie, Inc. Program

Analyte	Unit	Count	Minimum	Maximum	Mean	Median	Standard Deviation	Covariance (%)
2,3,7,8-TCDD	ng/kg	16	0.62	110	20	8.9	31	150
Total TCDD	ng/kg	16	8.5	1,200	120	32	300	260
PCB 24+27	ug/kg	16	0.006	2.4	1.1	1.2	0.96	90
PCB 31	ug/kg	16	0.069	37	16	19	15	93
PCB 50+53	ug/kg	16	0.014	9.7	4.0	4.1	3.8	95
PCB 52+69	ug/kg	16	0.13	54	22	24	20	93
PCB 61+70+74+76+66	ug/kg	16	0.30	120	51	51	48	95
PCB 83+99	ug/kg	16	0.11	38	14	14	14	95
PCB 90+101+113	ug/kg	16	0.19	54	22	23	21	92
PCB 93+95+98+100+102	ug/kg	16	0.17	46	19	20	17	93
PCB 110+115+111	ug/kg	16	0.30	57	24	26	21	90
PCB 129+138+158+160+163+164	ug/kg	16	0.46	74	29	32	27	90
PCB 139+140+149+147	ug/kg	16	0.22	57	22	24	21	93
PCB 170	ug/kg	16	0.10	19	6.8	7.3	6.4	94
PCB 180+193	ug/kg	16	0.26	46	17	17	16	94
PCB 196+203	ug/kg	16	0.10	18	6.1	6.1	5.7	93
Total PCB	ug/kg	16	6.4	1,600	670	710	620	92
Acenaphthene	mg/kg	18	0.028	4.1	0.57	0.29	0.92	160
Acenaphthylene	mg/kg	18	0.060	5.4	0.72	0.28	1.3	180
Anthracene	mg/kg	18	0.089	12	2.3	0.80	3.3	140
Fluorene	mg/kg	18	0.048	4.9	0.82	0.36	1.3	160
Naphthalene	mg/kg	18	0	1.3	0.54	0.55	0.45	83
Phenanthrene	mg/kg	18	0.95	22	8.7	7.3	6.1	71
Benz[a]anthracene	mg/kg	18	0.41	22	6.4	4.7	5.4	85
Benzo[a]pyrene	mg/kg	18	0.66	27	9.4	6.8	7.6	81
Benzo[g,h,i]perylene	mg/kg	18	0.90	25	9.1	7.2	6.7	74
Benzo[j,k]fluoranthene	mg/kg	18	0.96	32	11	8.1	8.7	79
Benzo[j]fluoranthene	mg/kg	18	1.0	140	19	10	30	160
Chrysene	mg/kg	18	1.3	190	24	12	43	180
Dibenz[a,h]anthracene	mg/kg	18	0.17	5.1	1.6	1.4	1.2	74
Fluoranthene	mg/kg	18	1.9	320	38	18	73	190
Indeno[1,2,3-c,d]-pyrene	mg/kg	18	0.77	26	9.0	6.9	6.9	77
Pyrene	mg/kg	18	1.6	250	31	15	57	180
LMW PAH	mg/kg	18	1.9	44	14	9.6	11	83
HMW PAH	mg/kg	18	9.8	980	160	89	220	140
Total PAH	mg/kg	18	12	1,000	170	100	230	130
DDD	ug/kg	16	6.9	500	53	19	120	230
DDE	ug/kg	16	19	240	58	47	53	91
DDT	ug/kg	15	41	390	130	110	86	69
Aldrin	ug/kg	16	0.081	280	23	2.8	70	300
Dieldrin	ug/kg	16	3.4	190	55	39	51	93
Trans-Chlordane	ug/kg	16	8.8	270	110	82	69	60
Arsenic	mg/kg	17	5.2	28	14	13	5.5	40
Cadmium	mg/kg	17	0.63	2.5	1.5	1.5	0.59	38
Chromium	mg/kg	17	24	150	87	81	39	45
Cobalt	mg/kg	17	2.3	35	14	14	7.5	54
Copper	mg/kg	17	39	390	220	230	92	42
Iron	mg/kg	17	8,900	67,000	35,000	34,000	14,000	39
Lead	mg/kg	17	42	630	300	310	160	53
Mercury	mg/kg	17	0.14	2.0	0.60	0.58	0.39	64
Nickel	mg/kg	17	11	110	53	55	25	48
Zinc	mg/kg	17	130	1,000	700	760	260	38

Note:
Data associated with a laboratory qualifier containing a "U" were considered to be not detected and were set equal to half of method detection limit and incorporated into statistics.

Table 6-5: CARP CSO/SWO Sampling Locations and Dates

Selected Stations	Associated Sampling Dates			
CSO: Christie Street		October 16, 2002	April 11, 2003	
CSO: Court Street		October 16, 2002	April 11, 2003	
CSO: Elm Street			April 11, 2003	
CSO: Ivy Street		October 16, 2002	April 11, 2003	April 13, 2004
CSO: West Side Road		October 16, 2002		
SWO: Blanchard Street[a]	September 25, 2001	October 16, 2002	April 11, 2003	
SWO: CCI		October 16, 2002	April 11, 2003	April 13, 2004
SWO: Smith Marina		October 16, 2002	April 11, 2003	April 13, 2004

a: Blanchard Street SWO sampled during USEPA/Malcolm Pirnie, Inc. Program and CARP Program.

Table 7-1: Results of Reible Model for Probable Groundwater Contributions to the Lower Passaic River

Contaminant	Probability that Pore Water Contributes 2% or More of River Contaminant Load	Probability that Pore Water Contributes 3% or More of River Contaminant Load	Probability that Pore Water Contributes 5% or More of River Contaminant Load	Probability that Pore Water Contributes 10% or More of River Contaminant Load
Mercury	0.00%	0.00%	0.00%	0.00%
Lead	0.00%	0.00%	0.00%	0.00%
DDE	0.07%	0.03%	0.00%	0.00%
2,3,7,8-TCDD	0.00%	0.00%	0.00%	0.00%
Total TCDD	0.00%	0.00%	0.00%	0.00%
PCB 52	0.00%	0.00%	0.00%	0.00%
PCB 180+193	0.00%	0.00%	0.00%	0.00%
Benzo[a]pyrene	0.00%	0.00%	0.00%	0.00%
Fluroanthene	0.00%	0.00%	0.00%	0.00%

Table 7-2: Comparison of Atmospheric Deposition to the Lower Passaic River *vs.* the Solids-Borne Contaminant Load at Dundee Dam

Compounds	Upper Passaic Load		Atmospheric Deposition Load		Atmospheric Flux Expressed as a Fraction of the Load at Dundee Dam
	Upper Passaic River Concentration on Suspended Matter (ug/kg)[a]	Mass Flux (g/d) at Dundee Dam [b]	Atmospheric Deposition Flux [c] (ug/m^2-day)	Mass Flux to Surface of Lower Passaic River via Atmospheric Deposition [d] (g/d)	
Arsenic	4,800	520	1.0	3.8	0.0073
Cadmium	1,800	200	0.50	1.9	0.010
Chromium	41,000	4,400	15	57	0.013
Copper	89,000	9,500	38	145	0.015
Cobalt	9,900	1,100	1.0	3.8	0.004
Lead	170,000	18,000	50	190	0.011
Nickel	24,000	2,600	10	38	0.015
Zinc	370,000	40,000	140	510	0.013
Benz[a]anthracene	4,900	520	0.13	0.49	0.00094
Benzo[a]pyrene	6,300	670	0.11	0.42	0.00062
Fluoranthene	11,000	1,200	1.4	5.5	0.0047
Pyrene	10,000	1,100	1.0	3.7	0.0034
Total PCB [e]	510	55	0.16	0.6	0.011
Chlordane,gamma (trans)	41	4.4	0.15	0.57	0.13
Dieldrin	10	1.1	0.02	0.08	0.071

Notes:

a: Values correspond to the mean concentration for Upper Passaic River samples collected during the 2007-2008 USEPA/Malcolm Pirnie, Inc. Program. Refer to Table 3-3 for additional statistics.

b: Mass flux calculated as the product of the annual solids delivery by the Upper Passaic River (73,000 cy) at a density of 0.7 g/cc times the mean Upper Passaic River concentration.

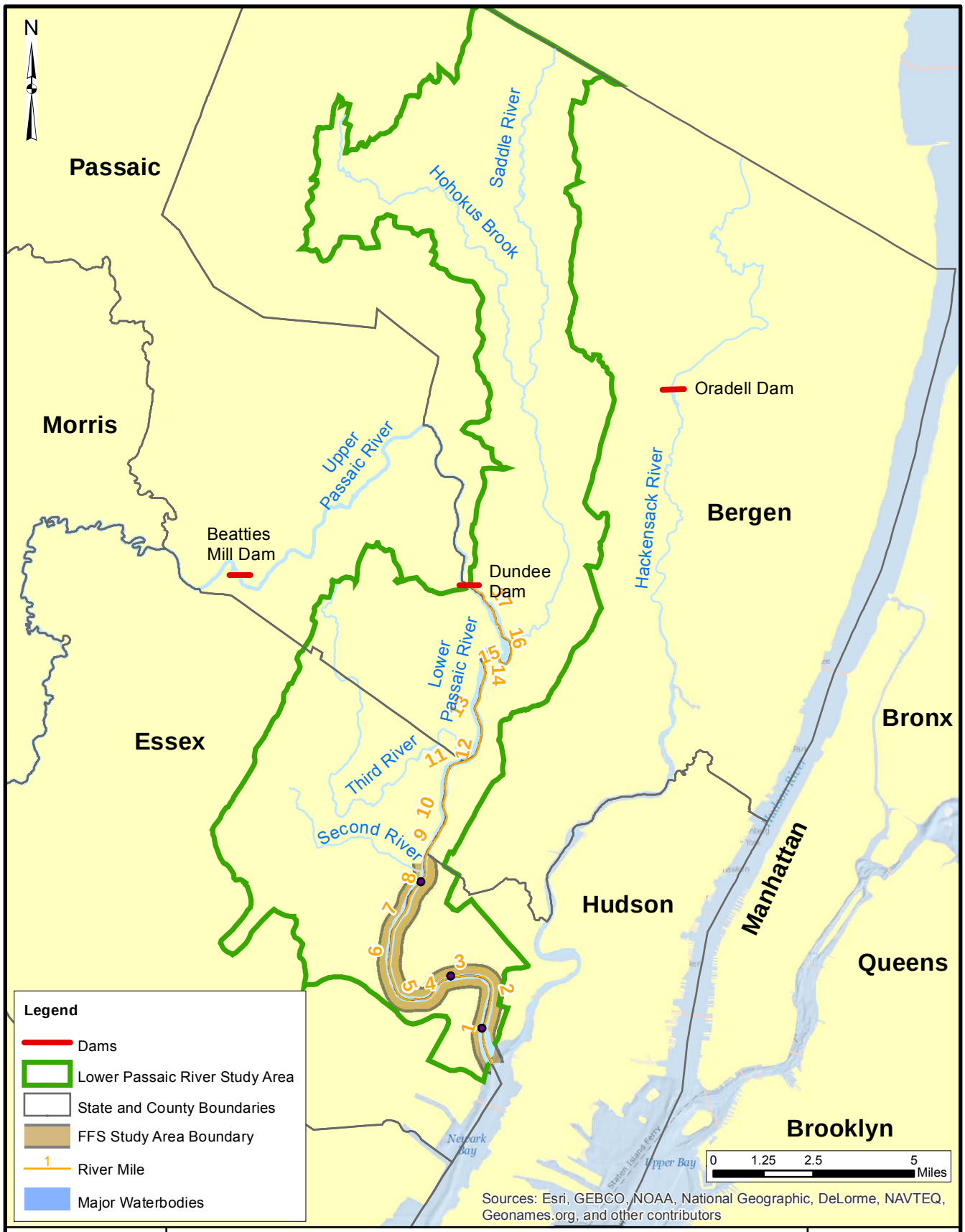
c: Atmospheric deposition flux for the contaminant was based on literature review. Metals fluxes were obtained from Yi, *et al.* , 2006; PAHs fluxes were obtained from Gigliotti, *et al.* , 2005 ;Total PCB flux was obtained from Totten, *et al.* , 2004; Pesticides fluxes were obtained from Gioia, *et al.* , 2005.

d: Mass flux to surface of Lower Passaic River calculated as the product of the atmospheric fallout flux times the surface area of the Upper Passaic River (940 acres).

e: The Total PCBs atmospheric deposition flux is based on the gross deposition estimated for the Hudson River Estuary. However, the high levels of PCBs in the water column of the estuary contribute to a large volatilization flux. The gas absorption flux of 0.16 $ug/m^2/d$ (into the water surface) is less than volatilization flux of 0.33 $ug/m^2/d$ (out of the water surface) [Totten, *et al.* , 2001 and Yan, 2003].

f: This table does not include loads from the Lower Passaic River tributaries, CSOs, SWOs or Newark Bay. Inclusion of these loads would further diminish the fractional contribution by atmospheric deposition.

FIGURES



FFS Study Area Location Map

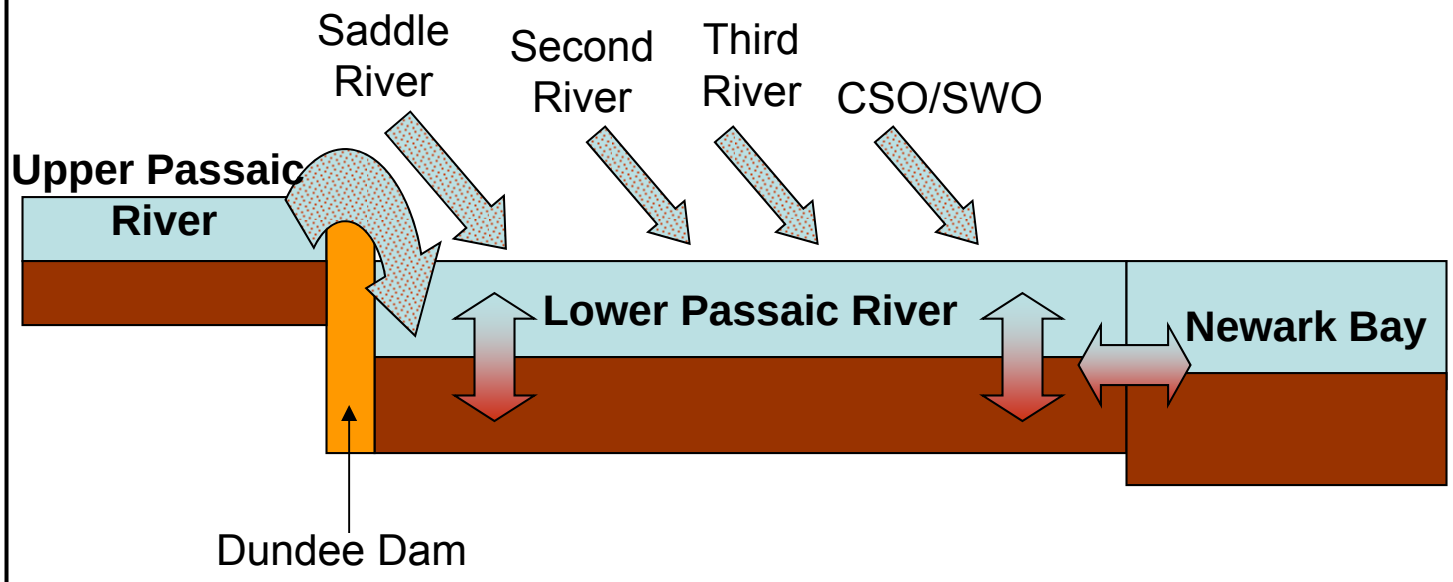
Lower Eight Miles of the Lower Passaic River

Figure 1-1

2014

Path: P:\0285924\Mapping\CSM_MassBalance\sitelocation_CSM_no_logos.mxd

R2-0026599



Legend

Water

Sediment

Notes

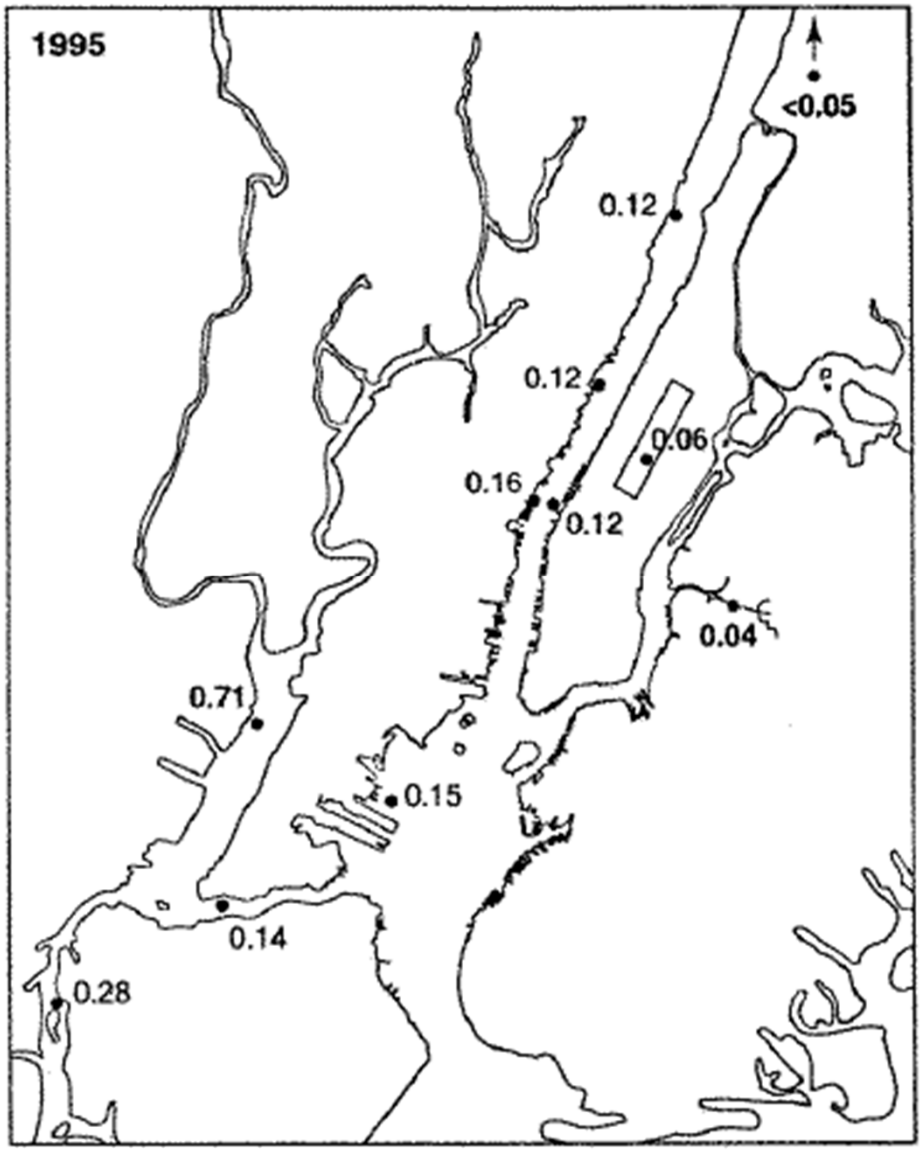
Schematic of Lower Passaic River Domain and Boundary Conditions

Lower Eight Miles of the Lower Passaic River

Figure 1-2

2014

R2-0026600



Legend

● 2,3,7,8-TCDD/Total TCDD Ratio

Notes

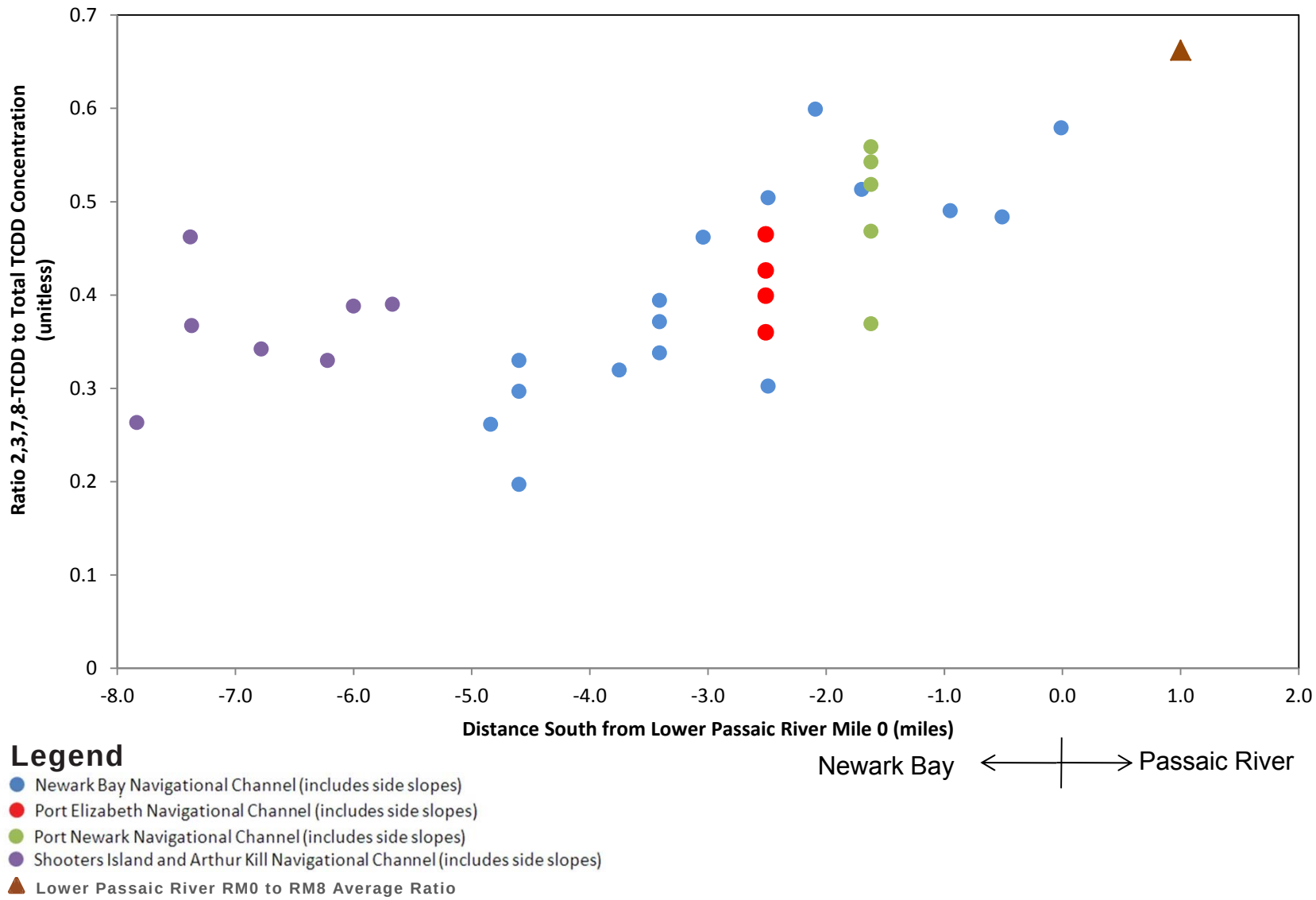
Chaky DA, 2003. "Polychlorinated Biphenyls, Polychlorinated Dibenzo-p-Dioxins and Furans in the New York Metropolitan Area; Interpreting Atmospheric Deposition and Sediment Chronologies." PhD Thesis, Rensselaer Polytechnic Institute, Troy, NY. August 2003.

Reprint from Chaky (2003): Ratio of 2,3,7,8-TCDD/Total TCDD in the Hudson-Raritan Estuary in 1995

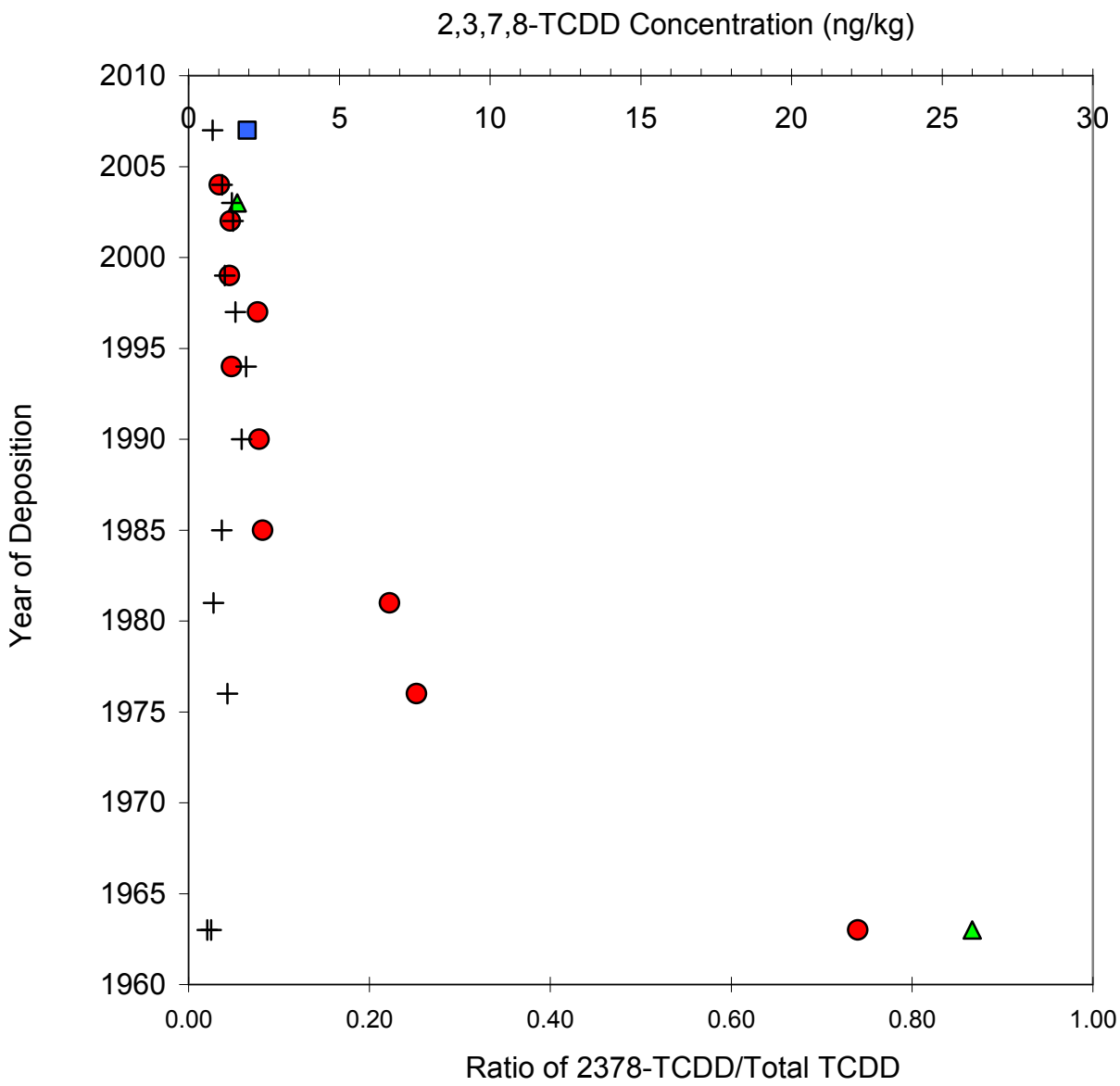
Lower Eight Miles of the Lower Passaic River

Figure 1-3

2014



	Ratio of 2,3,7,8-TCDD/Total TCDD in Newark Bay Surface Sediments at Highly Likely Recent-Depositional Locations (Defined as >1 pCi/g in the Channel) *Lower Eight Miles of the Lower Passaic River*	Figure 1-4 2014



Legend

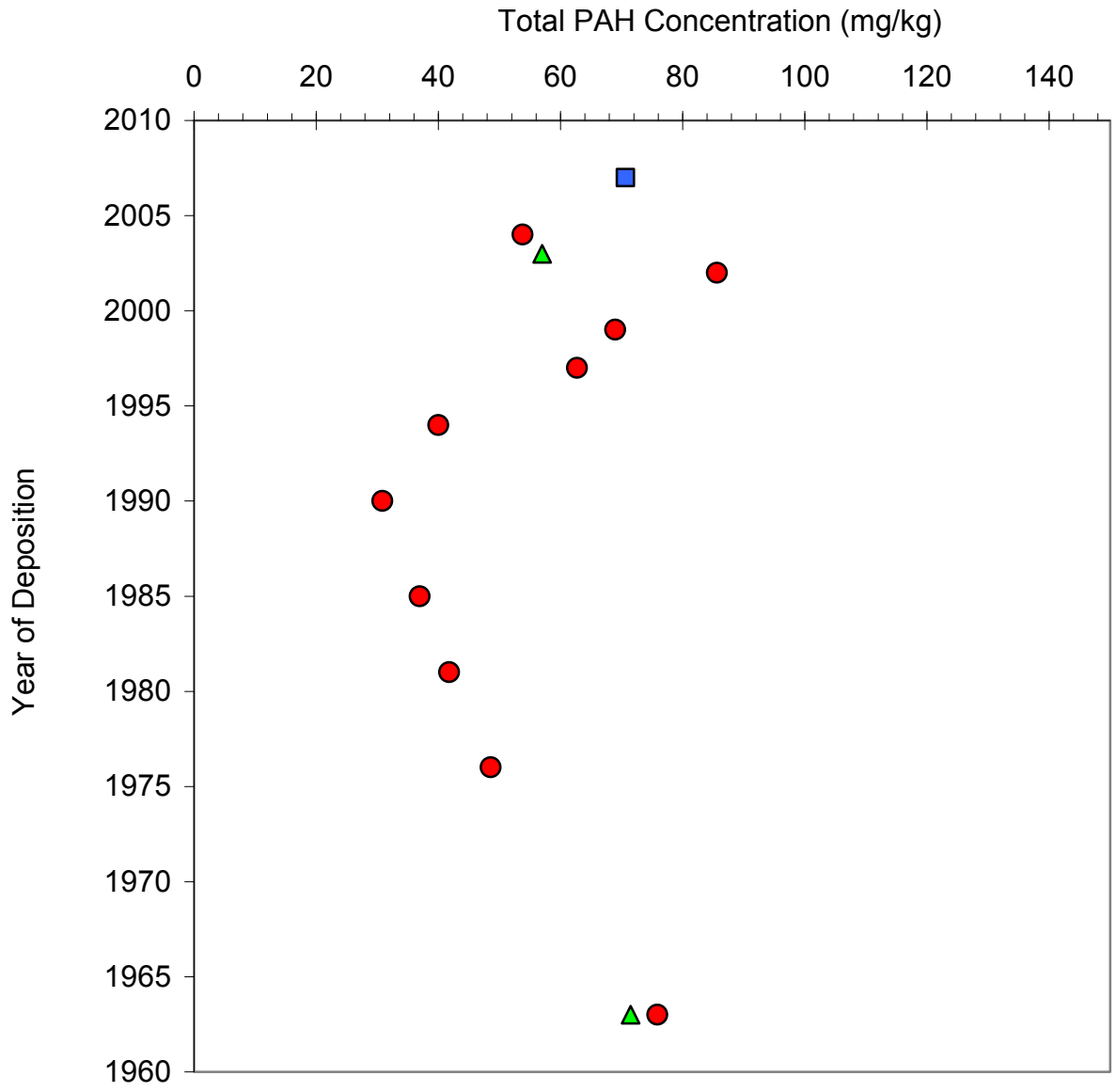
- Bopp 2005 Historical Core (Field ID = Pass8B) Unvalidated
- Bopp 2005 Historical Core Top (Field ID = Pass8BP) Unvalidated
- USEPA 2007 Core Top (Field ID = Core 2) Validated
- Ratio of 2,3,7,8-TCDD/Total TCDD from Bopp 2005 Historical Core (Field ID = Pass8B) Unvalidated

2,3,7,8-TCDD Downcore Profile for the Upper Passaic River

Lower Eight Miles of the Lower Passaic River

Figure 3-1

2014



Legend

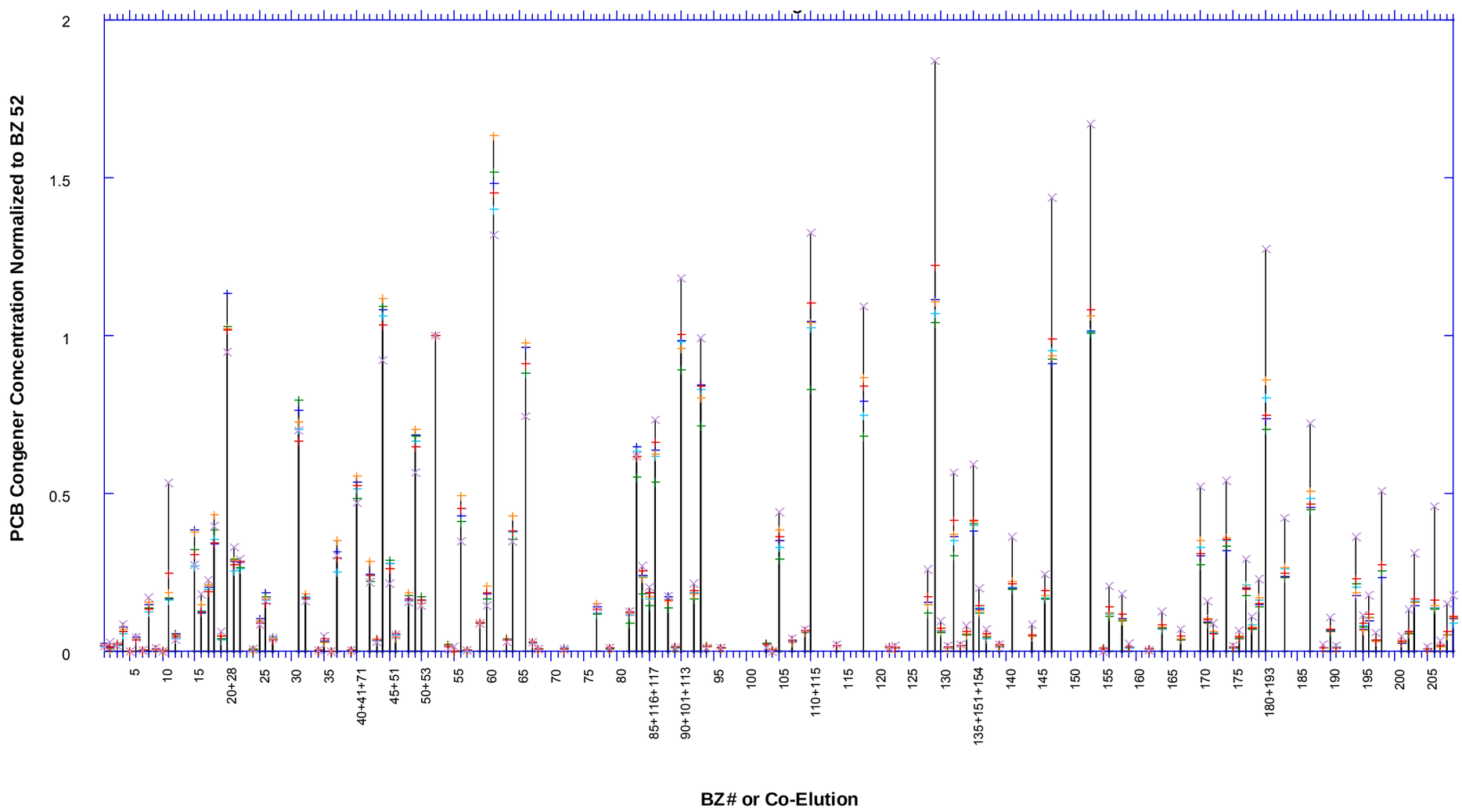
- Bopp 2005 Historical Core (Field ID = Pass8B) Unvalidated
- Bopp 2005 Historical Core Top (Field ID = Pass8BP) Unvalidated
- USEPA 2007 Core Top (Field ID = Core 2) Validated
- Ratio of 2,3,7,8-TCDD/Total TCDD from Bopp 2005 Historical Core (Field ID = Pass8B) Unvalidated

Total PAH Downcore Profile for the Upper Passaic River

Lower Eight Miles of the Lower Passaic River

Figure 3-2

2014



Legend

PCB Congeners Normalized to PCB 52 at the following locations:

- Lower Passaic River Core Top RM1.4
- Lower Passaic River Core Top RM2.2
- Lower Passaic River Core Top RM7.8
- Lower Passaic River Core Top RM11
- Lower Passaic River Core Top RM12.6
- Dundee Lake Core Top (0-2 cm)

Notes

1. Normalized PCB Congener Concentration <0.01 are not plotted.
2. <18 centimeters surface sediment collected in Upper Passaic River and Lower Passaic River.

Normalized PCB Congener Pattern for Recently-Deposited Sediment from the Upper Passaic River and Lower Passaic River

Lower Eight Miles of the Lower Passaic River

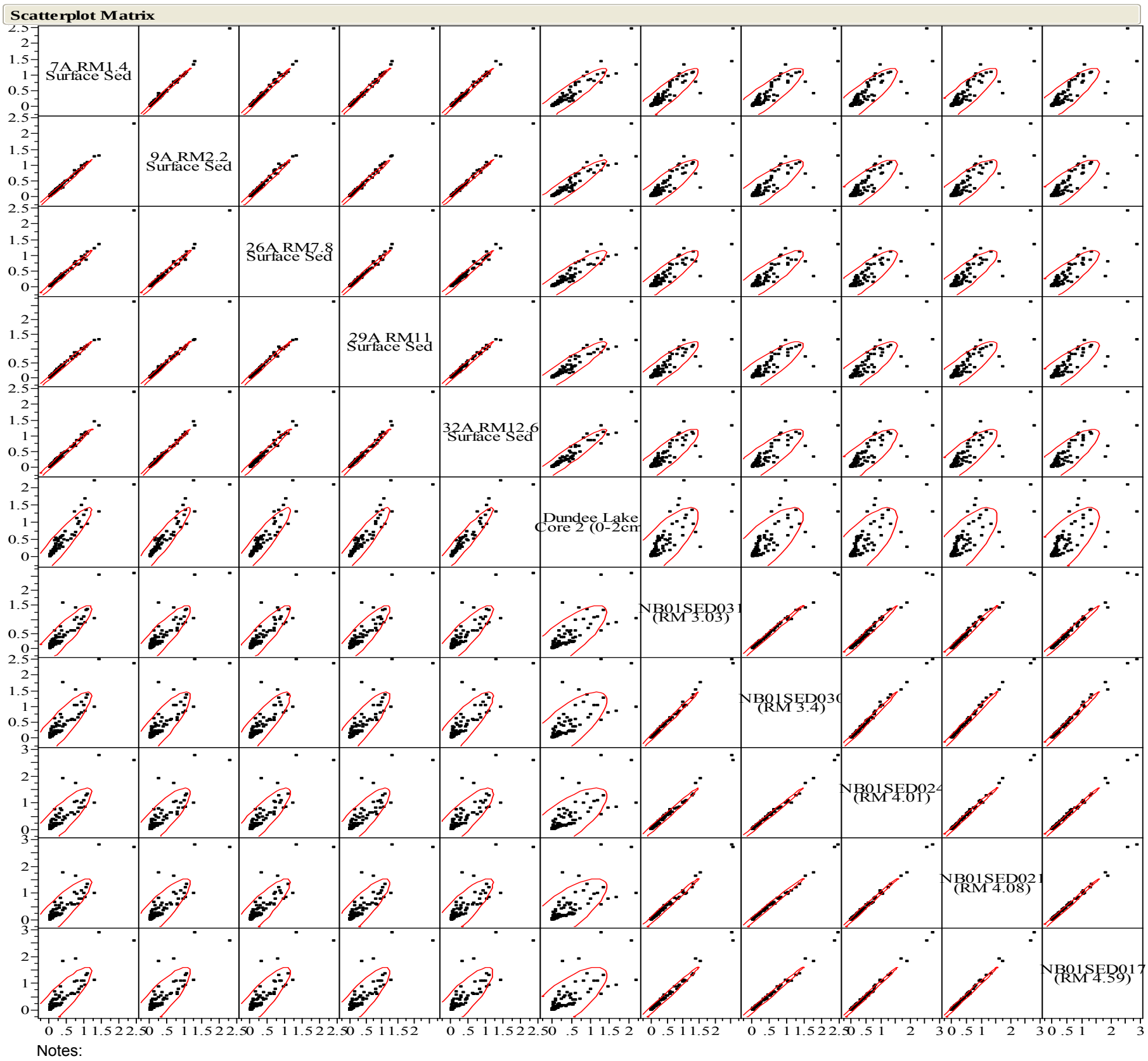
Figure 3-3

2014

Multivariate Correlations

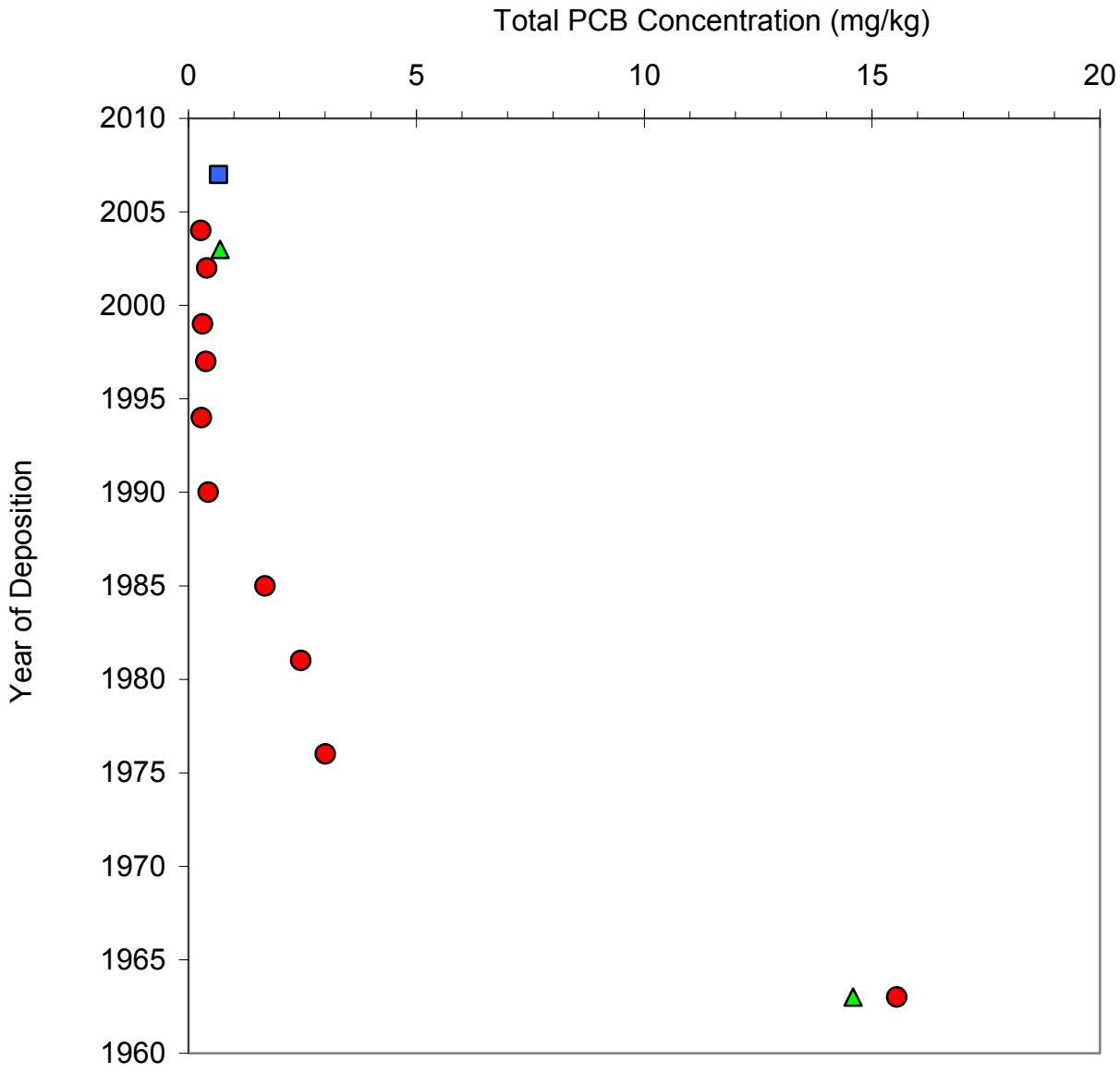
	7A RM1.4 Surface Sediment	9A RM2.2 Surface Sediment	26A RM7.8 Surface Sediment	29A RM11 Surface Sediment	32A RM12.6 Surface Sediment	Dundee Dam (0-2cm)	NB01SED031 (RM-3.0)	NB01SED030 (RM-3.4)	NB01SED024 (RM-4.0)	NB01SED021 (RM-4.1)	NB01SED017 (RM-4.6)
7A RM1.4 Surface Sediment	1.0000	0.9979	0.9964	0.9973	0.9967	0.9348	0.9167	0.8917	0.8755	0.8862	0.8802
9A RM2.2 Surface Sediment	0.9979	1.0000	0.9951	0.9968	0.9977	0.9467	0.8973	0.8710	0.8524	0.8629	0.8575
26A RM7.8 Surface Sediment	0.9964	0.9951	1.0000	0.9962	0.9922	0.9291	0.9119	0.8873	0.8718	0.8845	0.8774
29A RM11 Surface Sediment	0.9973	0.9968	0.9962	1.0000	0.9954	0.9346	0.9046	0.8787	0.8614	0.8731	0.8650
32A RM12.6 Surface Sediment	0.9967	0.9977	0.9922	0.9954	1.0000	0.9555	0.8931	0.8658	0.8467	0.8573	0.8525
Dundee Dam (0-2cm)	0.9348	0.9467	0.9291	0.9346	0.9555	1.0000	0.8000	0.7711	0.7475	0.7531	0.7582
NB01SED031 (RM-3.0)	0.9167	0.8973	0.9119	0.9046	0.8931	0.8000	1.0000	0.9965	0.9943	0.9952	0.9938
NB01SED030 (RM-3.4)	0.8917	0.8710	0.8873	0.8787	0.8658	0.7711	0.9965	1.0000	0.9972	0.9961	0.9965
NB01SED024 (RM-4.0)	0.8755	0.8524	0.8718	0.8614	0.8467	0.7475	0.9943	0.9972	1.0000	0.9978	0.9980
NB01SED021 (RM-4.1)	0.8862	0.8629	0.8845	0.8731	0.8573	0.7531	0.9952	0.9961	0.9978	1.0000	0.9976
NB01SED017 (RM-4.6)	0.8802	0.8575	0.8774	0.8650	0.8525	0.7582	0.9938	0.9965	0.9980	0.9976	1.0000

Scatterplot Matrix



Notes:
1. In this presentation, river miles for the Newark Bay sampling locations are assigned with respect to the distance from the mouth of the Lower Passaic River (RM0.0) and following the federal navigation channel.
2. PCB Congeners Concentration Normalized to Congener 52

	Correlation Among Sampling Locations for PCB Congeners in Upper Passaic River, Lower Passaic River, and Newark Bay Surface Sediment *Lower Eight Miles of the Lower Passaic River*	Figure 3-4 2014



Legend

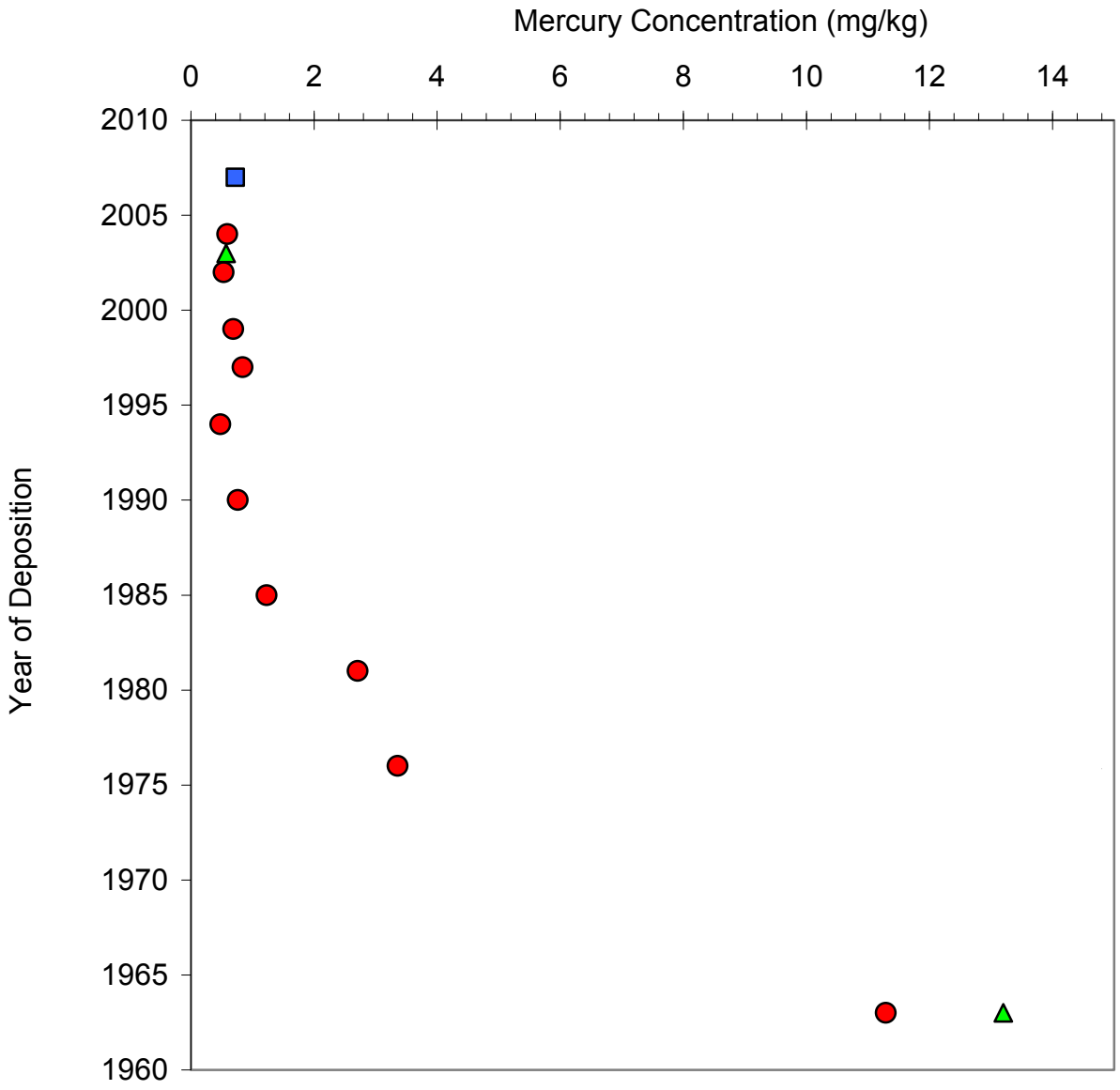
- Bopp 2005 Historical Core (Field ID = Pass8B) Unvalidated
- Bopp 2005 Historical Core Top (Field ID = Pass8BP) Unvalidated
- USEPA 2007 Core Top (Field ID = Core 2) Validated
- Ratio of 2,3,7,8-TCDD/Total TCDD from Bopp 2005 Historical Core (Field ID = Pass8B) Unvalidated

Total PCB Downcore Profile for the Upper Passaic River

Lower Eight Miles of the Lower Passaic River

Figure 3-5

2014



Legend

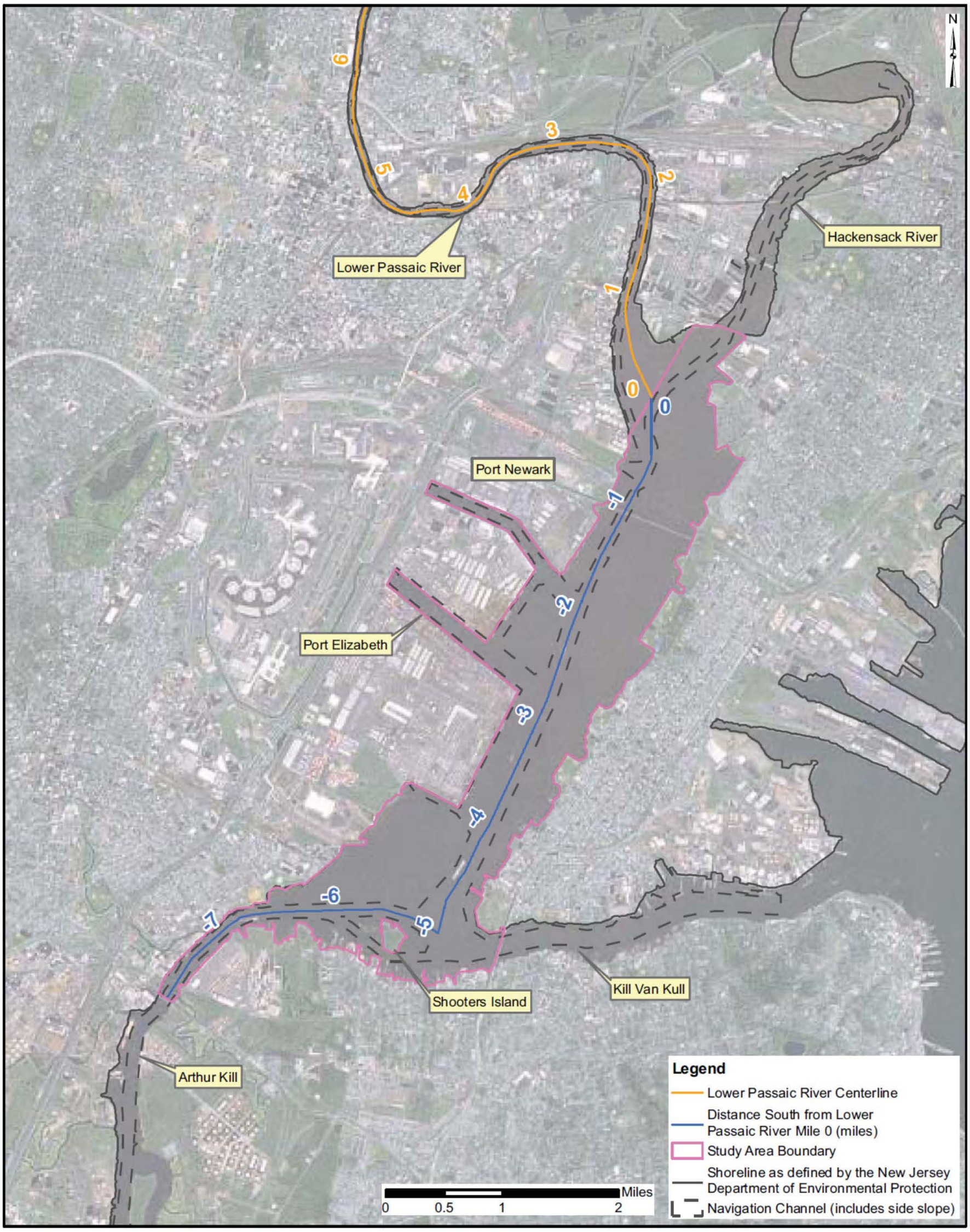
- Bopp 2005 Historical Core (Field ID = Pass8B) Unvalidated
- Bopp 2005 Historical Core Top (Field ID = Pass8BP) Unvalidated
- USEPA 2007 Core Top (Field ID = Core 2) Validated
- Ratio of 2,3,7,8-TCDD/Total TCDD from Bopp 2005 Historical Core (Field ID = Pass8B) Unvalidated

Mercury Downcore Profile for the Upper Passaic River

Lower Eight Miles of the Lower Passaic River

Figure 3-6

2014

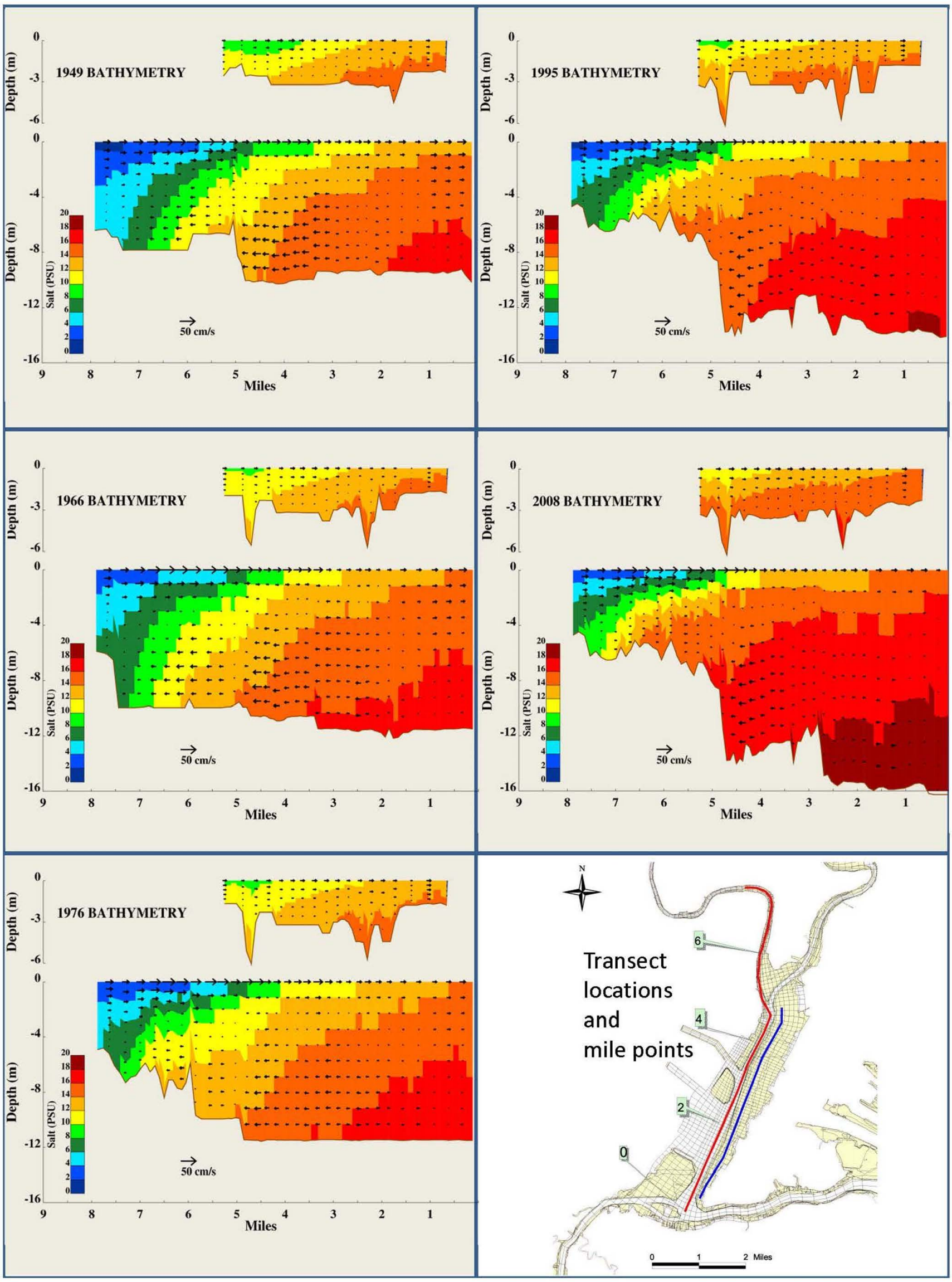


River Mile System in Newark Bay Study Area

Lower Eight Miles of the Lower Passaic River

Figure 4-1

2014

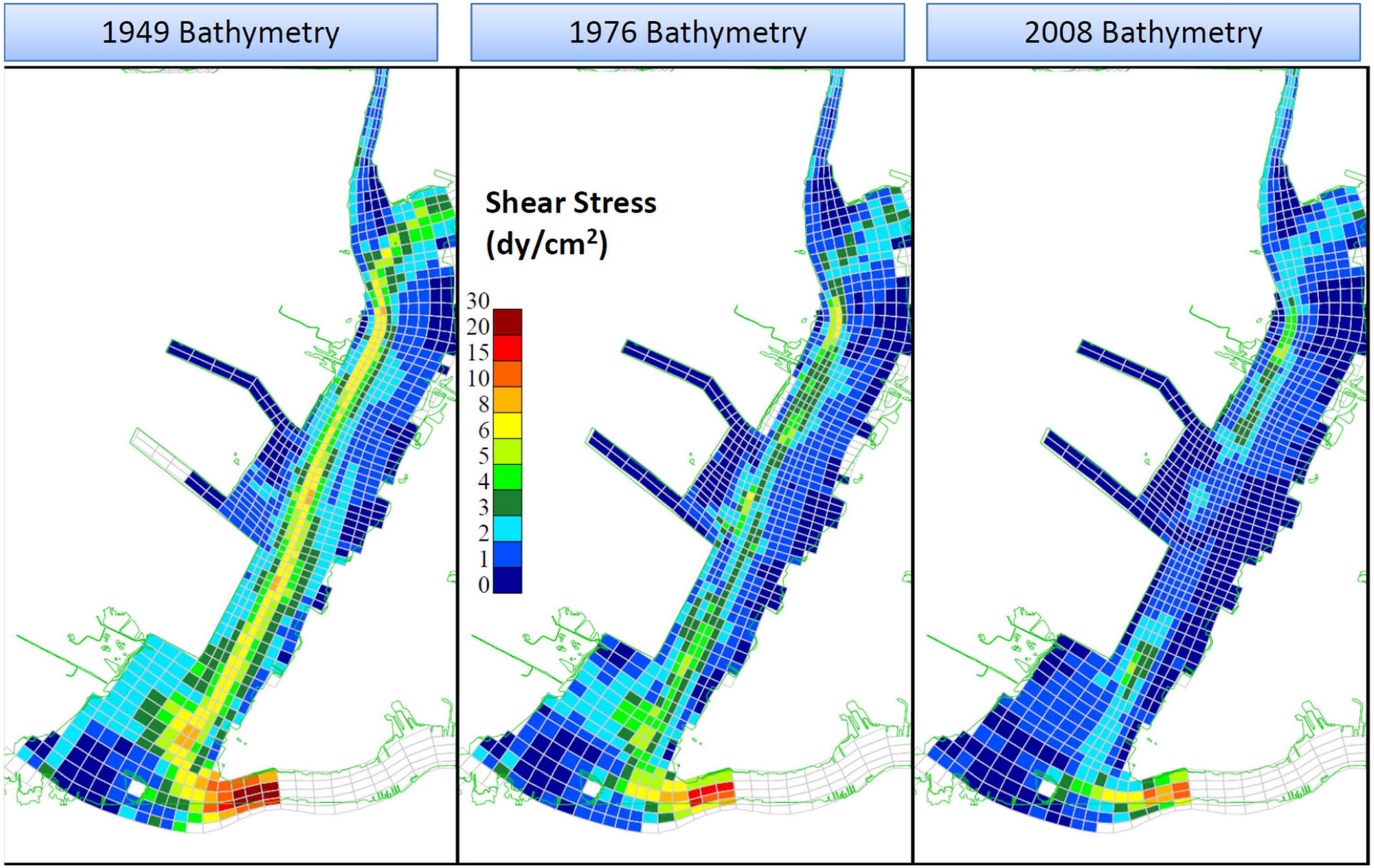


Comparison of Salinity Intrusion and Residual Currents Based on ECOM Simulations Using Bathymetry from 1949, 1966, 1976, 1995 and 2008

Lower Eight Miles of the Lower Passaic River

Figure 4-2

2014

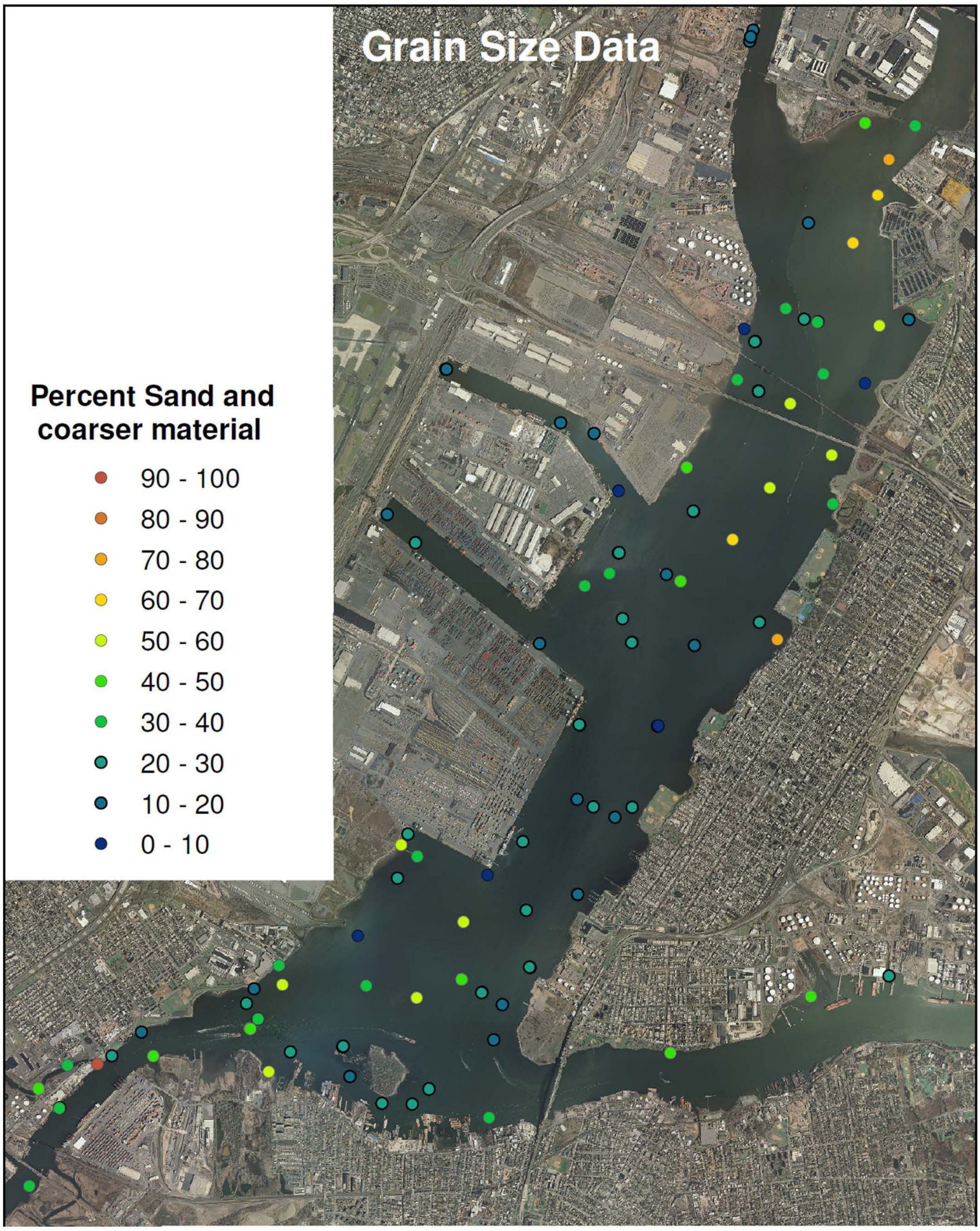


Effect of changing bathymetry on bottom shear stress in Newark Bay and the Lower Passaic River

Lower Eight Miles of the Lower Passaic River

Figure 4-3

2014

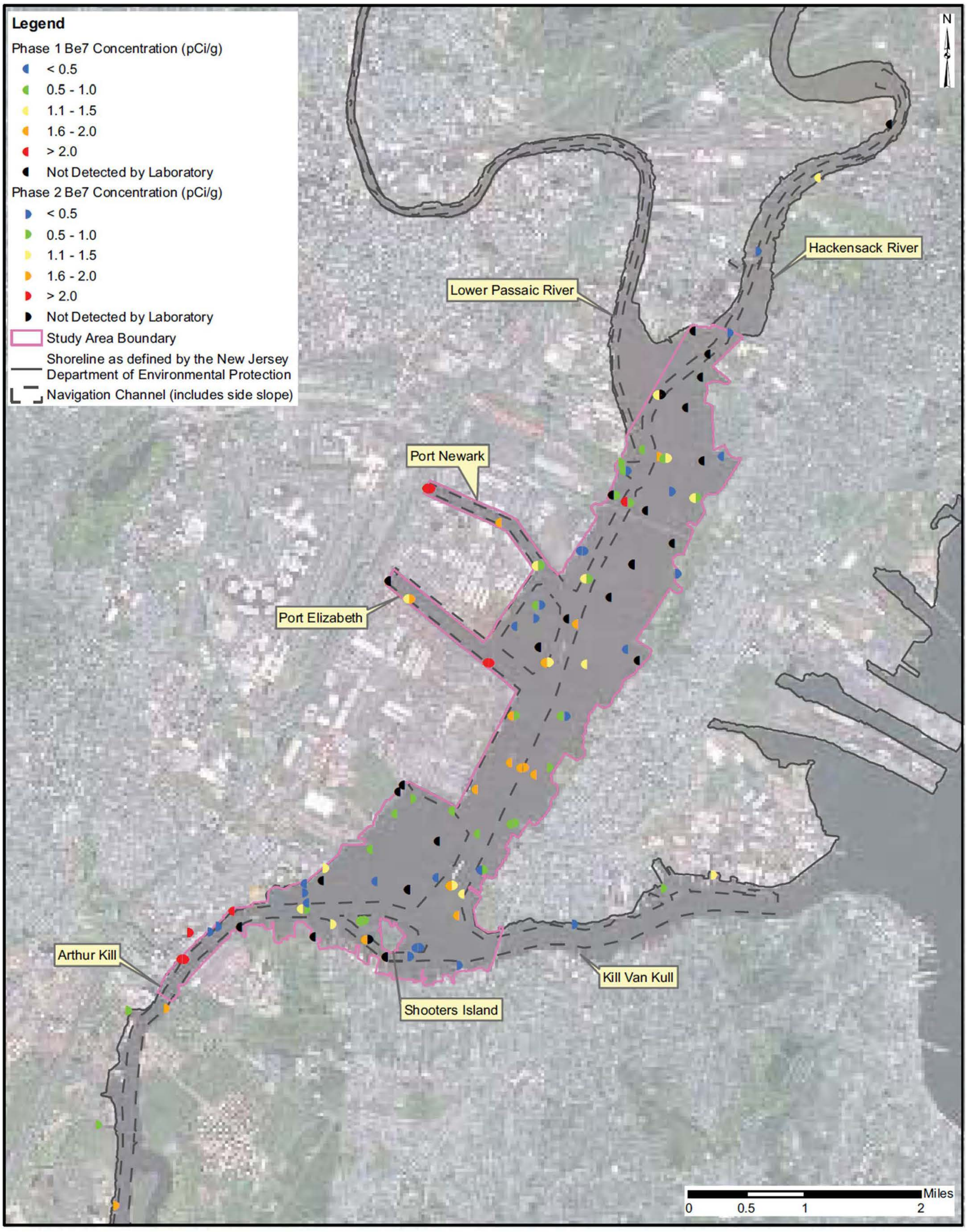


Newark Bay Grain Size Data

Lower Eight Miles of the Lower Passaic River

Figure 4-4

2014

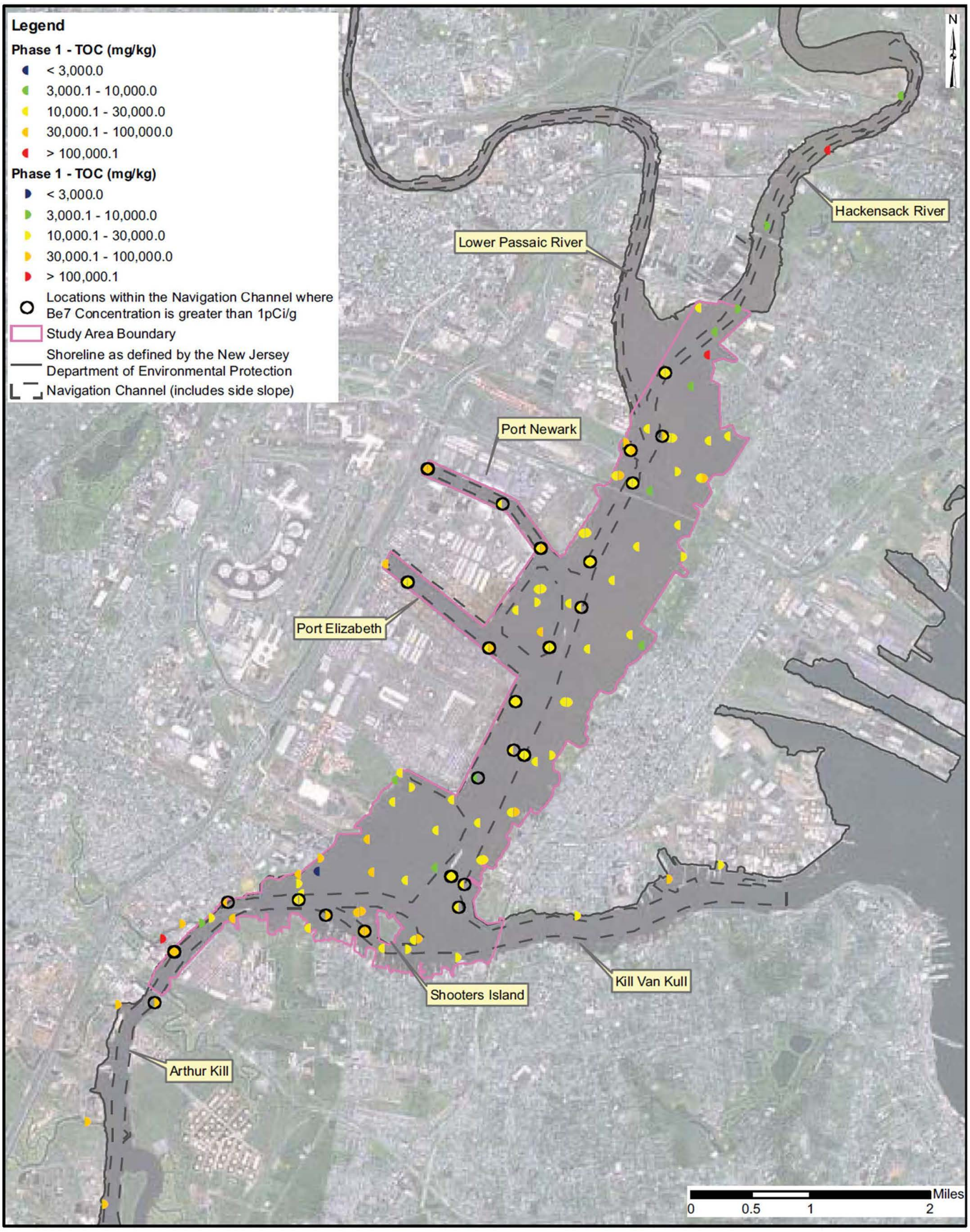


Beryllium-7 Concentration in Phase I and Phase II Surface Sediment (0-1 inch)

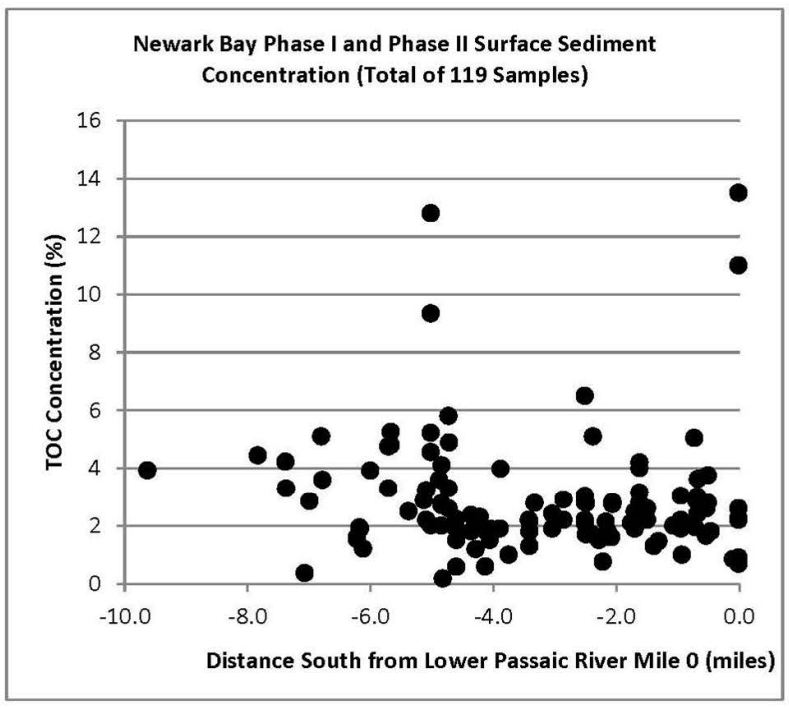
Lower Eight Miles of the Lower Passaic River

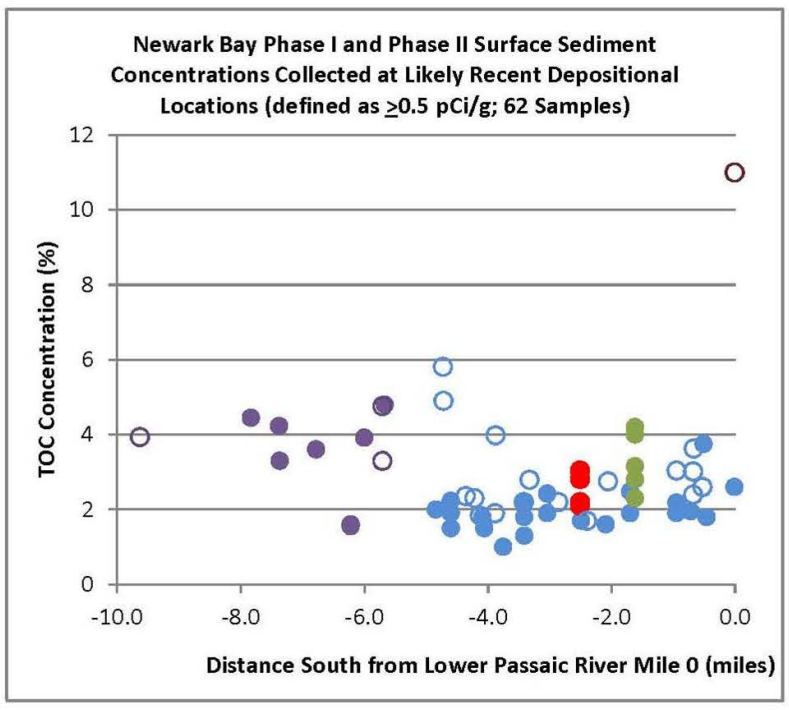
Figure 4-5

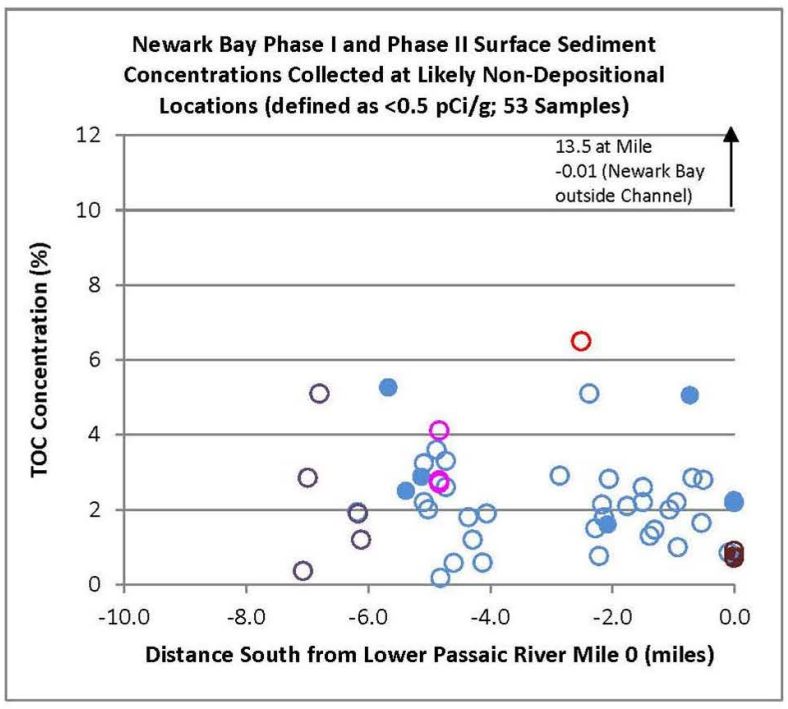
2014

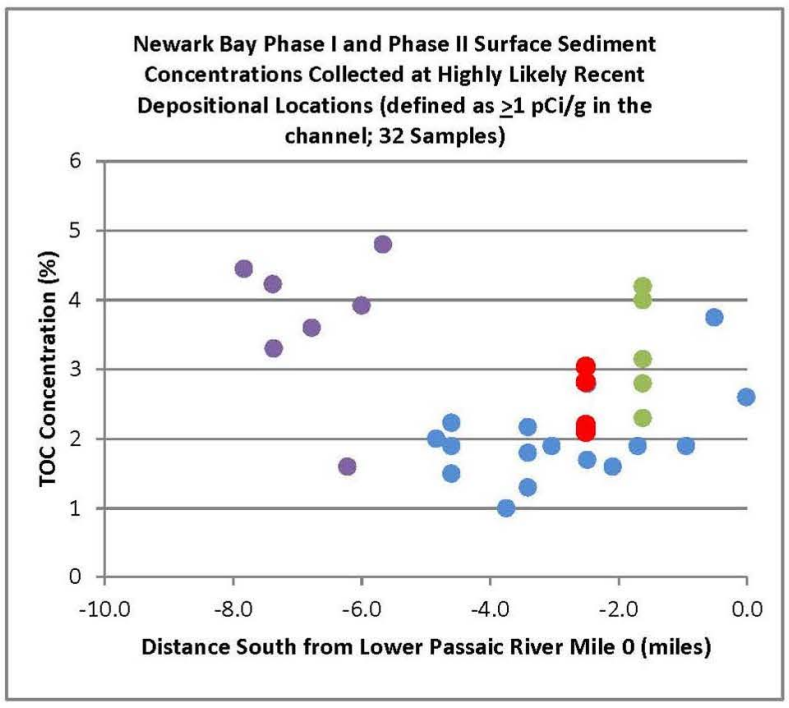


	TOC Concentration in Phase I and Phase II Surface Sediment (0-6 inch) *Lower Eight Miles of the Lower Passaic River*	Figure 4-6 2014









Legend

- All Phase I and II Sampling Locations
- Newark Bay Navigational Channel (includes side slopes)
- Newark Bay Outside of Channel
- Port Elizabeth Navigational Channel (includes side slopes)
- Port Elizabeth Outside of Channel
- Port Newark Navigational Channel (includes side slopes)
- Shooters Island and Arthur Kill Navigational Channel (includes side slopes)
- Shooters Island and Arthur Kill Outside of Channel
- Hackensack River Navigational Channel (includes side slopes)
- Hackensack River Outside of Channel
- Kill Van Kull Outside of Channel

Notes

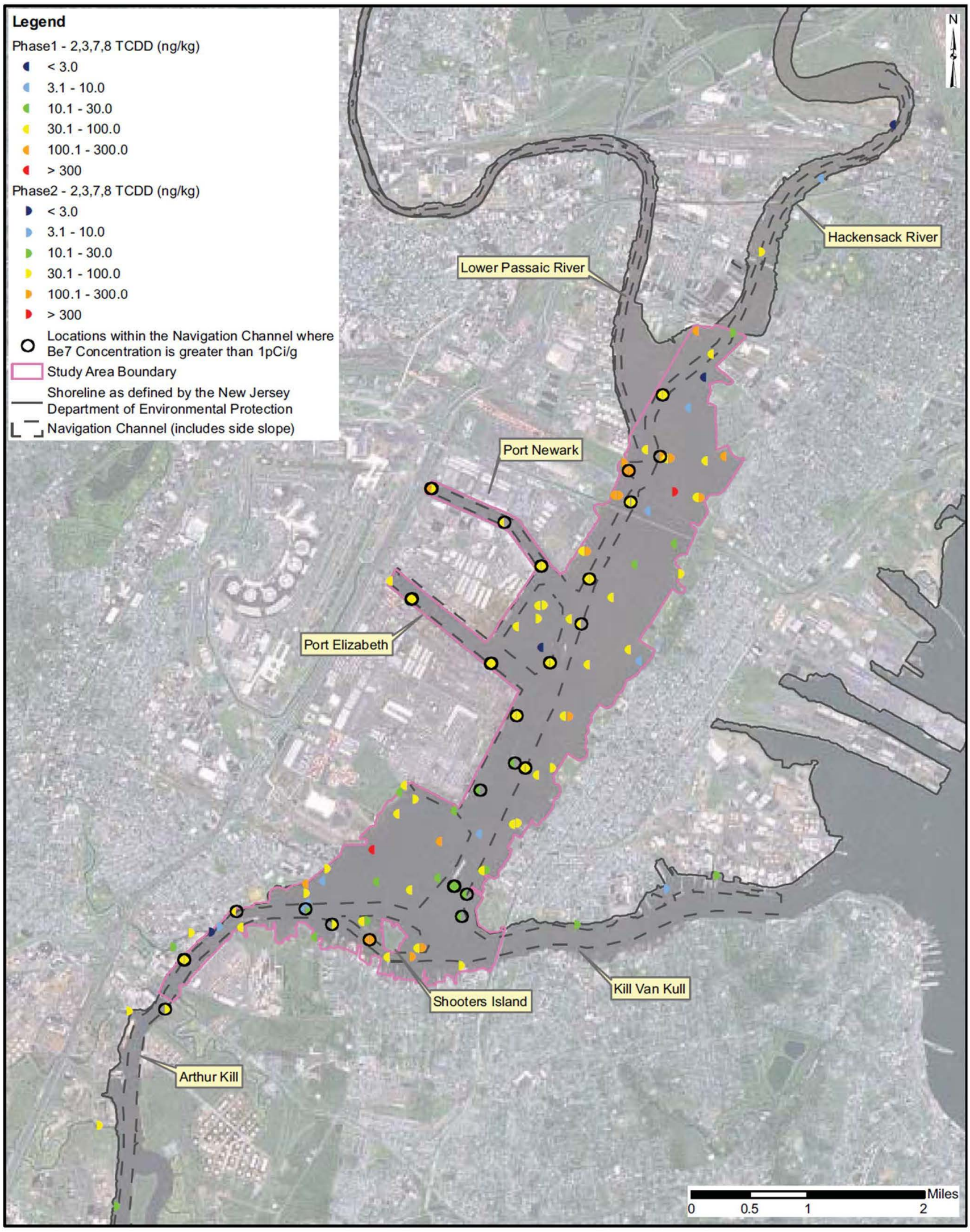
1. TOC surface concentrations represent the top 6 inches of the core.
2. When duplicate TOC values are provided by the laboratory, the average concentration is plotted.
3. No nondetect TOC concentrations were reported.
4. Beryllium-7 (Be7) analysis was conducted on top 1 inch of sediment. Plot A represents all 119 sample locations from Phase I and Phase II. Plot B represents sampling locations where Be7 concentrations were greater than or equal to 0.5 pCi/g (excludes coring locations that targeted source trackdown). Plot C represents sampling locations where Be7 concentrations were less than 0.5 pCi/g. Plot D represents sampling locations where Be7 concentrations were greater than or equal to 1 pCi/g in the navigational channel.
5. Mile 0 on the plot is equal to River Mile 0 on the Lower Passaic River (at the northern end of the bay). Mile -4.8 represents the confluence of the bay and Kill Van Kull. Mile -4.8 to Mile -9.6 extend south through Arthur Kill (north of Shooters Island). Port Newark plots at Mile - 1.62, and Port Elizabeth plots at Mile -2.51.
6. Data Source: Tierra Solutions, Inc. Newark Bay Phase I and Phase II Data Evaluation and Analysis Report (April 2010). Phase I samples were collected from October-December 2005; Phase II samples were collected from October-December 2007.

TOC Surface Sediment Concentrations

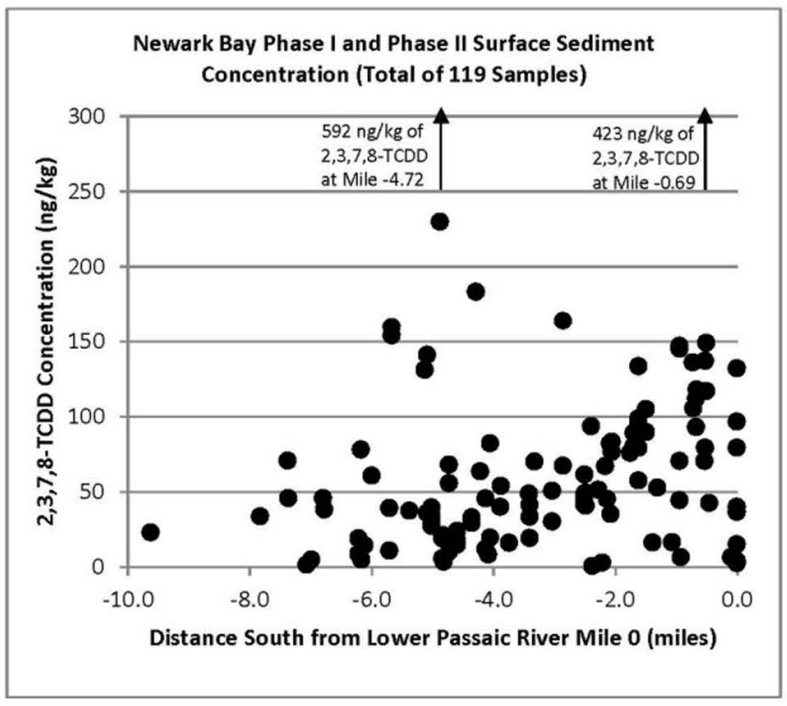
Lower Eight Miles of the Lower Passaic River

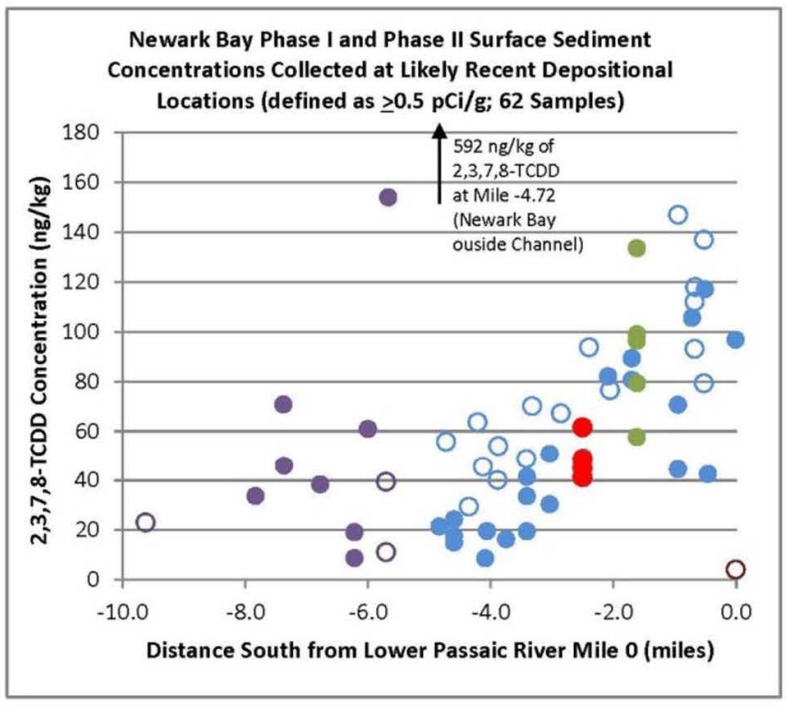
Figure 4-7

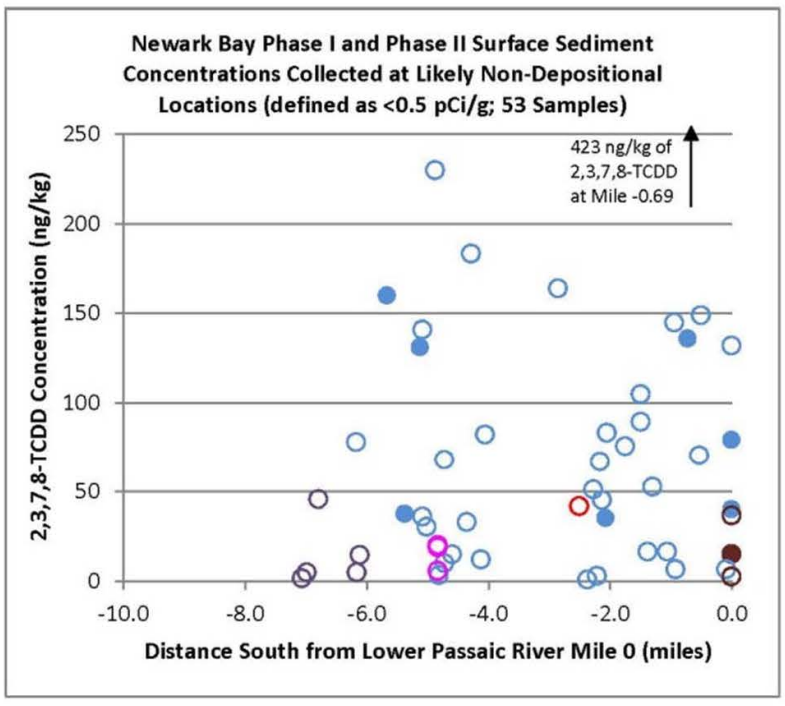
2014

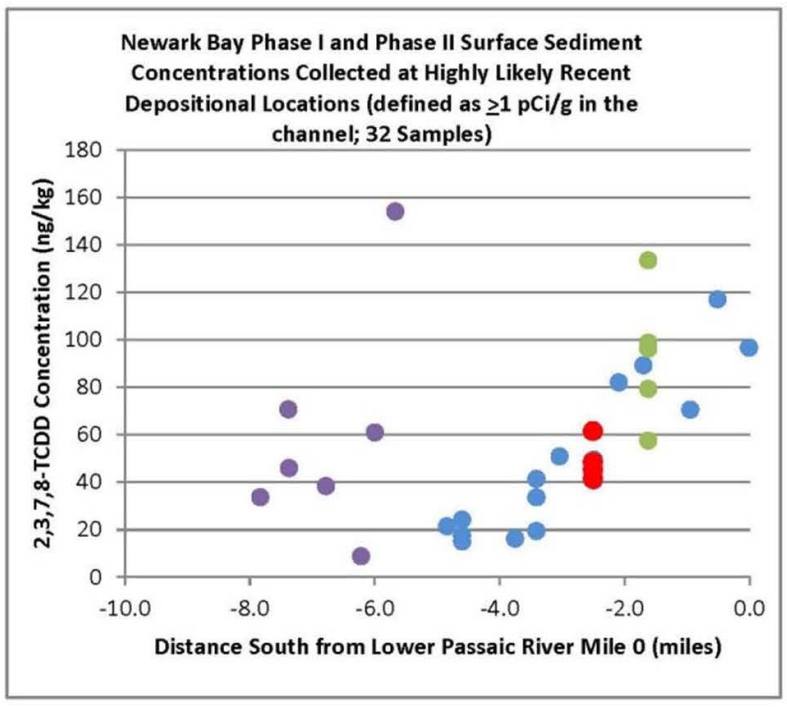


	2,3,7,8-TCDD Concentration in Phase I and Phase II Surface Sediment (0-6 inch) *Lower Eight Miles of the Lower Passaic River*	Figure 4-8 2014









Legend

- All Phase I and II Sampling Locations
- Newark Bay Navigational Channel (includes side slopes)
- Newark Bay Outside of Channel
- Port Elizabeth Navigational Channel (includes side slopes)
- Port Elizabeth Outside of Channel
- Port Newark Navigational Channel (includes side slopes)
- Shooters Island and Arthur Kill Navigational Channel (includes side slopes)
- Shooters Island and Arthur Kill Outside of Channel
- Hackensack River Navigational Channel (includes side slopes)
- Hackensack River Outside of Channel
- Kill Van Kull Outside of Channel

Notes

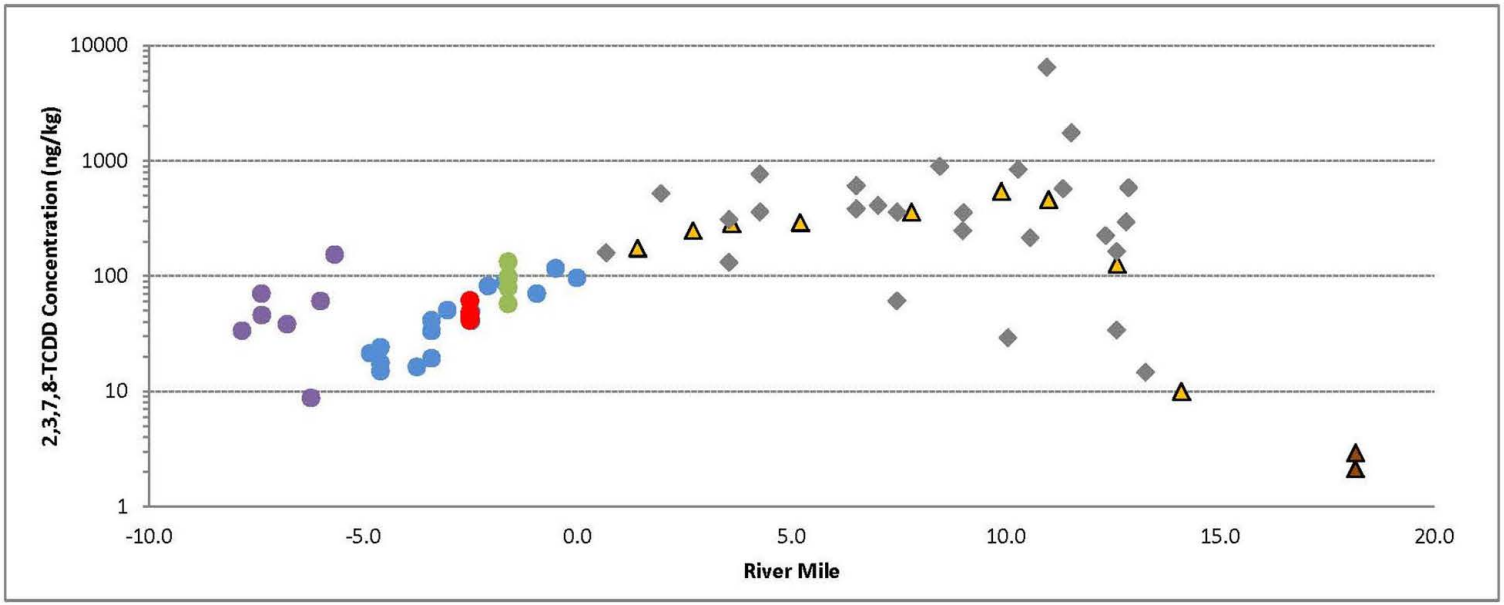
1. 2,3,7,8-TCDD surface concentrations represent the top 6 inches of the core.
2. When duplicate 2,3,7,8-TCDD values are provided by the laboratory, the average concentration is plotted.
3. No nondetect 2,3,7,8-TCDD concentrations were reported in surface sediment samples.
4. Beryllium-7 (Be7) analysis was conducted on top 1 inch of sediment. Plot A represents all 119 sample locations from Phase I and Phase II. Plot B represents sampling locations where Be7 concentrations were greater than or equal to 0.5 pCi/g (excludes coring locations that targeted source trackdown). Plot C represents sampling locations where Be7 concentrations were less than 0.5 pCi/g. Plot D represents sampling locations where Be7 concentrations were greater than or equal to 1 pCi/g in the navigational channel.
5. Mile 0 on the plot is equal to River Mile 0 on the Lower Passaic River (at the northern end of the bay). Mile -4.8 represents the confluence of the bay and Kill Van Kull. Mile -4.8 to Mile -9.6 extend south through Arthur Kill (north of Shooters Island). Port Newark plots at Mile -1.62, and Port Elizabeth plots at Mile -2.51.
6. Data Source: Tierra Solutions, Inc. Newark Bay Phase I and Phase II Data Evaluation and Analysis Report (April 2010). Phase I samples were collected from October-December 2005; Phase II samples were collected from October-December 2007.

2,3,7,8-TCDD Surface Sediment Concentrations in Newark Bay

Lower Eight Miles of the Lower Passaic River

Figure 4-9

2014



Legend

- Newark Bay Navigational Channel (includes side slopes; TSI 2005/2007)
- Port Elizabeth Navigational Channel (includes side slopes; TSI 2005/2007)
- Port Newark Navigational Channel (includes side slopes; TSI 2005/2007)
- Shooters Island and Arthur Kill Navigational Channel (includes side slopes; TSI 2005/2007)
- Lower Passaic River (MPI 2008)
- Upper Passaic River (MPI 2008)
- Lower Passaic River (CPG 2008)

Notes

1- Newark Bay Phase I and Phase II surface sediment concentrations collected at highly likely recent depositional locations (defined as ≥1 pCi/g in the channel; 32 samples).

2- Lower Passaic River surface sediment concentrations collected at likely recent depositional locations (defined as ≥0.5 pCi/g in the channel; 9 samples).

3- Upper Passaic River surface sediment concentrations collected at likely recent depositional locations (defined as ≥0.5 pCi/g in the channel; 2 samples).

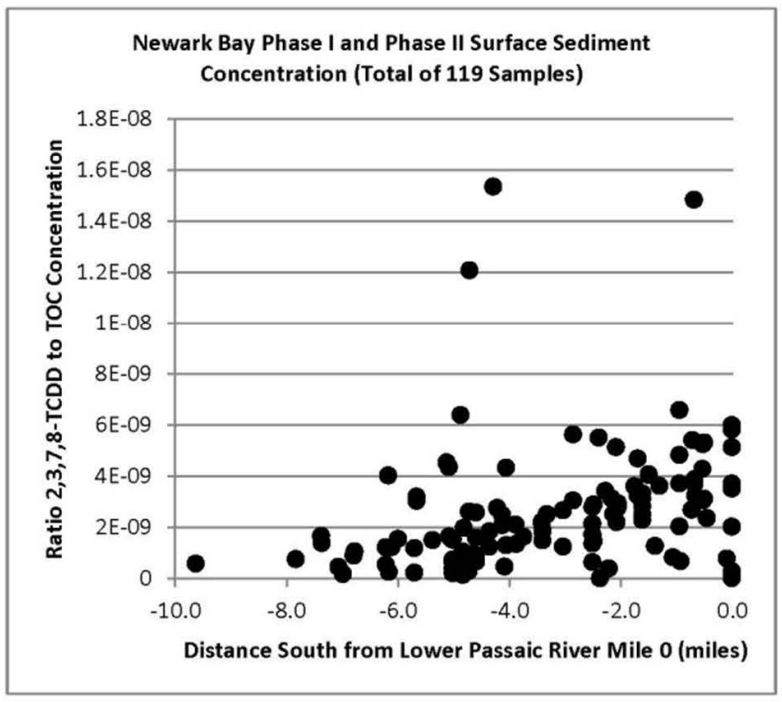
4- Lower Passaic River CPG 2008 surface sediment concentrations collected at highly likely recent depositional locations (defined as ≥1 pCi/g; 26 samples).

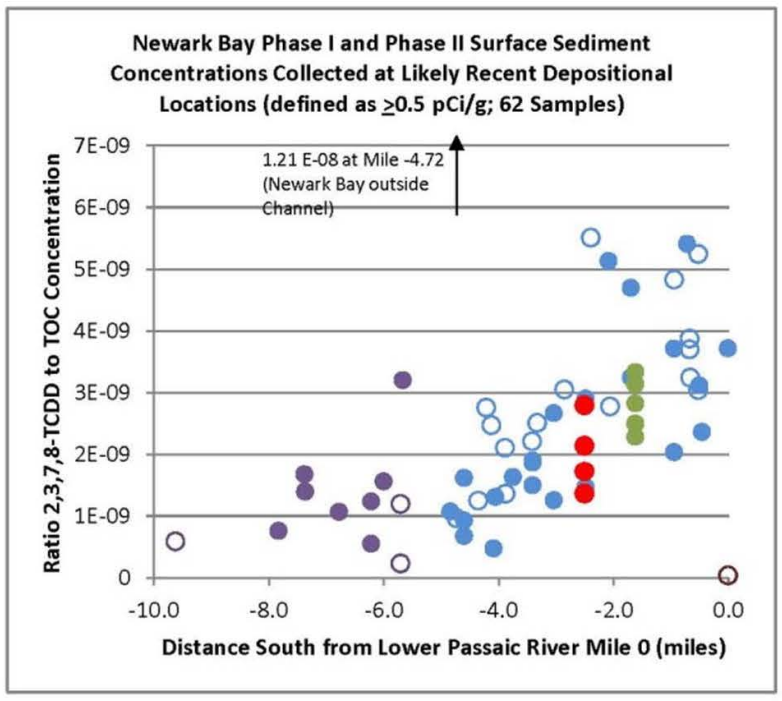
2,3,7,8-TCDD Surface Sediment Concentrations in Newark Bay, Lower and Upper Passaic River

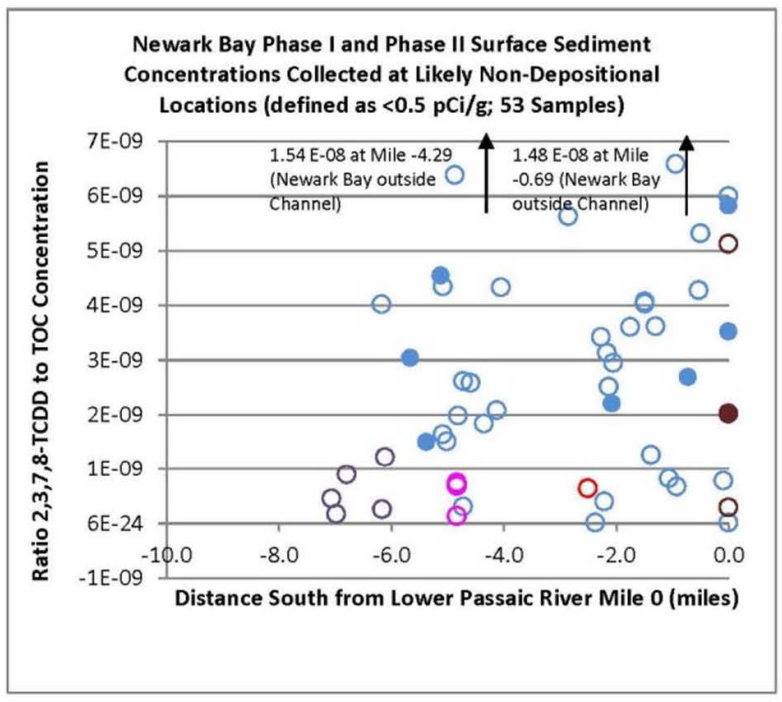
Lower Eight Miles of the Lower Passaic River

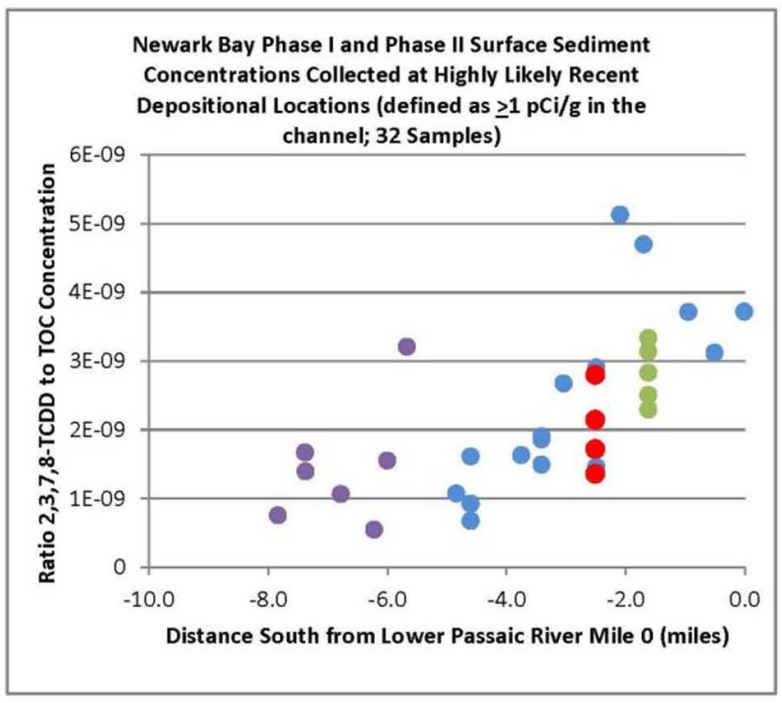
Figure 4-10

2014









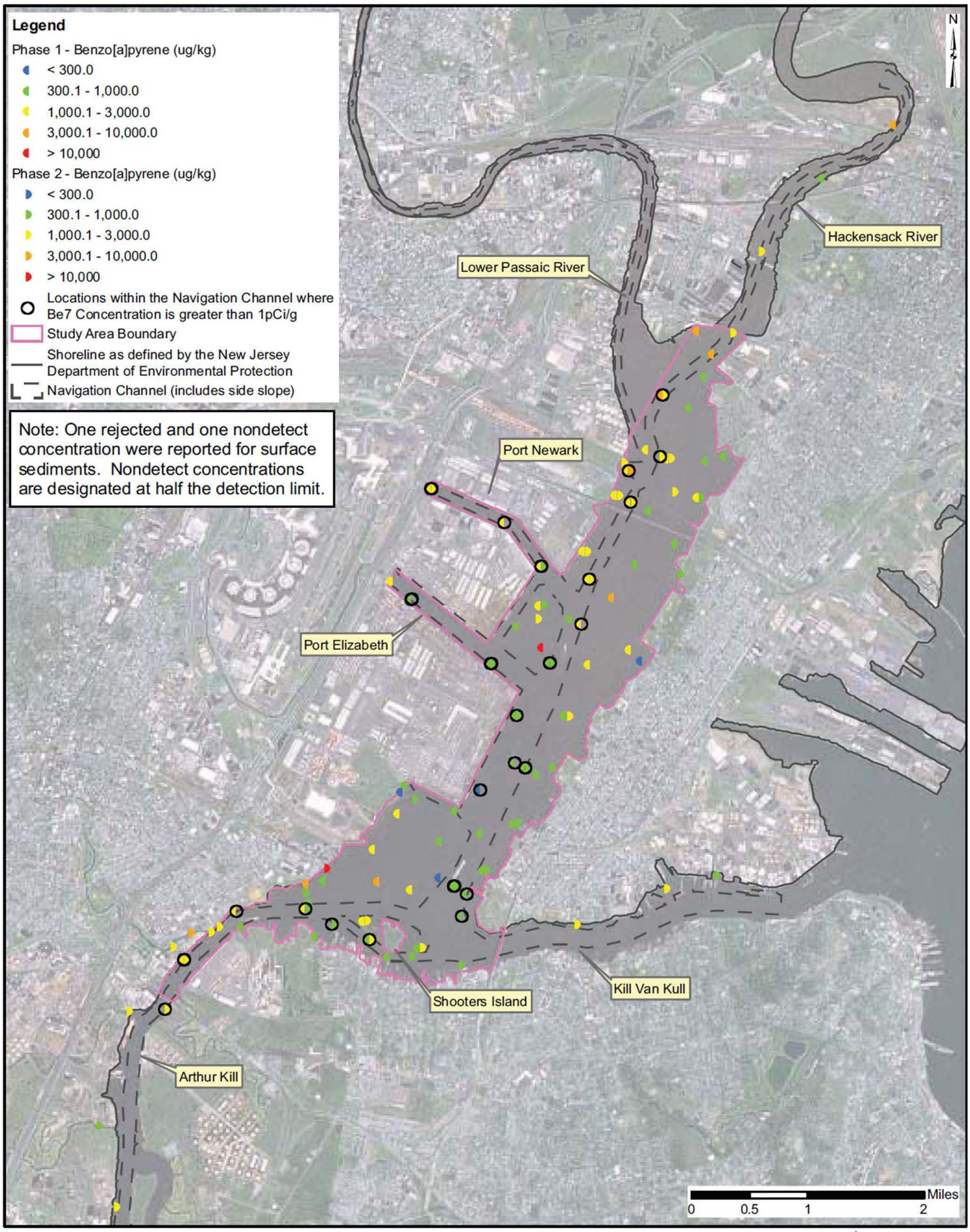
Legend

- All Phase I and II Sampling Locations
- Newark Bay Navigational Channel (includes side slopes)
- Newark Bay Outside of Channel
- Port Elizabeth Navigational Channel (includes side slopes)
- Port Elizabeth Outside of Channel
- Port Newark Navigational Channel (includes side slopes)
- Shooters Island and Arthur Kill Navigational Channel (includes side slopes)
- Shooters Island and Arthur Kill Outside of Channel
- Hackensack River Navigational Channel (includes side slopes)
- Hackensack River Outside of Channel
- Kill Van Kull Outside of Channel

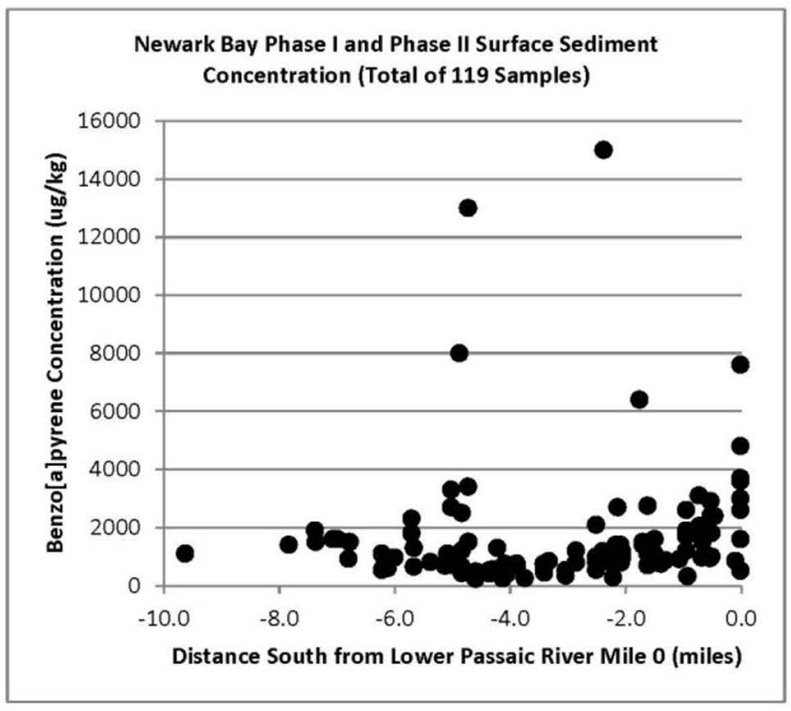
Notes

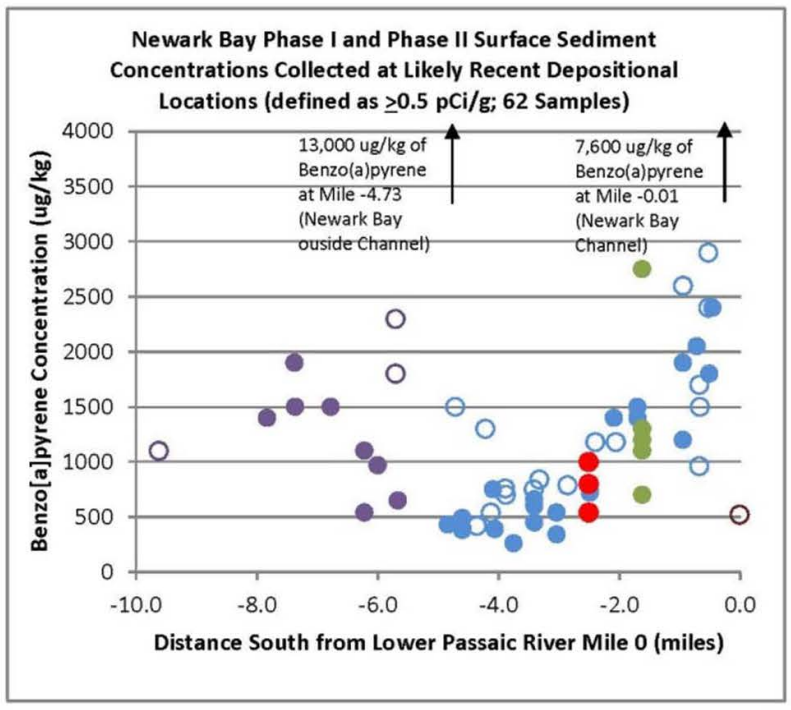
1. 2,3,7,8-TCDD and TOC and iron surface concentrations represent the top 6 inches of the core.
2. When duplicate 2,3,7,8-TCDD and TOC values are provided by the laboratory, the average concentration is used in the ratio.
3. No nondetect 2,3,7,8-TCDD and TOC concentrations were reported in surface sediment samples.
4. Beryllium-7 (Be7) analysis was conducted on top 1 inch of sediment. Plot A represents all 119 sample locations from Phase I and Phase II. Plot B represents sampling locations where Be7 concentrations were greater than or equal to 0.5 pCi/g (excludes coring locations that targeted source trackdown). Plot C represents sampling locations where Be7 concentrations were less than 0.5 pCi/g. Plot D represents sampling locations where Be7 concentrations were greater than or equal to 1 pCi/g in the navigational channel.
5. Mile 0 on the plot is equal to River Mile 0 on the Lower Passaic River (at the northern end of the bay). Mile -4.8 represents the confluence of the bay and Kill Van Kull. Mile -4.8 to Mile -9.6 extend south through Arthur Kill (north of Shooters Island). Port Newark plots at Mile - 1.62, and Port Elizabeth plots at Mile -2.51.
6. Data Source: Tierra Solutions, Inc. Newark Bay Phase I and Phase II Data Evaluation and Analysis Report (April 2010). Phase I samples were collected from October-December 2005; Phase II samples were collected from October-December 2007.

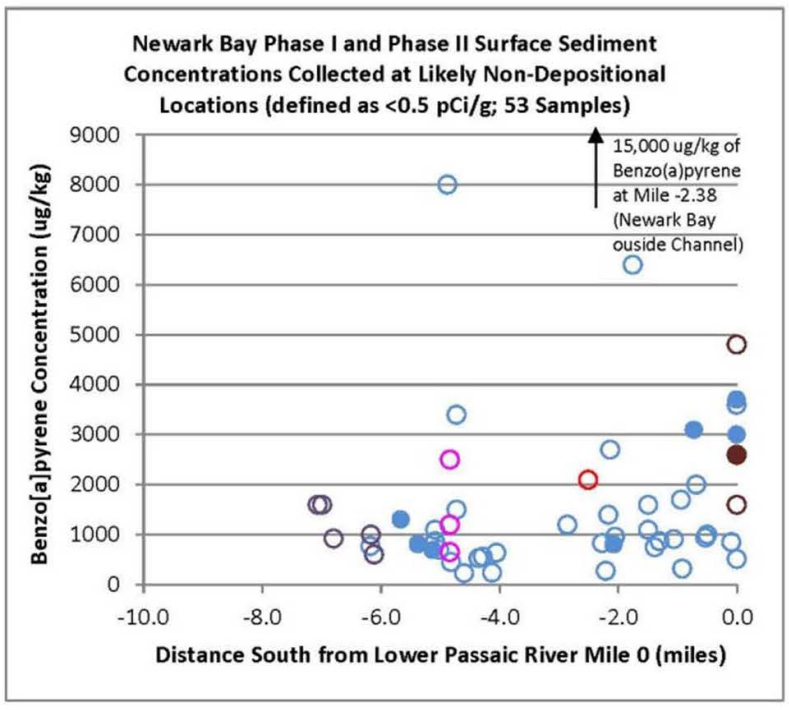
	Ratio of 2,3,7,8-TCDD to TOC Surface Sediment Concentrations	Figure 4-11
	Lower Eight Miles of the Lower Passaic River	2014

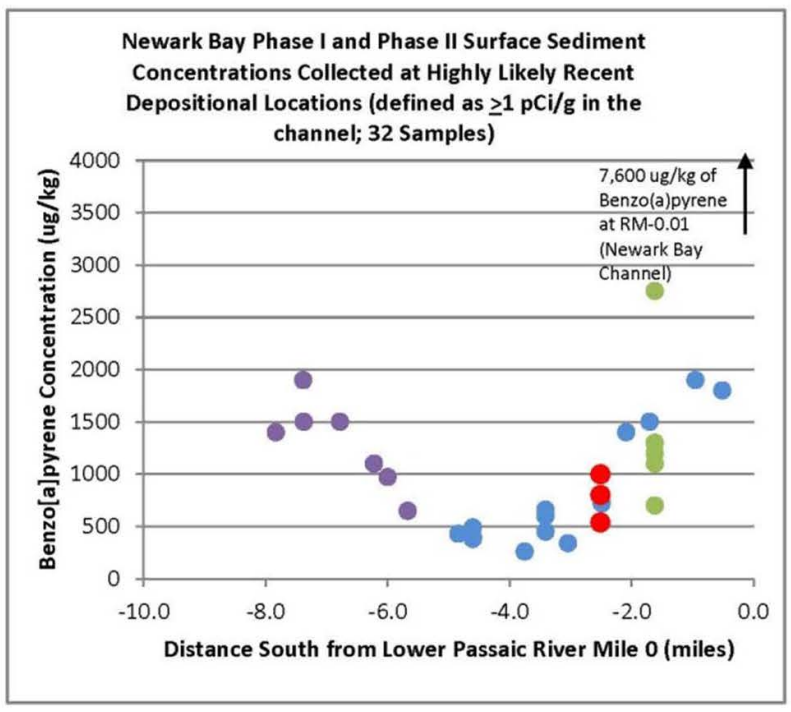


	Benzo(a)pyrene Concentration in Phase 1 and Phase 2 Surface Sediment (0-6 inch) *Lower Eight Miles of the Lower Passaic River*	Figure 4-12 2014









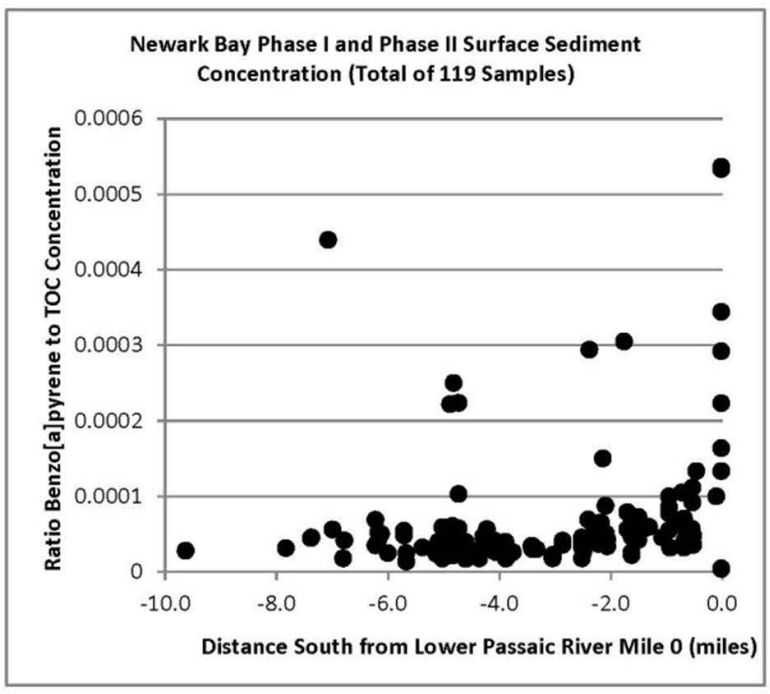
Legend

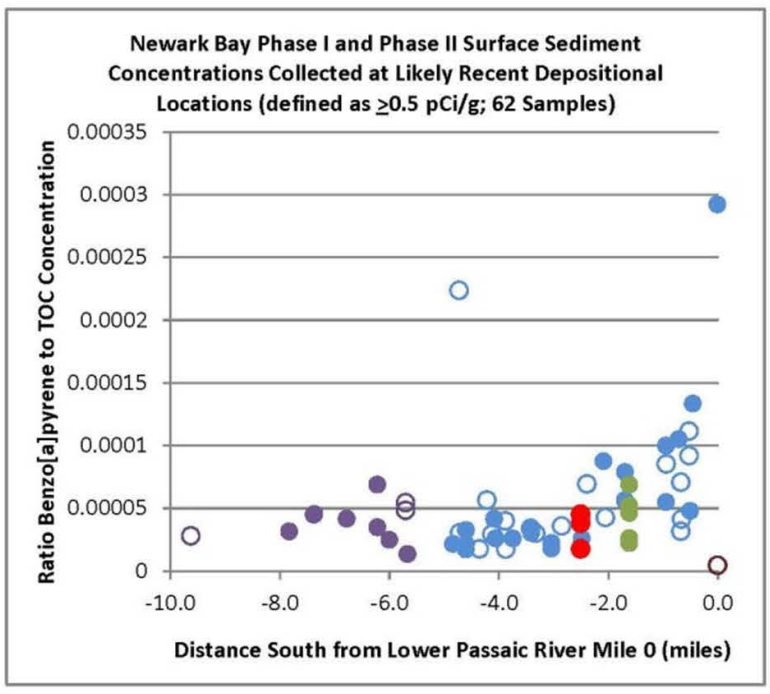
- All Phase I and II Sampling Locations
- Newark Bay Navigational Channel (includes side slopes)
- Newark Bay Outside of Channel
- Port Elizabeth Navigational Channel (includes side slopes)
- Port Elizabeth Outside of Channel
- Port Newark Navigational Channel (includes side slopes)
- Shooters Island and Arthur Kill Navigational Channel (includes side slopes)
- Shooters Island and Arthur Kill Outside of Channel
- Hackensack River Navigational Channel (includes side slopes)
- Hackensack River Outside of Channel
- Kill Van Kull Outside of Channel

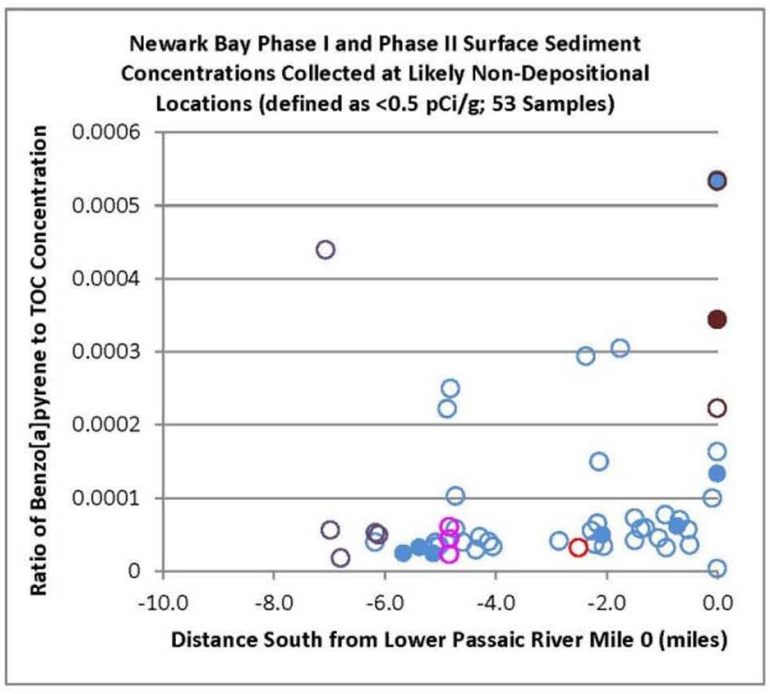
Notes

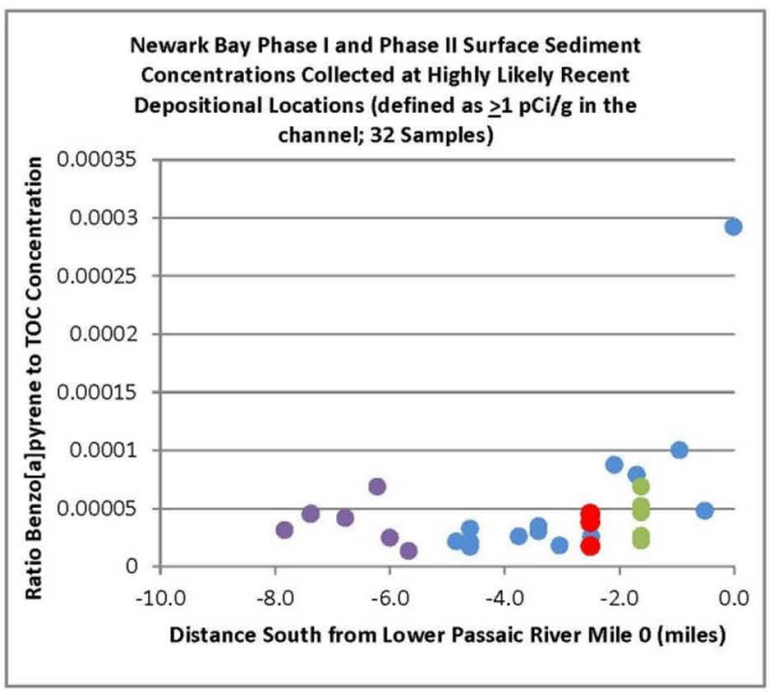
1. Benzo[a]pyrene surface concentrations represent the top 6 inches of the core.
2. When duplicate benzo[a]pyrene values are provided by the laboratory, the average concentration is plotted.
3. One rejected and one nondetect benzo[a]pyrene concentration were reported for surface sediments. Nondetect concentrations are presented at half the detection limit.
4. Beryllium-7 (Be7) analysis was conducted on top 1 inch of sediment. Plot A represents all 119 sample locations from Phase I and Phase II. Plot B represents sampling locations where Be7 concentrations were greater than or equal to 0.5 pCi/g (excludes coring locations that targeted source trackdown). Plot C represents sampling locations where Be7 concentrations were less than 0.5 pCi/g. Plot D represents sampling locations where Be7 concentrations were greater than or equal to 1 pCi/g in the navigational channel.
5. Mile 0 on the plot is equal to River Mile 0 on the Lower Passaic River (at the northern end of the bay). Mile -4.8 represents the confluence of the bay and Kill Van Kull. Mile -4.8 to Mile -9.6 extend south through Arthur Kill (north of Shooters Island). Port Newark plots at Mile - 1.62, and Port Elizabeth plots at Mile -2.51.
6. Data Source: Tierra Solutions, Inc. Newark Bay Phase I and Phase II Data Evaluation and Analysis Report (April 2010). Phase I samples were collected from October-December 2005; Phase II samples were collected from October-December 2007.

	Benzo(a)pyrene Surface Sediment Concentrations in Newark Bay *Lower Eight Miles of the Lower Passaic River*	Figure 4-13 2014









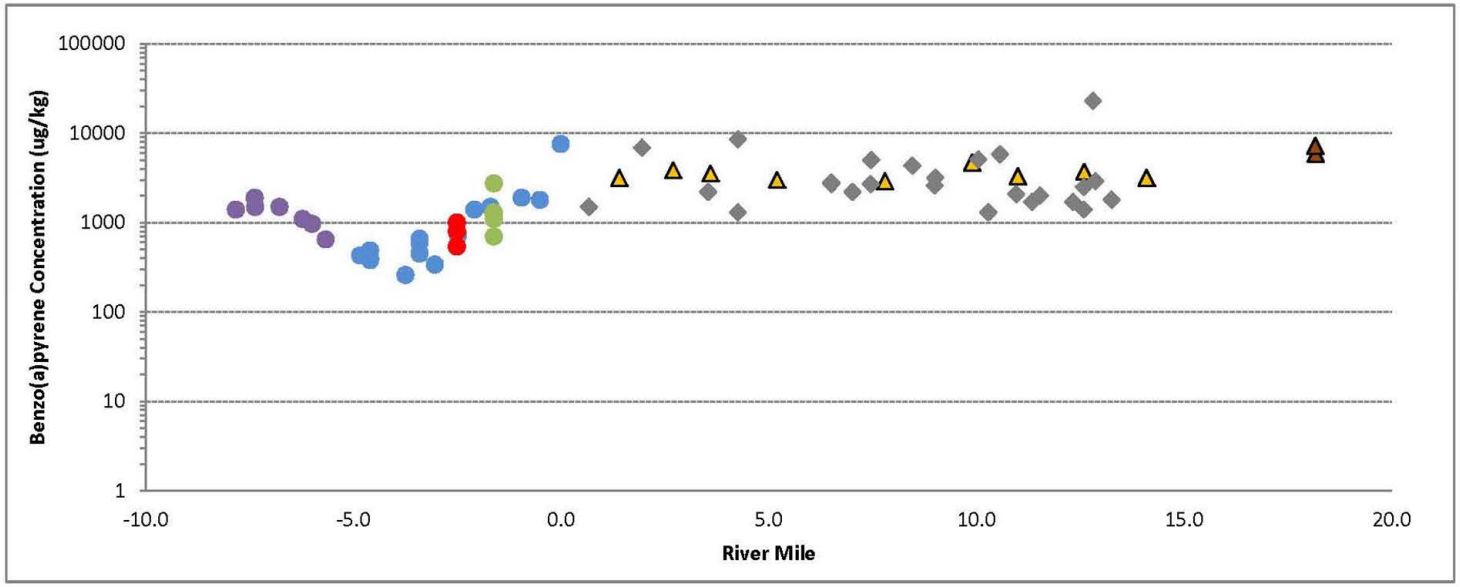
Legend

- All Phase I and II Sampling Locations
- Newark Bay Navigational Channel (includes side slopes)
- Newark Bay Outside of Channel
- Port Elizabeth Navigational Channel (includes side slopes)
- Port Elizabeth Outside of Channel
- Port Newark Navigational Channel (includes side slopes)
- Shooters Island and Arthur Kill Navigational Channel (includes side slopes)
- Shooters Island and Arthur Kill Outside of Channel
- Hackensack River Navigational Channel (includes side slopes)
- Hackensack River Outside of Channel
- Kill Van Kull Outside of Channel

Notes

1. Benzo[a]pyrene and TOC surface concentrations represent the top 6 inches of the core.
2. When duplicate benzo[a]pyrene or TOC values are provided by the laboratory, the average concentration is used in the ratio.
3. No nondetect TOC concentrations were reported. One rejected and one nondetect benzo[a]pyrene concentration were reported for surface sediments. Nondetect concentrations are presented as half the detection limit.
4. Beryllium-7 (Be7) analysis was conducted on top 1 inch of sediment. Plot A represents all 119 sample locations from Phase I and Phase II. Plot B represents sampling locations where Be7 concentrations were greater than or equal to 0.5 pCi/g (excludes coring locations that targeted source trackdown). Plot C represents sampling locations where Be7 concentrations were less than 0.5 pCi/g. Plot D represents sampling locations where Be7 concentrations were greater than or equal to 1 pCi/g in the navigational channel.
5. Mile 0 on the plot is equal to River Mile 0 on the Lower Passaic River (at the northern end of the bay). Mile -4.8 represents the confluence of the bay and Kill Van Kull. Mile -4.8 to Mile -9.6 extend south through Arthur Kill (north of Shooters Island). Port Newark plots at Mile -1.62, and Port Elizabeth plots at Mile -2.51.
6. Data Source: Tierra Solutions, Inc. Newark Bay Phase I and Phase II Data Evaluation and Analysis Report (April 2010). Phase I samples were collected from October-December 2005; Phase II samples were collected from October-December 2007.

	Ratio of Benzo(a)pyrene to TOC Surface Sediment Concentrations *Lower Eight Miles of the Lower Passaic River*	Figure 4-14 2014



Legend

- Newark Bay Navigational Channel (includes side slopes; TSI 2005/2007)
- Port Elizabeth Navigational Channel (includes side slopes; TSI 2005/2007)
- Port Newark Navigational Channel (includes side slopes; TSI 2005/2007)
- Shooters Island and Arthur Kill Navigational Channel (includes side slopes; TSI 2005/2007)
- Lower Passaic River (MPI 2008)
- Upper Passaic River (MPI 2008)
- Lower Passaic River (CPG 2008)

Notes

1- Newark Bay Phase I and Phase II surface sediment concentrations collected at highly likely recent depositional locations (defined as ≥1 pCi/g in the channel; 31 samples).

2- Lower Passaic River surface sediment concentrations collected at likely recent depositional locations (defined as ≥0.5 pCi/g in the channel; 9 samples).

3- Upper Passaic River surface sediment concentrations collected at likely recent depositional locations (defined as ≥0.5 pCi/g in the channel; 2 samples).

4- Lower Passaic River CPG 2008 surface sediment concentrations collected at highly likely recent depositional locations (defined as ≥1 pCi/g; 26 samples).

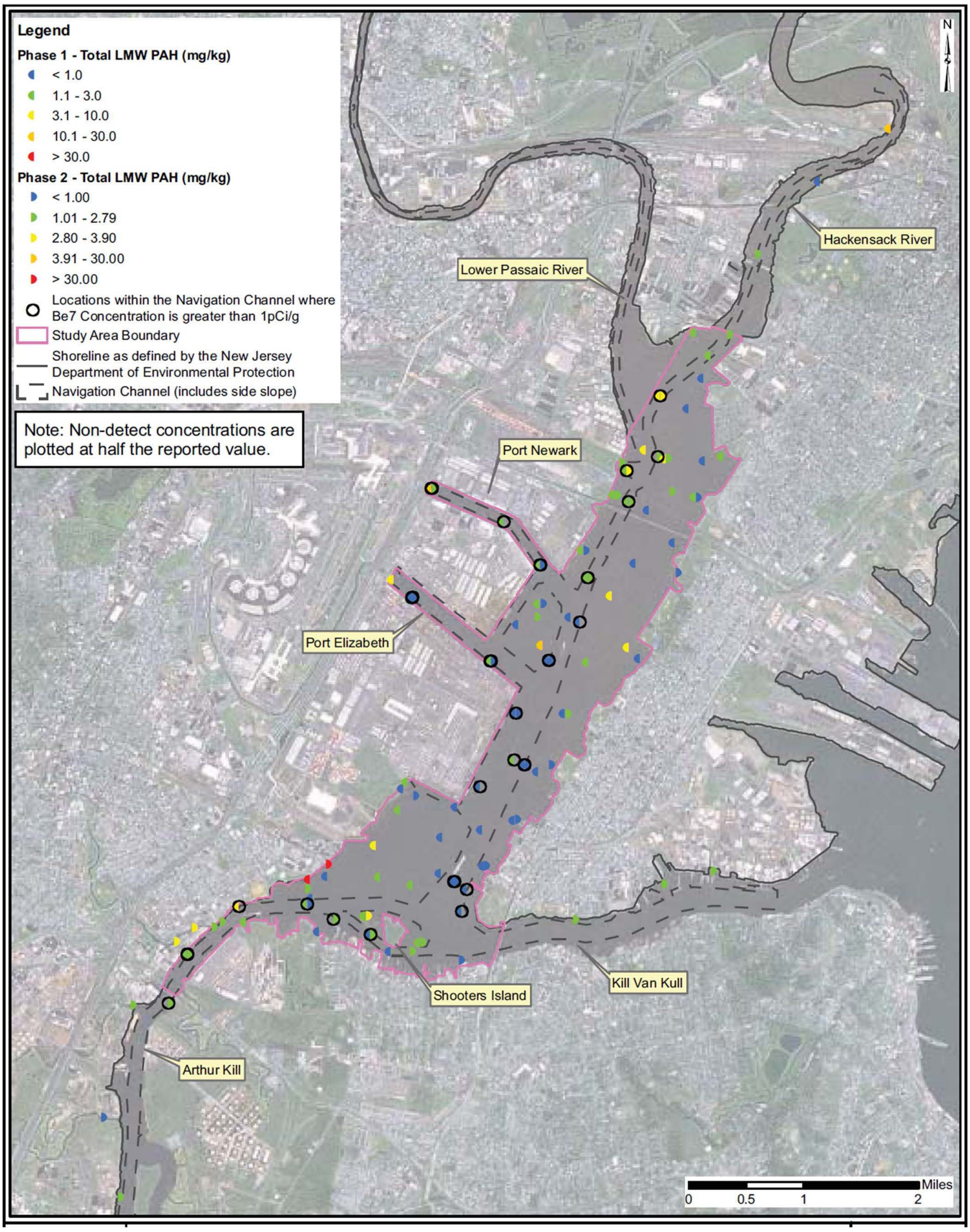
5- All nondetect concentrations are presented at half the detection limit and rejected concentrations are not represented on the plot.

Benzo(a)pyrene Surface Sediment Concentrations in Newark Bay, Lower and Upper Passaic River

Lower Eight Miles of the Lower Passaic River

Figure 4-15

2014

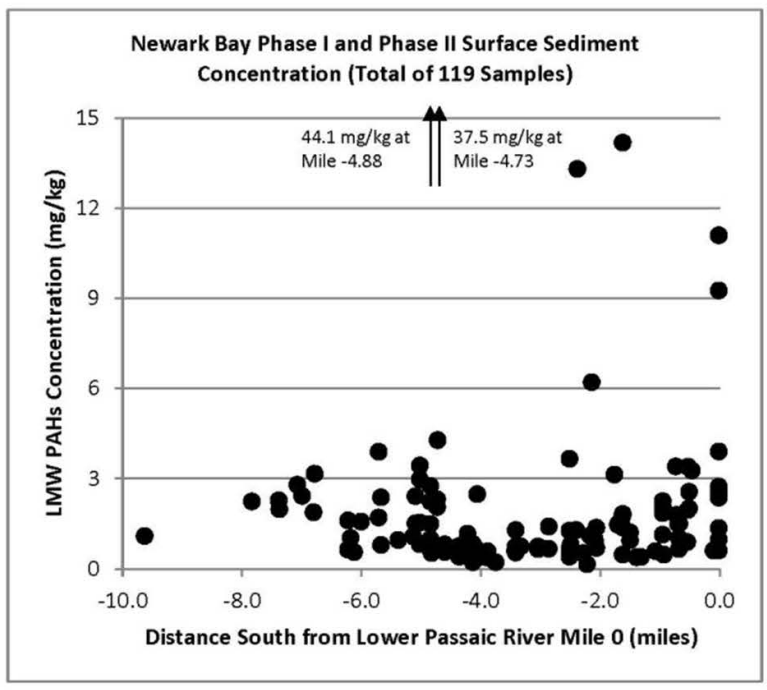


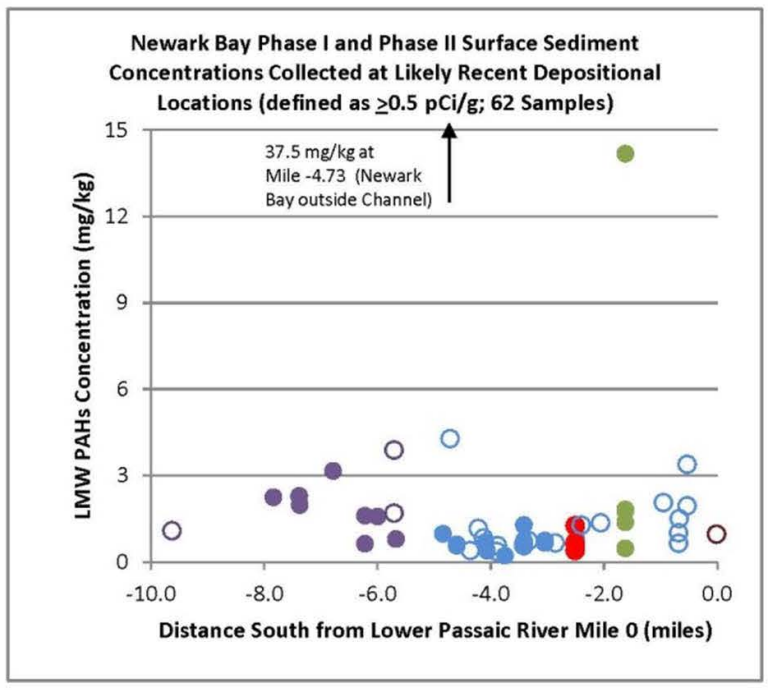
Low Molecular Weight PAH Concentration in Phase I and Phase II Surface Sediment (0-6 inch)

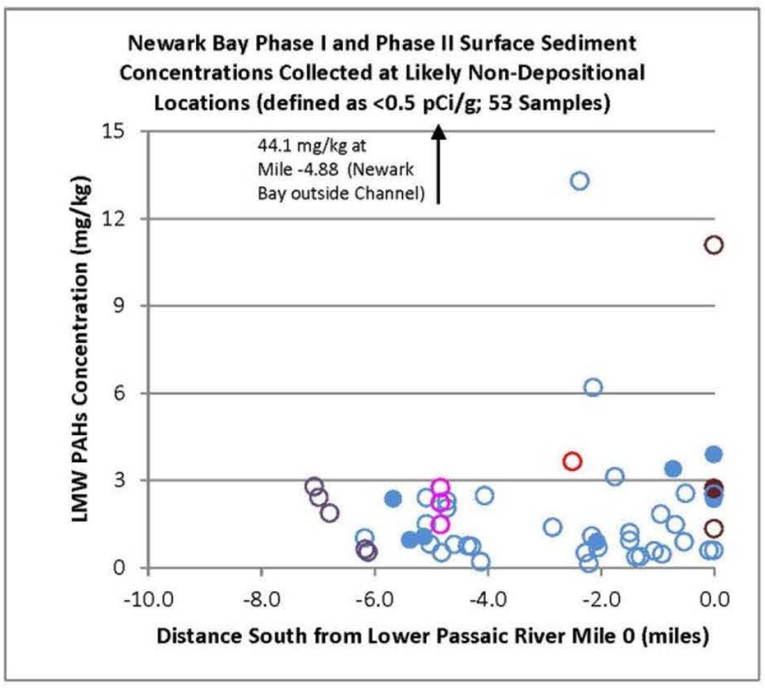
Lower Eight Miles of the Lower Passaic River

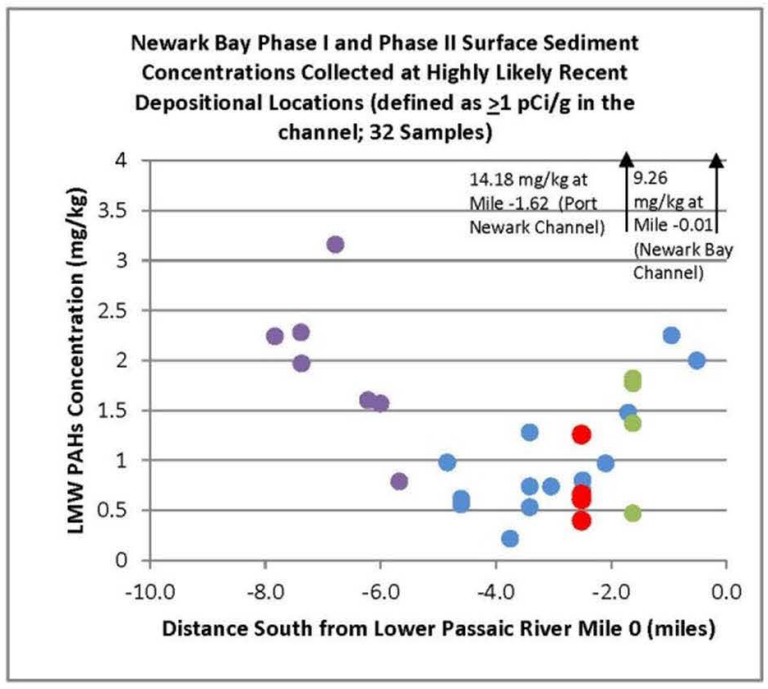
Figure 4-16

2014









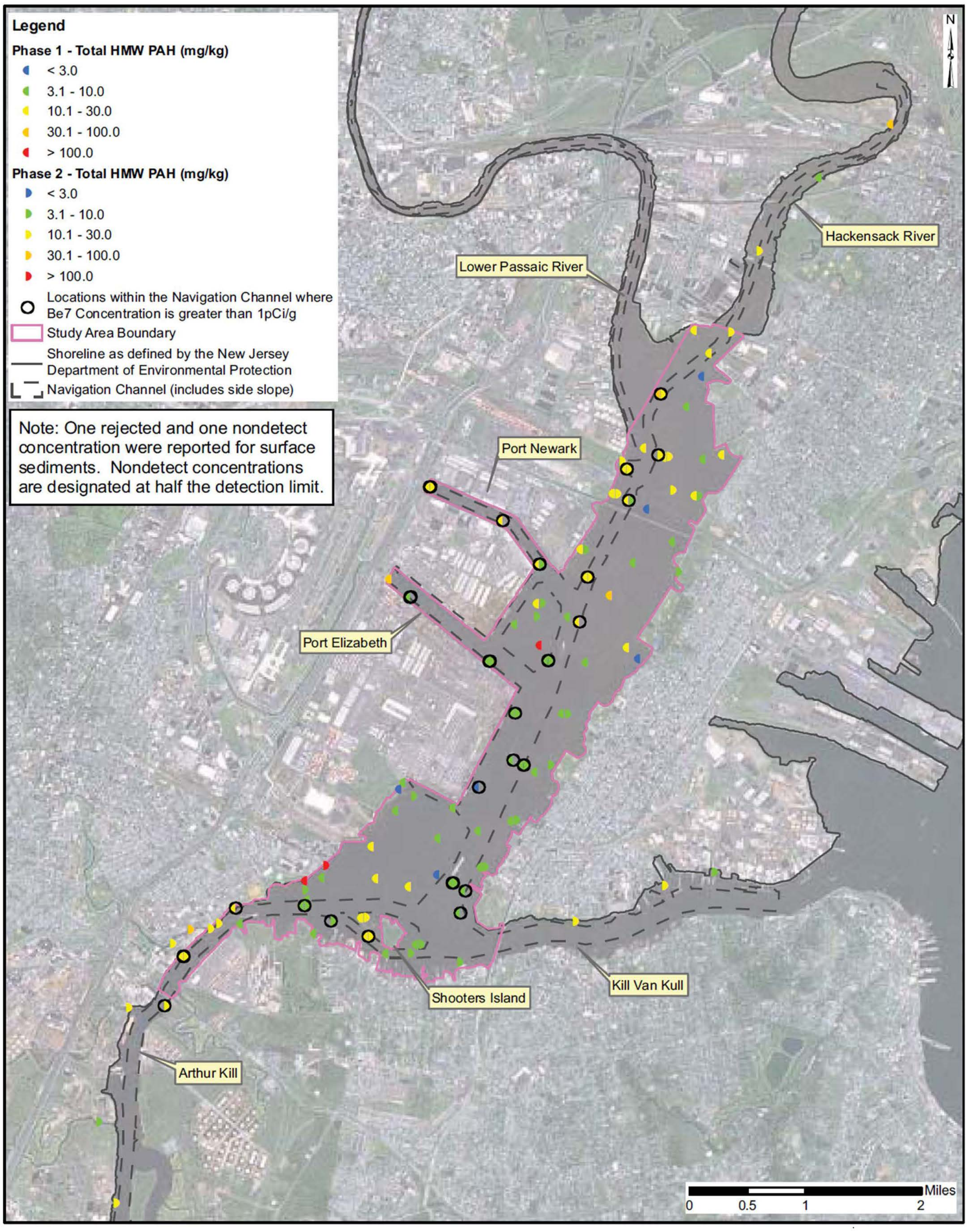
Legend

- All Phase I and II Sampling Locations
- Newark Bay Navigational Channel (includes side slopes)
- Newark Bay Outside of Channel
- Port Elizabeth Navigational Channel (includes side slopes)
- Port Elizabeth Outside of Channel
- Port Newark Navigational Channel (includes side slopes)
- Shooters Island and Arthur Kill Navigational Channel (includes side slopes)
- Shooters Island and Arthur Kill Outside of Channel
- Hackensack River Navigational Channel (includes side slopes)
- Hackensack River Outside of Channel
- Kill Van Kull Outside of Channel

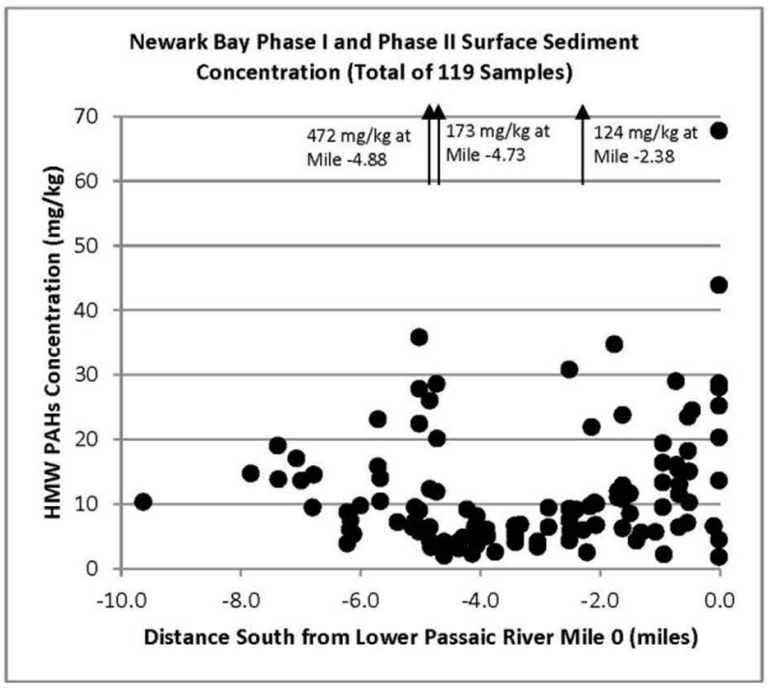
Notes

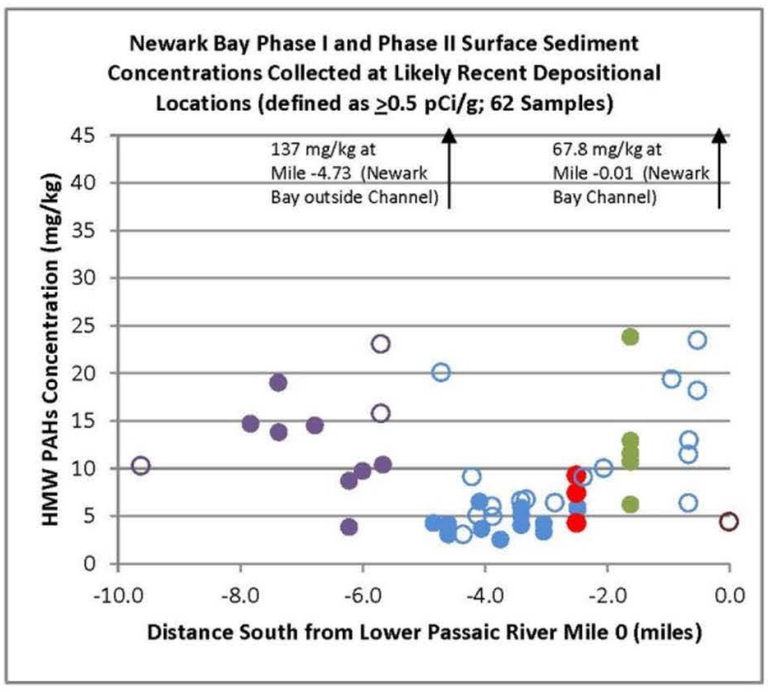
1. Low molecular weight PAHs surface concentrations represent the top 6 inches of the core.
2. When duplicate low molecular weight PAHs values were provided by the laboratory, the average concentration is plotted.
3. Four nondetect low molecular weight PAHs concentrations were reported for surface sediments. Nondetect concentrations are presented as half the sample result value.
4. Beryllium-7 (Be7) analysis was conducted on top 1 inch of sediment. Plot A represents all 119 sample locations from Phase I and Phase II. Plot B represents sampling locations where Be7 concentrations were greater than or equal to 0.5 pCi/g (excludes coring locations that targeted source trackdown). Plot C represents sampling locations where Be7 concentrations were less than 0.5 pCi/g. Plot D represents sampling locations where Be7 concentrations were greater than or equal to 1 pCi/g in the navigational channel.
5. Mile 0 on the plot is equal to River Mile 0 on the Lower Passaic River (at the northern end of the bay). Mile -4.8 represents the confluence of the bay and Kill Van Kull. Mile -4.8 to Mile -9.6 extend south through Arthur Kill (north of Shooters Island). Port Newark plots at Mile - 1.62, and Port Elizabeth plots at Mile -2.51.
6. Data Source: Tierra Solutions, Inc. Newark Bay Phase I and Phase II Data Evaluation and Analysis Report (April 2010). Phase I samples were collected from October-December 2005; Phase II samples were collected from October-December 2007.
7. Low molecular weight PAH concentrations represent laboratory reported totals.
8. LMW = Low Molecular Weight

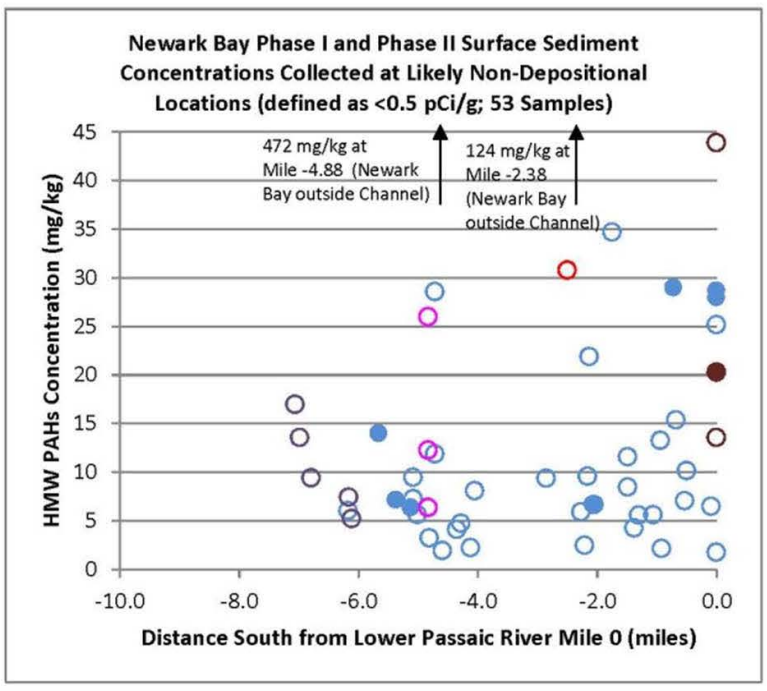
	Low Molecular Weight PAHs Surface Sediment Concentrations *Lower Eight Miles of the Lower Passaic River*	Figure 4-17 2014

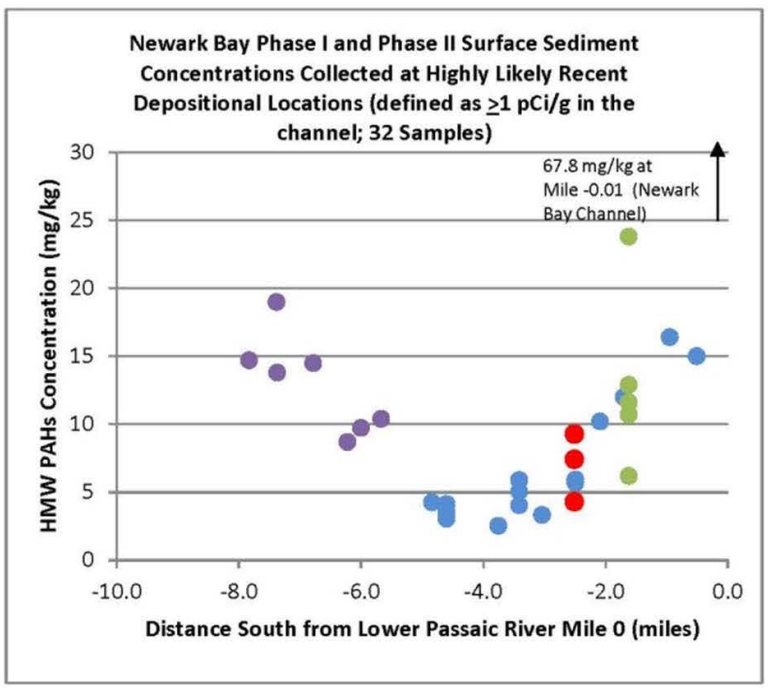


	High Molecular Weight PAH Concentration in Phase I and Phase II Surface Sediment (0-6 inch) *Lower Eight Miles of the Lower Passaic River*	Figure 4-18 2014









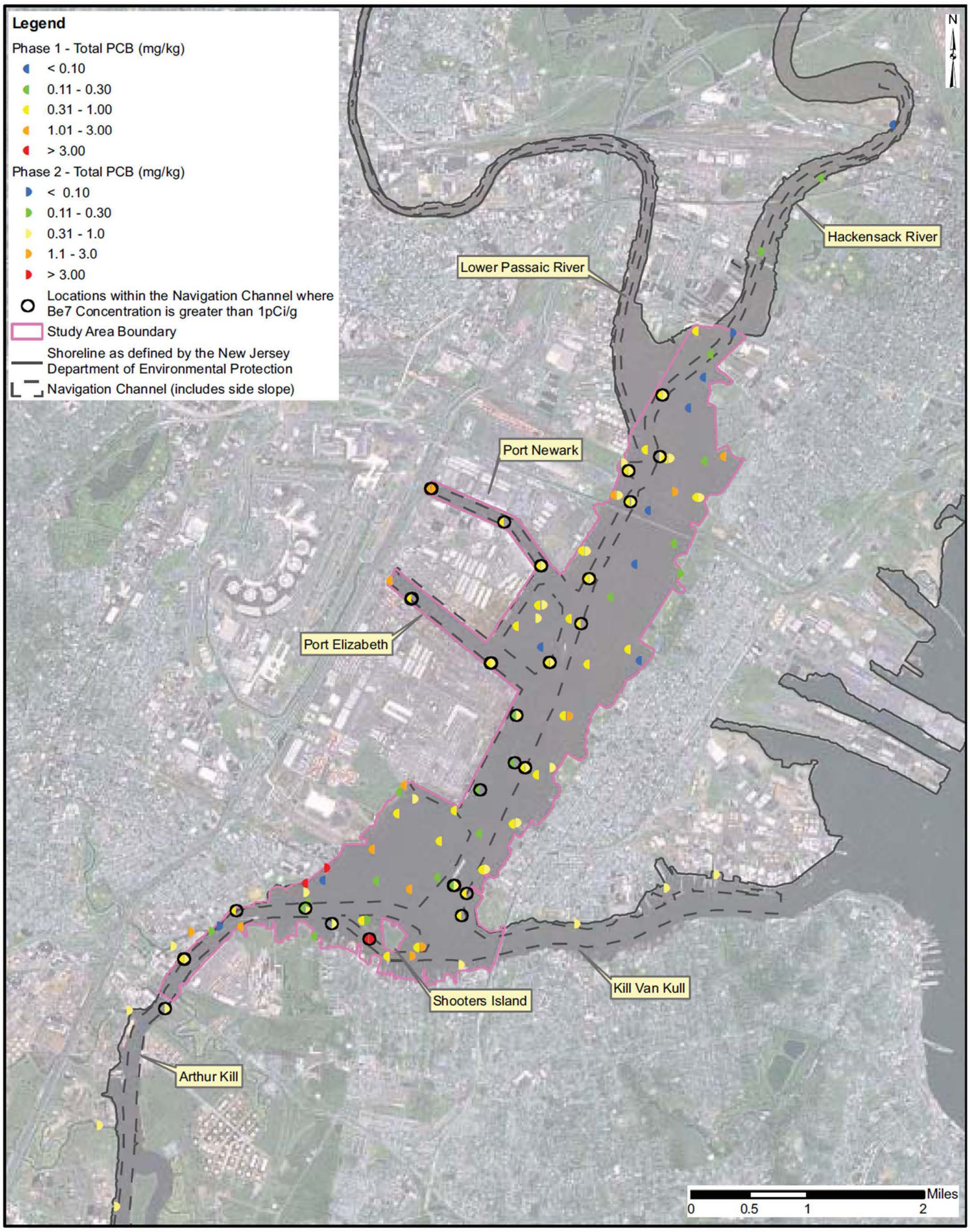
Legend

- All Phase I and II Sampling Locations
- Newark Bay Navigational Channel (includes side slopes)
- Newark Bay Outside of Channel
- Port Elizabeth Navigational Channel (includes side slopes)
- Port Elizabeth Outside of Channel
- Port Newark Navigational Channel (includes side slopes)
- Shooters Island and Arthur Kill Navigational Channel (includes side slopes)
- Shooters Island and Arthur Kill Outside of Channel
- Hackensack River Navigational Channel (includes side slopes)
- Hackensack River Outside of Channel
- Kill Van Kull Outside of Channel

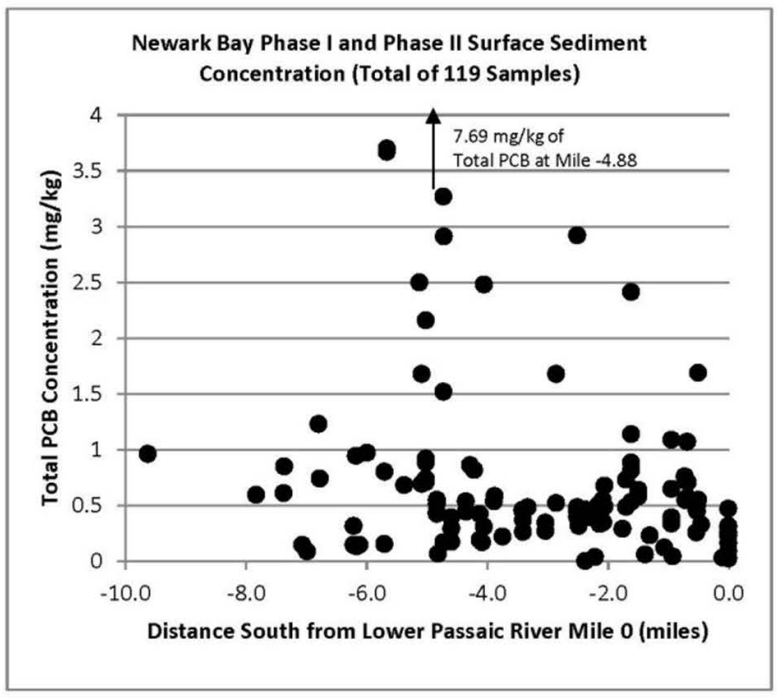
Notes

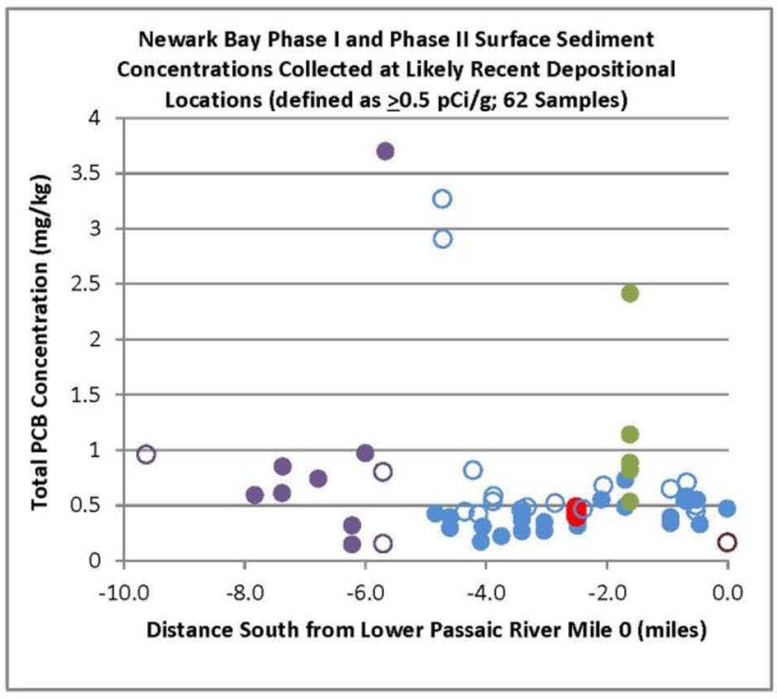
1. High molecular weight PAHs surface concentrations represent the top 6 inches of the core.
2. When duplicate high molecular weight PAHs values are provided by the laboratory, the average concentration is plotted.
3. One rejected and one nondetect high molecular weight PAHs concentration were reported for surface sediments. Nondetect concentrations are presented at half the detection limit.
4. Beryllium-7 (Be7) analysis was conducted on top 1 inch of sediment. Plot A represents all 119 sample locations from Phase I and Phase II. Plot B represents sampling locations where Be7 concentrations were greater than or equal to 0.5 pCi/g (excludes coring locations that targeted source trackdown). Plot C represents sampling locations where Be7 concentrations were less than 0.5 pCi/g. Plot D represents sampling locations where Be7 concentrations were greater than or equal to 1 pCi/g in the navigational channel.
5. Mile 0 on the plot is equal to River Mile 0 on the Lower Passaic River (at the northern end of the bay). Mile -4.8 represents the confluence of the bay and Kill Van Kull. Mile -4.8 to Mile -9.6 extend south through Arthur Kill (north of Shooters Island). Port Newark plots at Mile - 1.62, and Port Elizabeth plots at Mile -2.51.
6. Data Source: Tierra Solutions, Inc. Newark Bay Phase I and Phase II Data Evaluation and Analysis Report (April 2010). Phase I samples were collected from October-December 2005; Phase II samples were collected from October-December 2007.
7. High molecular weight PAH concentrations represent laboratory reported totals.
8. HMW = High Molecular Weight

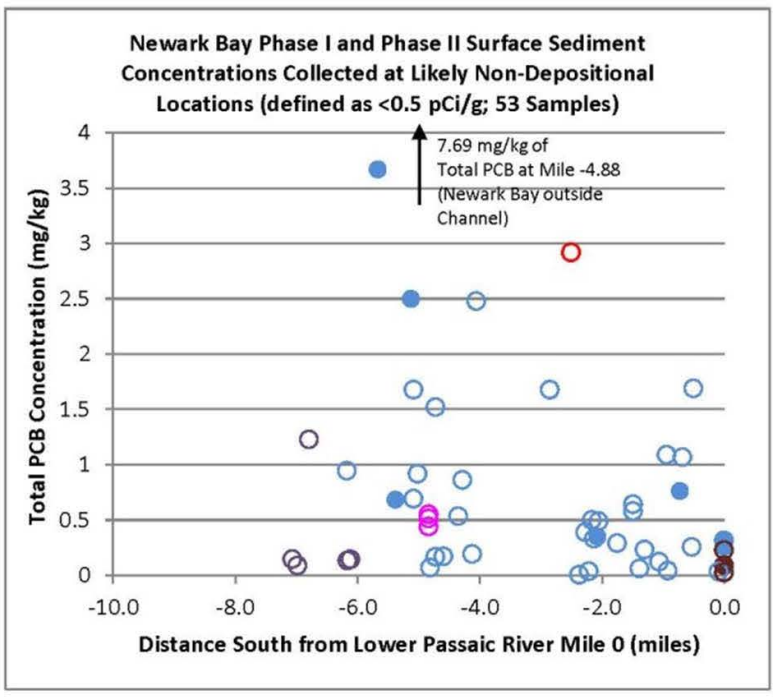
	High Molecular Weight PAHs Surface Sediment Concentrations *Lower Eight Miles of the Lower Passaic River*	Figure 4-19 2014

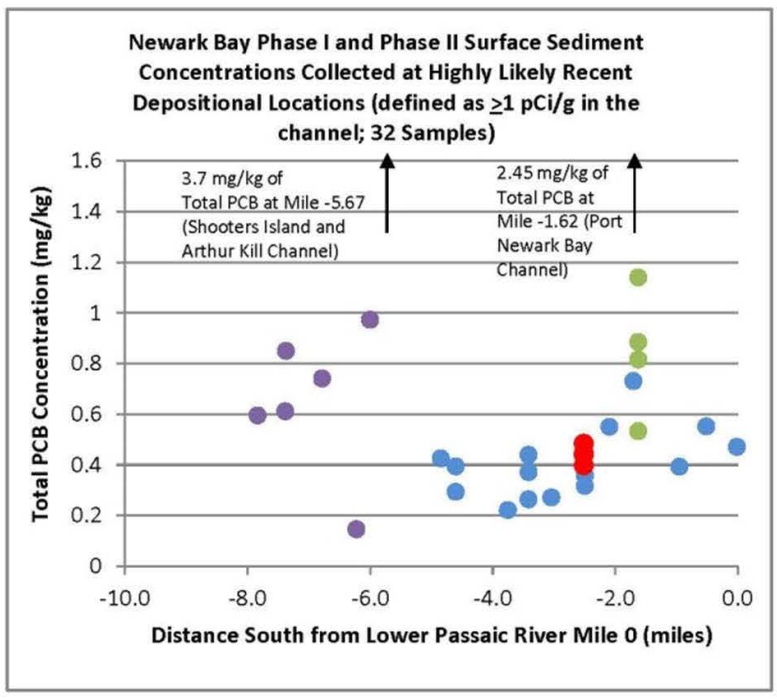


	Total PCB Concentration in Phase I and Phase II Surface Sediment (0-6 inch) *Lower Eight Miles of the Lower Passaic River*	Figure 4-20 2014









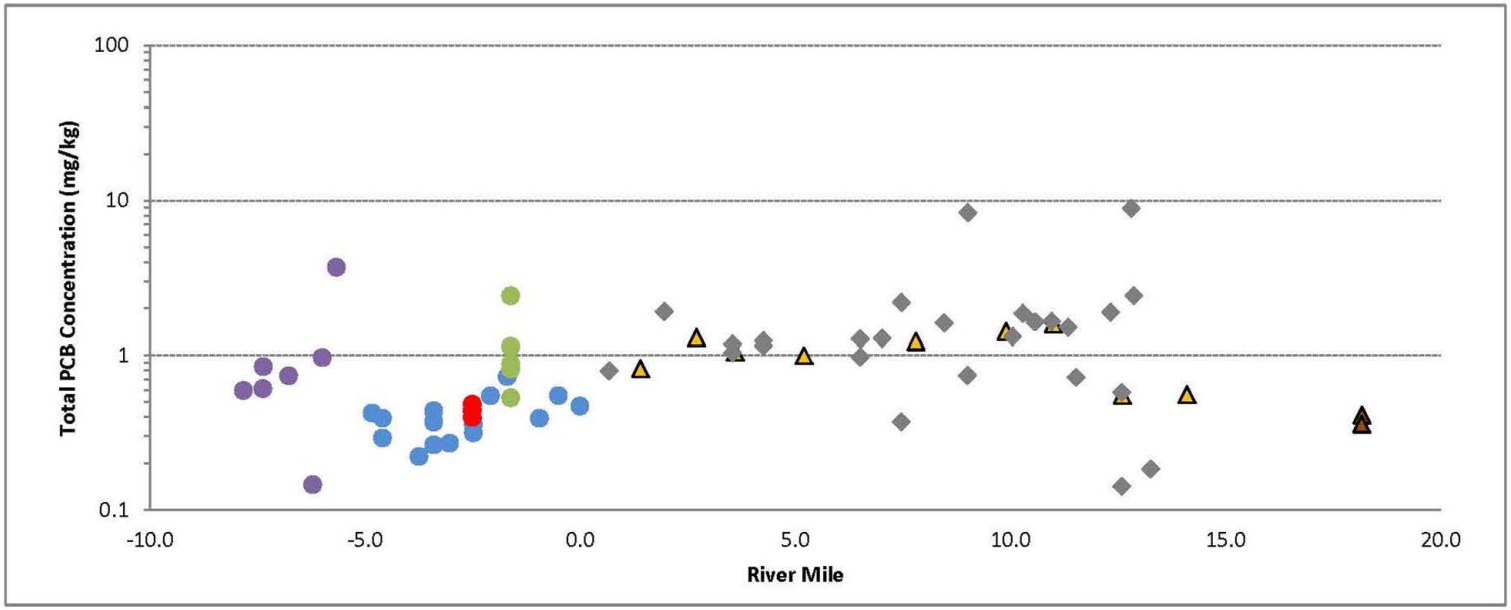
Legend

- All Phase I and II Sampling Locations
- Newark Bay Navigational Channel (includes side slopes)
- Newark Bay Outside of Channel
- Port Elizabeth Navigational Channel (includes side slopes)
- Port Elizabeth Outside of Channel
- Port Newark Navigational Channel (includes side slopes)
- Shooters Island and Arthur Kill Navigational Channel (includes side slopes)
- Shooters Island and Arthur Kill Outside of Channel
- Hackensack River Navigational Channel (includes side slopes)
- Hackensack River Outside of Channel
- Kill Van Kull Outside of Channel

Notes

1. Total PCB surface concentrations represent the top 6 inches of the core.
2. When duplicate Total PCB values are provided by the laboratory, the average concentration is plotted.
3. No nondetect Total PCB concentrations were reported in surface sediment samples.
4. Beryllium-7 (Be7) analysis was conducted on top 1 inch of sediment. Plot A represents all 119 sample locations from Phase I and Phase II. Plot B represents sampling locations where Be7 concentrations were greater than or equal to 0.5 pCi/g (excludes coring locations that targeted source trackdown). Plot C represents sampling locations where Be7 concentrations were less than 0.5 pCi/g. Plot D represents sampling locations where Be7 concentrations were greater than or equal to 1 pCi/g in the navigational channel.
5. Mile 0 on the plot is equal to River Mile 0 on the Lower Passaic River (at the northern end of the bay). Mile -4.8 represents the confluence of the bay and Kill Van Kull. Mile -4.8 to Mile -9.6 extend south through Arthur Kill (north of Shooters Island). Port Newark plots at Mile -1.62, and Port Elizabeth plots at Mile -2.51.
6. Data Source: Tierra Solutions, Inc. Newark Bay Phase I and Phase II Data Evaluation and Analysis Report (April 2010). Phase I samples were collected from October-December 2005; Phase II samples were collected from October-December 2007.

	Total PCB Surface Sediment Concentrations in Newark Bay *Lower Eight Miles of the Lower Passaic River*	Figure 4-21 2014



Legend

- Newark Bay Navigational Channel (includes side slopes; TSI 2005/2007)
- Port Elizabeth Navigational Channel (includes side slopes; TSI 2005/2007)
- Port Newark Navigational Channel (includes side slopes; TSI 2005/2007)
- Shooters Island and Arthur Kill Navigational Channel (includes side slopes; TSI 2005/2007)
- Lower Passaic River (MPI 2008)
- Upper Passaic River (MPI 2008)
- Lower Passaic River (CPG 2008)

Notes

1- Newark Bay Phase I and Phase II surface sediment concentrations collected at highly likely recent depositional locations (defined as ≥1 pCi/g in the channel; 32 samples).

2- Lower Passaic River surface sediment concentrations collected at likely recent depositional locations (defined as ≥0.5 pCi/g in the channel; 9 samples).

3- Upper Passaic River surface sediment concentrations collected at likely recent depositional locations (defined as ≥0.5 pCi/g in the channel; 2 samples).

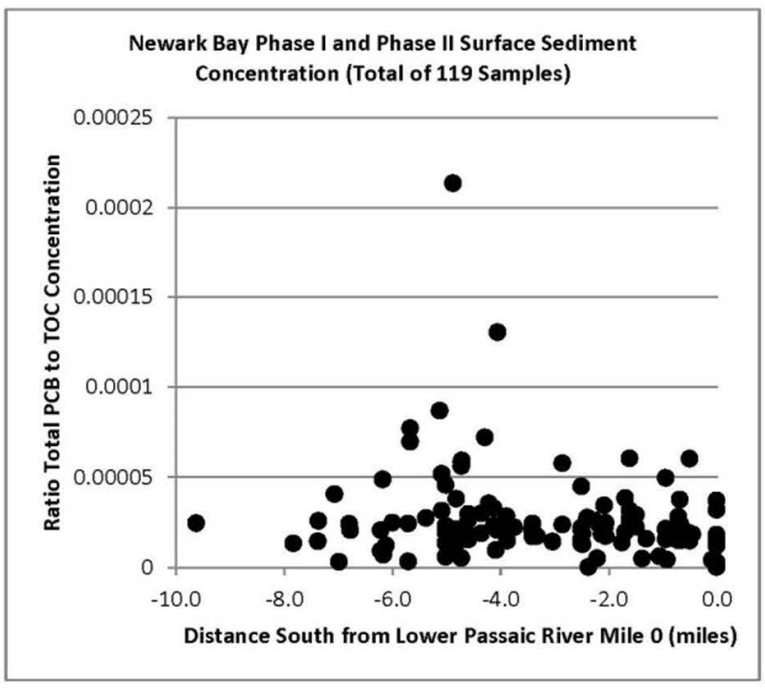
4- Lower Passaic River CPG 2008 surface sediment concentrations collected at highly likely recent depositional locations (defined as ≥1 pCi/g; 26 samples).

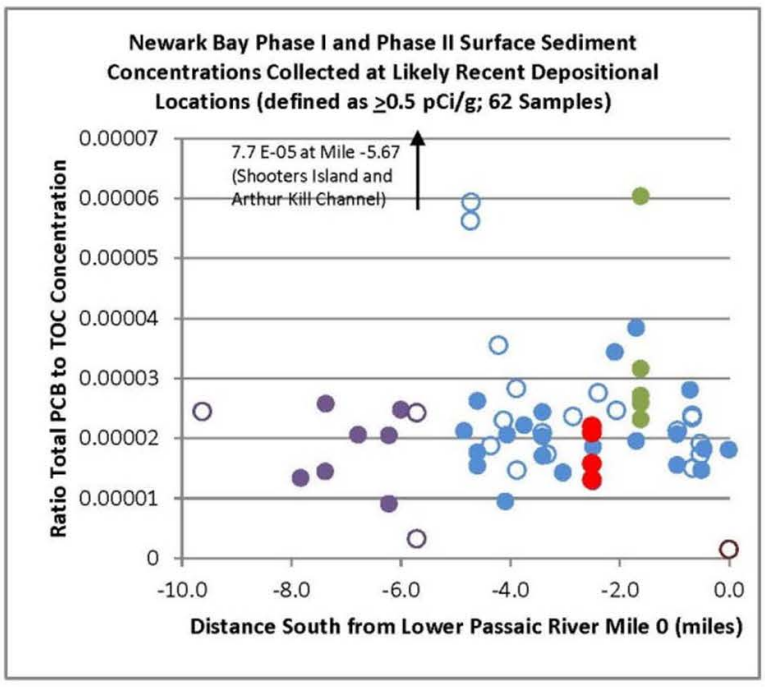
Total PCB Surface Sediment Concentrations in Newark Bay, Lower and Upper Passaic River

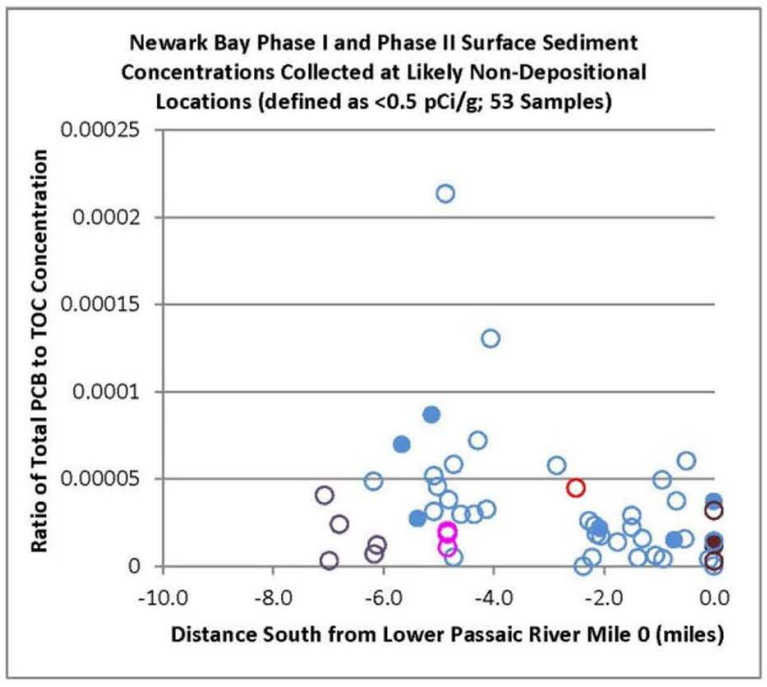
Lower Eight Miles of the Lower Passaic River

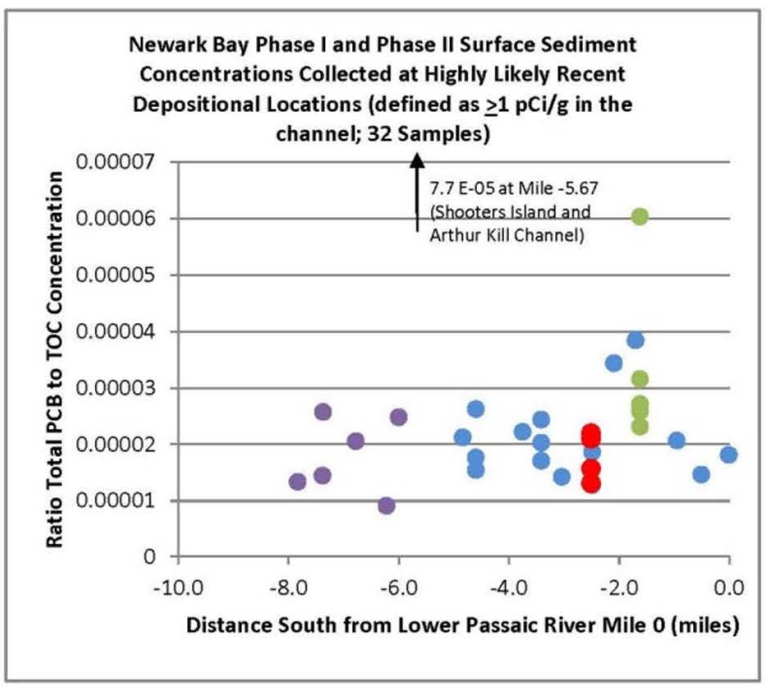
Figure 4-22

2014









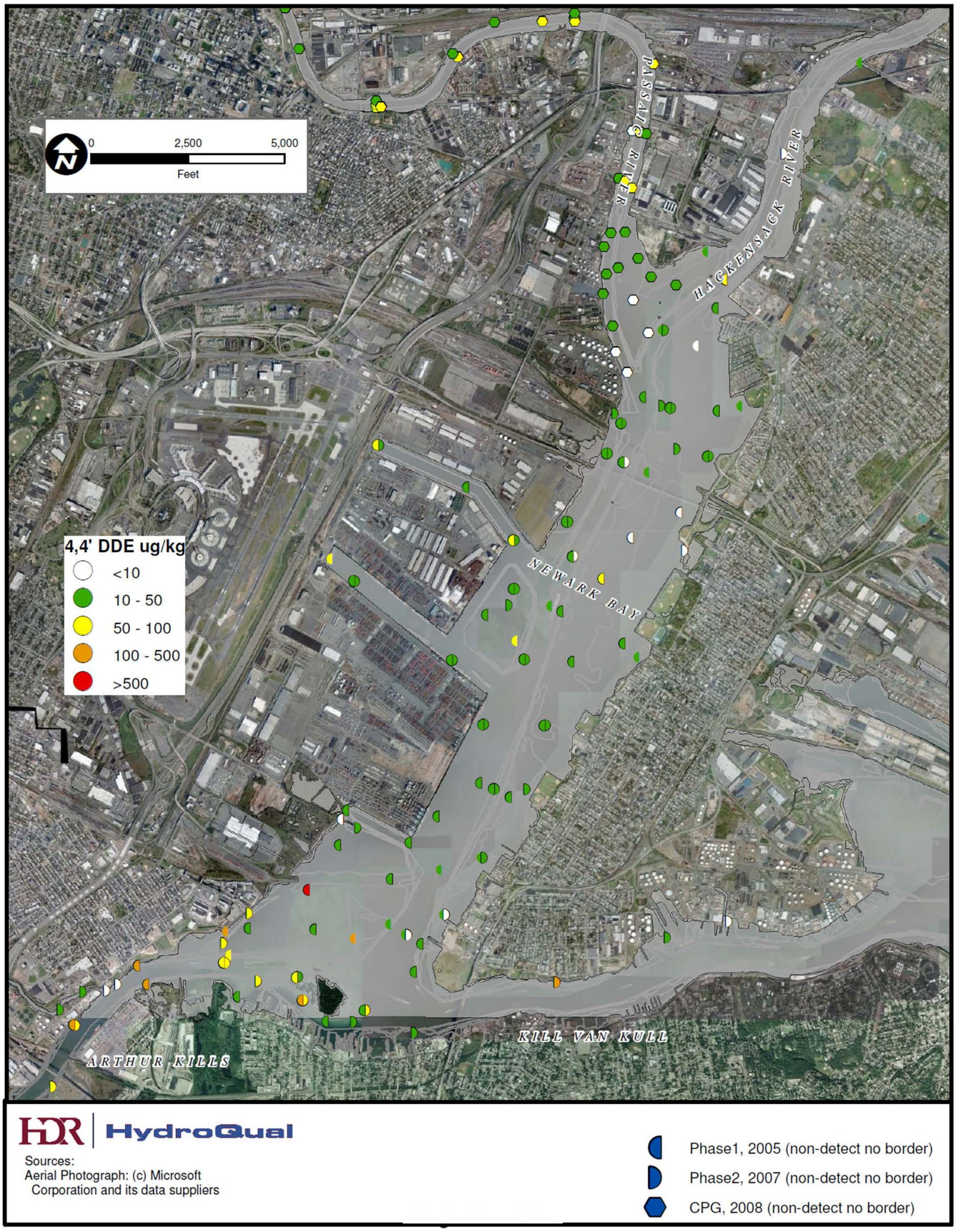
Legend

- All Phase I and II Sampling Locations
- Newark Bay Navigational Channel (includes side slopes)
- Newark Bay Outside of Channel
- Port Elizabeth Navigational Channel (includes side slopes)
- Port Elizabeth Outside of Channel
- Port Newark Navigational Channel (includes side slopes)
- Shooters Island and Arthur Kill Navigational Channel (includes side slopes)
- Shooters Island and Arthur Kill Outside of Channel
- Hackensack River Navigational Channel (includes side slopes)
- Hackensack River Outside of Channel
- Kill Van Kull Outside of Channel

Notes

1. Total PCB and TOC surface concentrations represent the top 6 inches of the core.
2. When duplicate Total PCB or TOC values are provided by the laboratory, the average concentration is used in the ratio.
3. No nondetect Total PCB or TOC concentrations were reported in surface sediment samples.
4. Beryllium-7 (Be7) analysis was conducted on top 1 inch of sediment. Plot A represents all 119 sample locations from Phase I and Phase II. Plot B represents sampling locations where Be7 concentrations were greater than or equal to 0.5 pCi/g (excludes coring locations that targeted source trackdown). Plot C represents sampling locations where Be7 concentrations were less than 0.5 pCi/g. Plot D represents sampling locations where Be7 concentrations were greater than or equal to 1 pCi/g in the navigational channel.
5. Mile 0 on the plot is equal to River Mile 0 on the Lower Passaic River (at the northern end of the bay). Mile -4.8 represents the confluence of the bay and Kill Van Kull. Mile -4.8 to Mile -9.6 extend south through Arthur Kill (north of Shooters Island). Port Newark plots at Mile - 1.62, and Port Elizabeth plots at Mile -2.51.
6. Data Source: Tierra Solutions, Inc. Newark Bay Phase I and Phase II Data Evaluation and Analysis Report (April 2010). Phase I samples were collected from October-December 2005; Phase II samples were collected from October-December 2007.

	Ratio of Total PCB to TOC Surface Sediment Concentrations *Lower Eight Miles of the Lower Passaic River*	Figure 4-23 2014

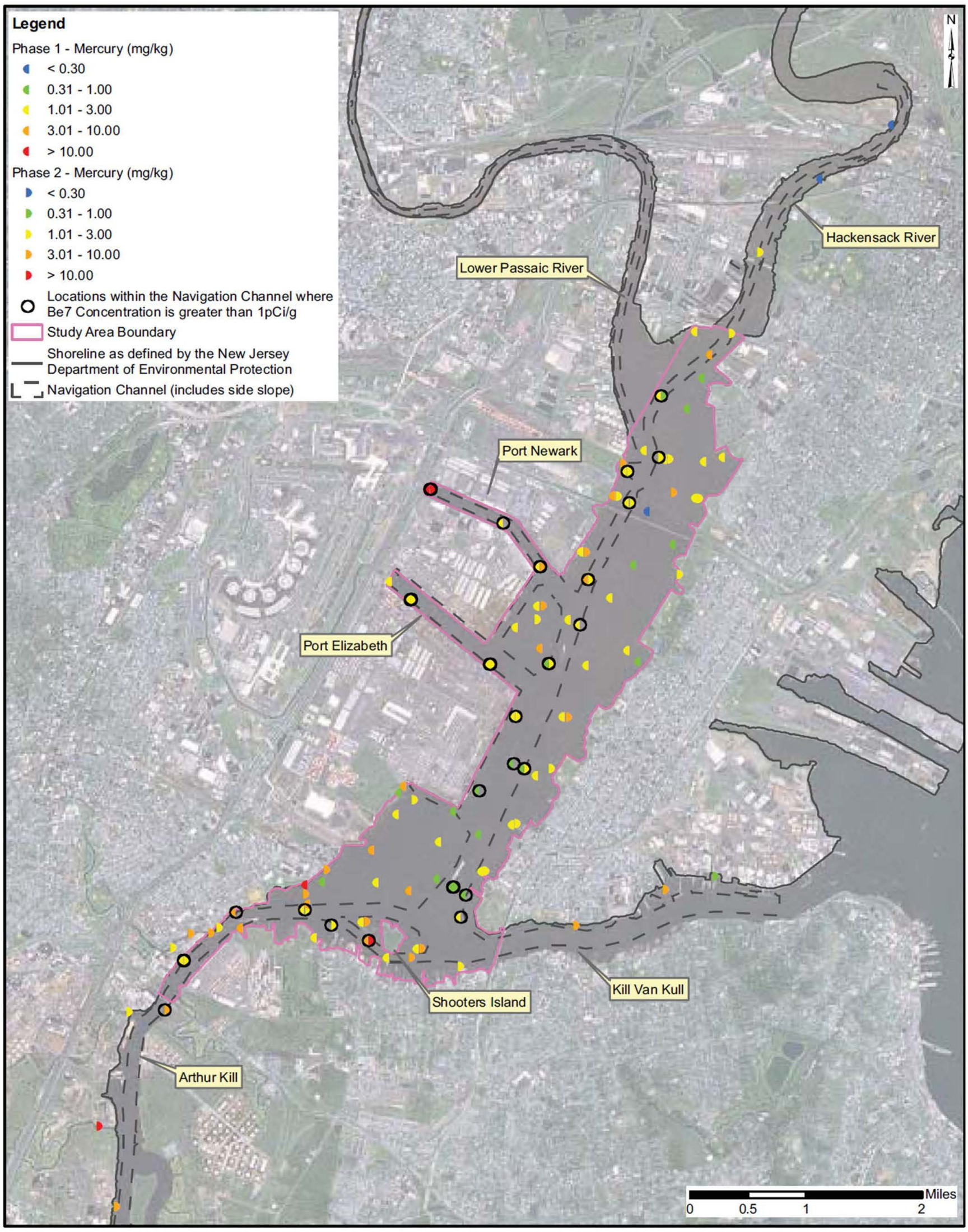


4,4'-DDE Concentrations in Sediment (0-0.5ft)

Lower Eight Miles of the Lower Passaic River

Figure 4-24

2014

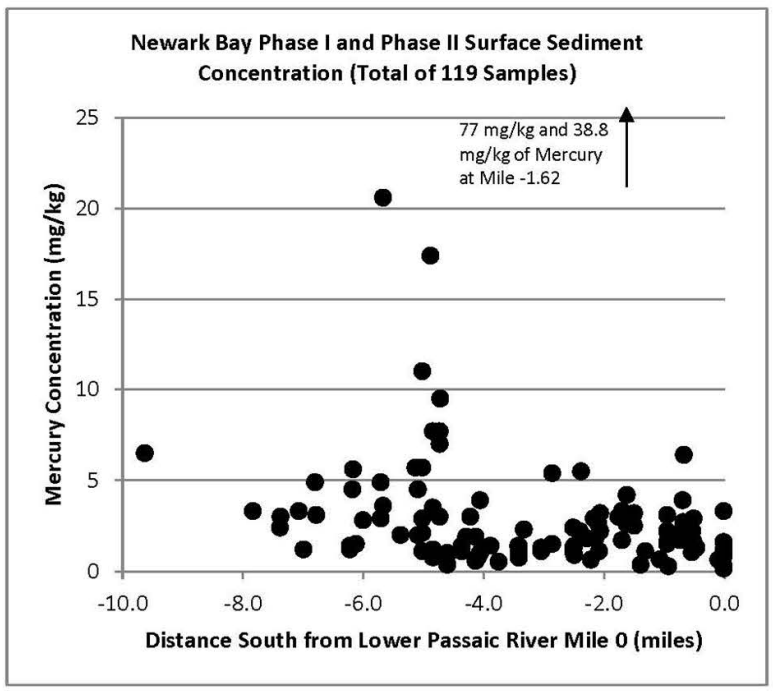


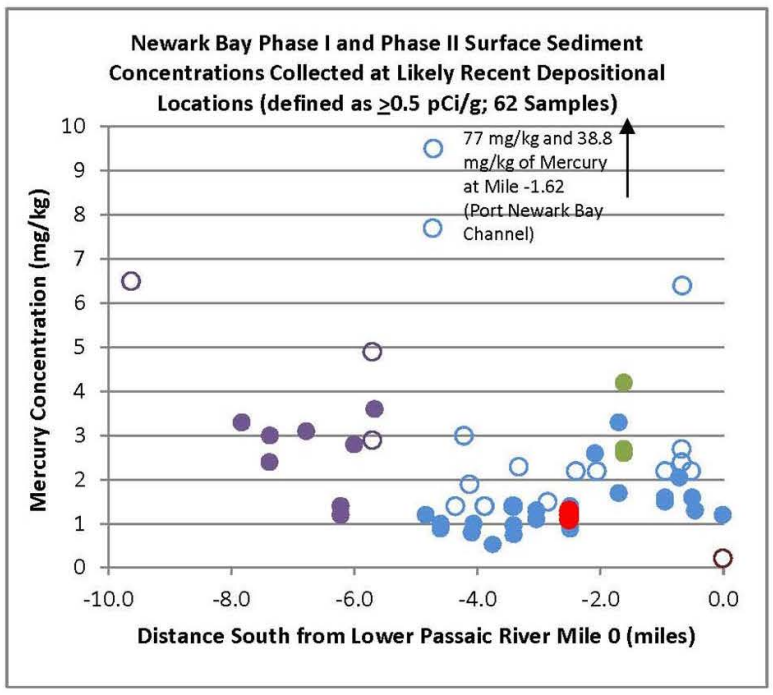
Mercury Concentration in Phase I and Phase II Surface Sediment (0-6 inch)

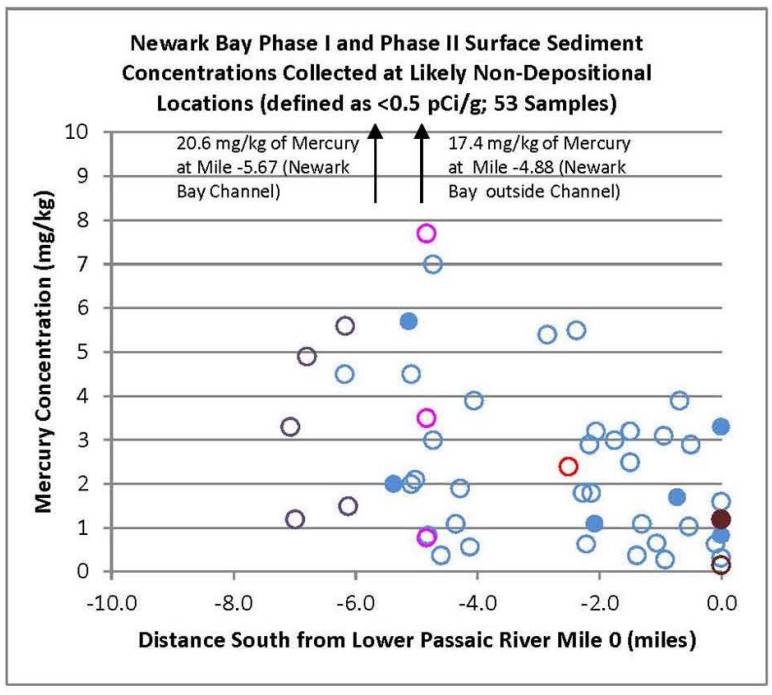
Lower Eight Miles of the Lower Passaic River

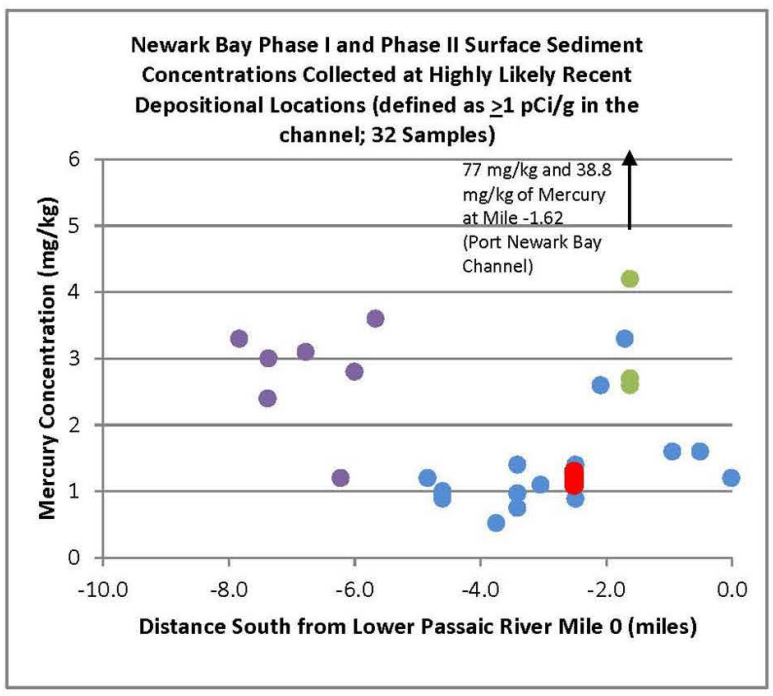
Figure 4-25

2014









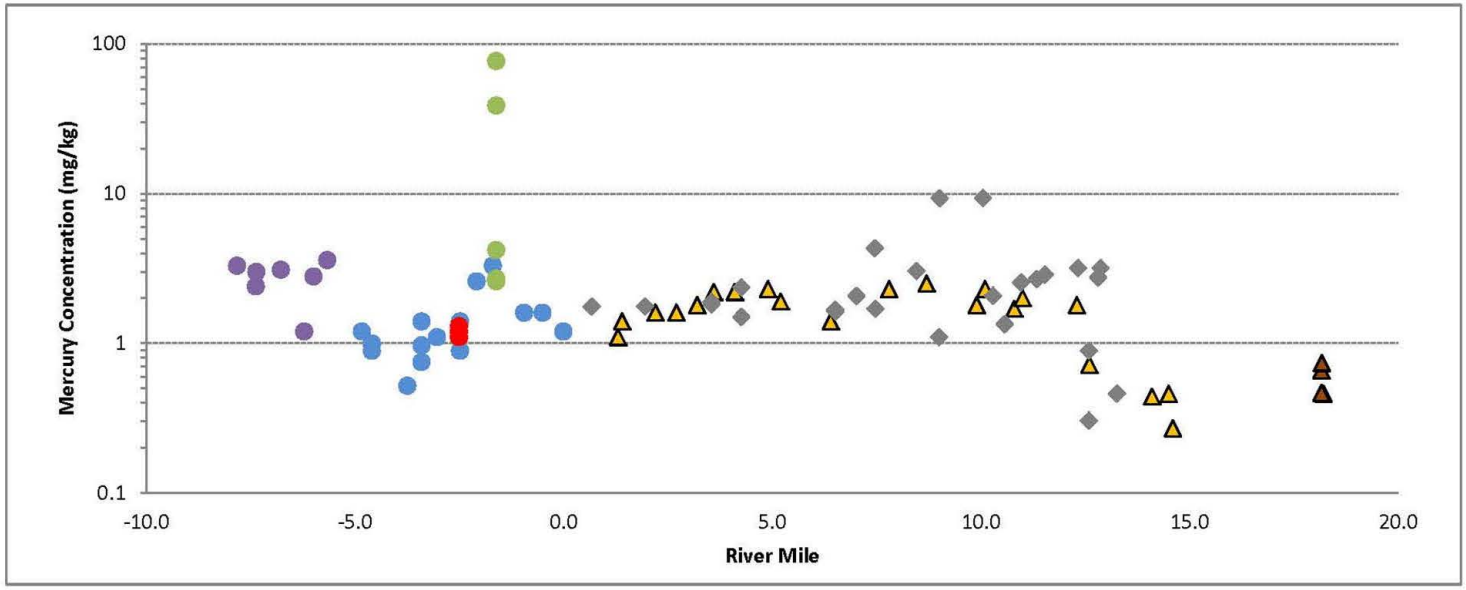
Legend

- All Phase I and II Sampling Locations
- Newark Bay Navigational Channel (includes side slopes)
- Newark Bay Outside of Channel
- Port Elizabeth Navigational Channel (includes side slopes)
- Port Elizabeth Outside of Channel
- Port Newark Navigational Channel (includes side slopes)
- Shooters Island and Arthur Kill Navigational Channel (includes side slopes)
- Shooters Island and Arthur Kill Outside of Channel
- Hackensack River Navigational Channel (includes side slopes)
- Hackensack River Outside of Channel
- Kill Van Kull Outside of Channel

Notes

1. Mercury surface concentrations represent the top 6 inches of the core.
2. When duplicate mercury values are provided by the laboratory, the average concentration is plotted.
3. No nondetect mercury concentrations were reported in surface sediment samples.
4. Beryllium-7 (Be7) analysis was conducted on top 1 inch of sediment. Plot A represents all 119 sample locations from Phase I and Phase II. Plot B represents sampling locations where Be7 concentrations were greater than or equal to 0.5 pCi/g (excludes coring locations that targeted source trackdown). Plot C represents sampling locations where Be7 concentrations were less than 0.5 pCi/g. Plot D represents sampling locations where Be7 concentrations were greater than or equal to 1 pCi/g in the navigational channel.
5. Mile 0 on the plot is equal to River Mile 0 on the Lower Passaic River (at the northern end of the bay). Mile -4.8 represents the confluence of the bay and Kill Van Kull. Mile -4.8 to Mile -9.6 extend south through Arthur Kill (north of Shooters Island). Port Newark plots at Mile - 1.62, and Port Elizabeth plots at Mile -2.51.
6. Data Source: Tierra Solutions, Inc. Newark Bay Phase I and Phase II Data Evaluation and Analysis Report (April 2010). Phase I samples were collected from October-December 2005; Phase II samples were collected from October-December 2007.

	Mercury Surface Sediment Concentrations in Newark Bay *Lower Eight Miles of the Lower Passaic River*	Figure 4-26 2014



Legend

- Newark Bay Navigational Channel (includes side slopes; TSI 2005/2007)
- Port Elizabeth Navigational Channel (includes side slopes; TSI 2005/2007)
- Port Newark Navigational Channel (includes side slopes; TSI 2005/2007)
- Shooters Island and Arthur Kill Navigational Channel (includes side slopes; TSI 2005/2007)
- Lower Passaic River (MPI 2008)
- Upper Passaic River (MPI 2008)
- Lower Passaic River (CPG 2008)

Notes

1- Newark Bay Phase I and Phase II surface sediment concentrations collected at highly likely recent depositional locations (defined as ≥1 pCi/g in the channel; 32 samples).

2- Lower Passaic River surface sediment concentrations collected at likely recent depositional locations (defined as ≥0.5 pCi/g in the channel; 21 samples).

3- Upper Passaic River surface sediment concentrations collected at likely recent depositional locations (defined as ≥0.5 pCi/g in the channel; 4 samples).

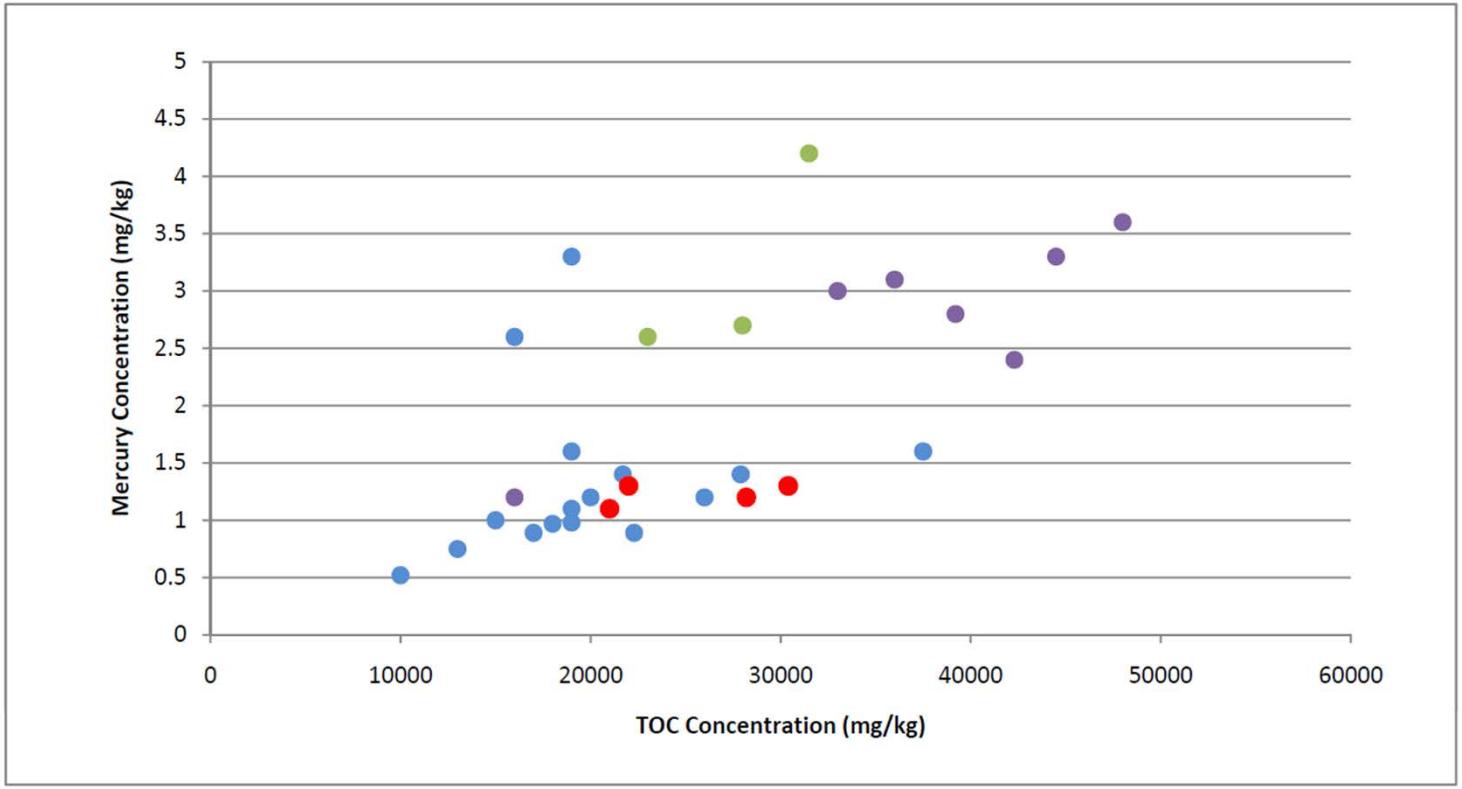
4- Lower Passaic River CPG 2008 surface sediment concentrations collected at highly likely recent depositional locations (defined as ≥1 pCi/g; 26 samples).

Mercury Surface Sediment Concentrations in Newark Bay, Lower and Upper Passaic River

Lower Eight Miles of the Lower Passaic River

Figure 4-27

2014

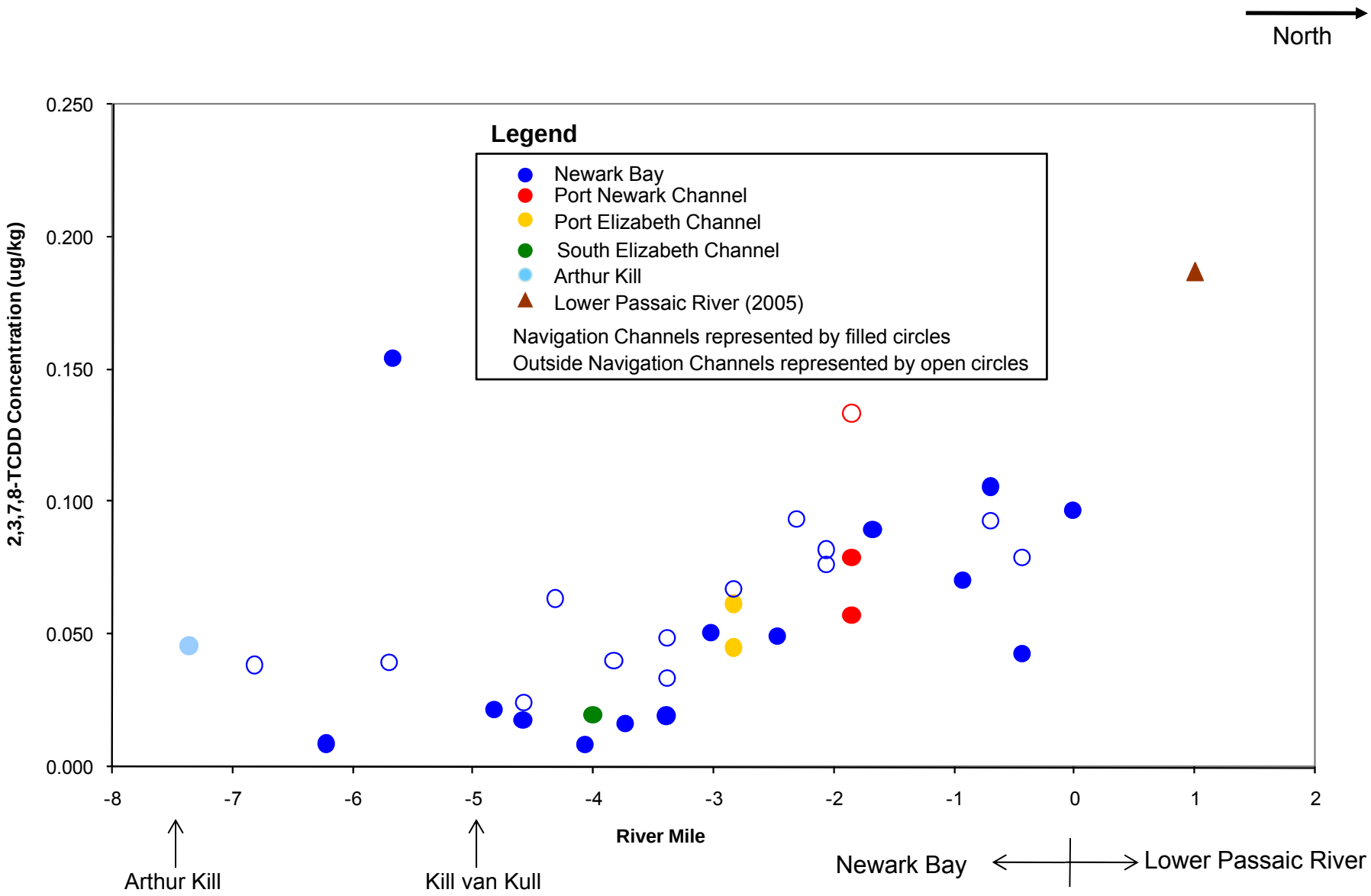


Legend

- Newark Bay Navigational Channel (includes side slopes)
- Port Elizabeth Navigational Channel (includes side slopes)
- Port Newark Navigational Channel (includes side slopes)
- Shooters Island and Arthur Kill Navigational Channel (includes side slopes)

Note: Newark Bay Phase I and Phase II Surface Sediment Samples Collected at Highly Likely Recently Depositional Locations (defined as ≥1 pCi/g)

	Correlation between Mercury and TOC for Newark Bay Phase I and Phase II Surface Sediment *Lower Eight Miles of the Lower Passaic River*	Figure 4-28 2014



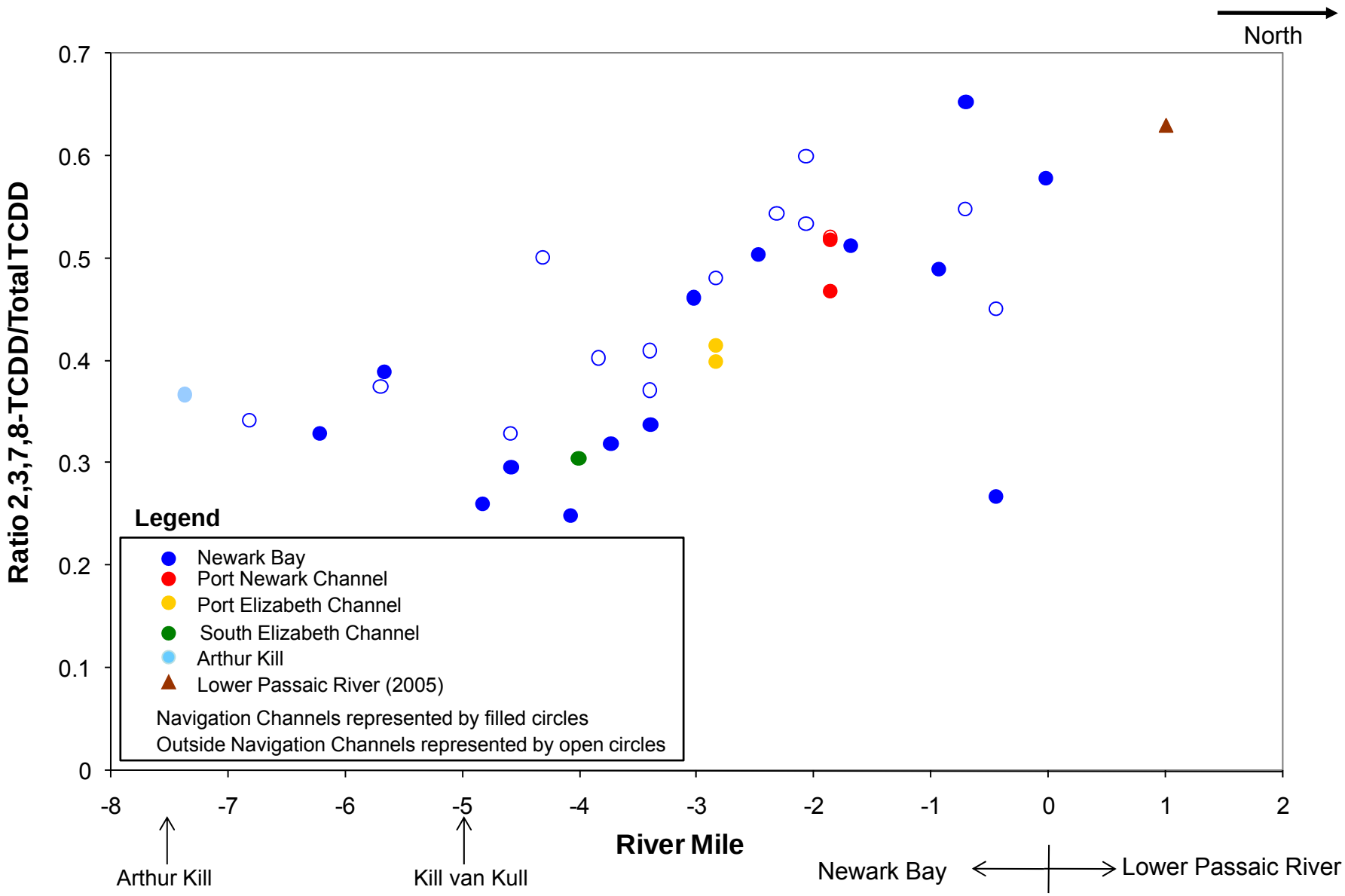
2,3,7,8-TCDD Surface Sediment Concentrations in Newark Bay Complex

Lower Eight Miles of the Lower Passaic River

Figure 4-29a

2014

R2-0026637



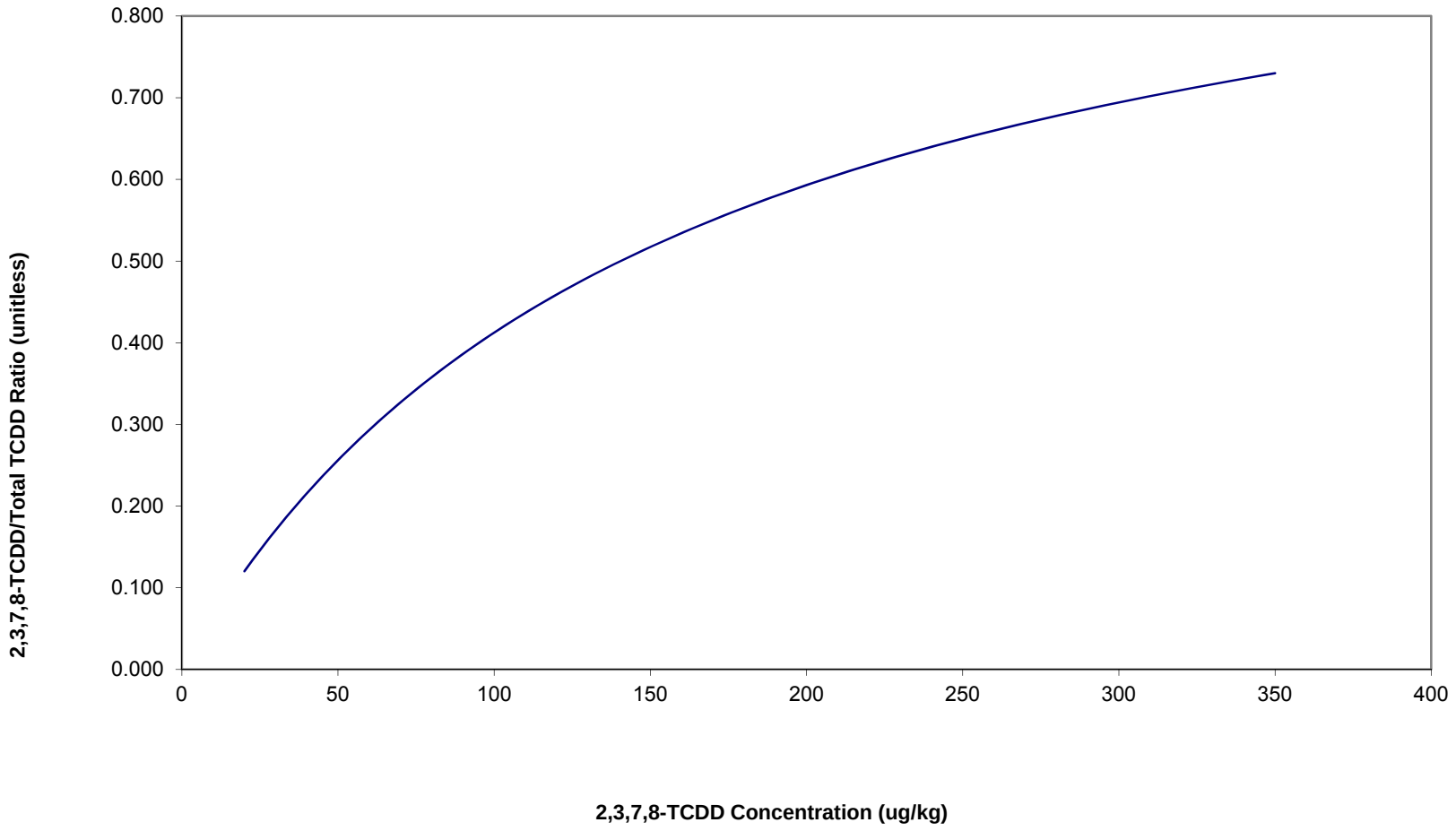
Ratio of 2,3,7,8-TCDD to Total TCDD Surface Sediments Concentrations in Newark Bay Complex

Lower Eight Miles of the Lower Passaic River

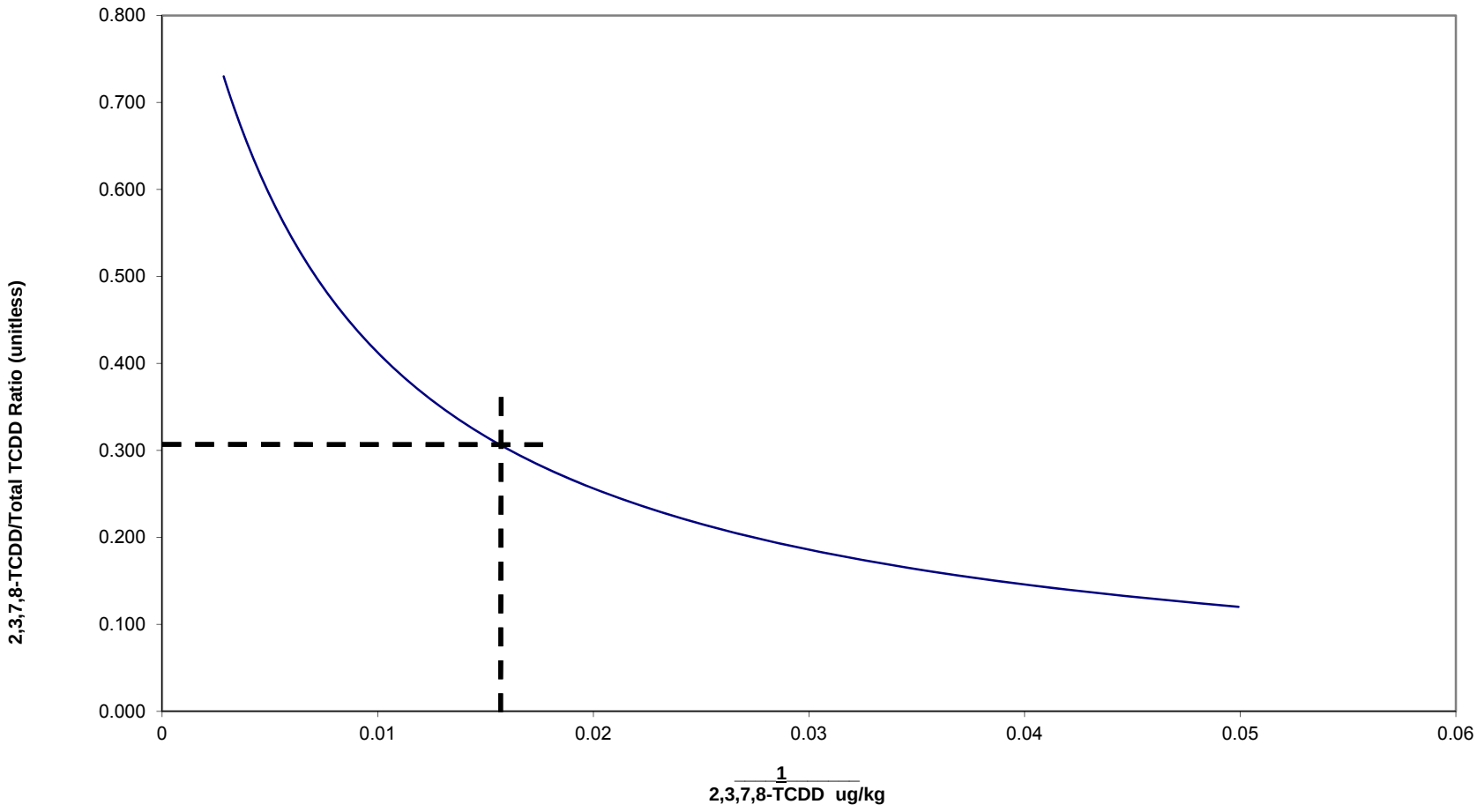
Figure 4-29b

2014

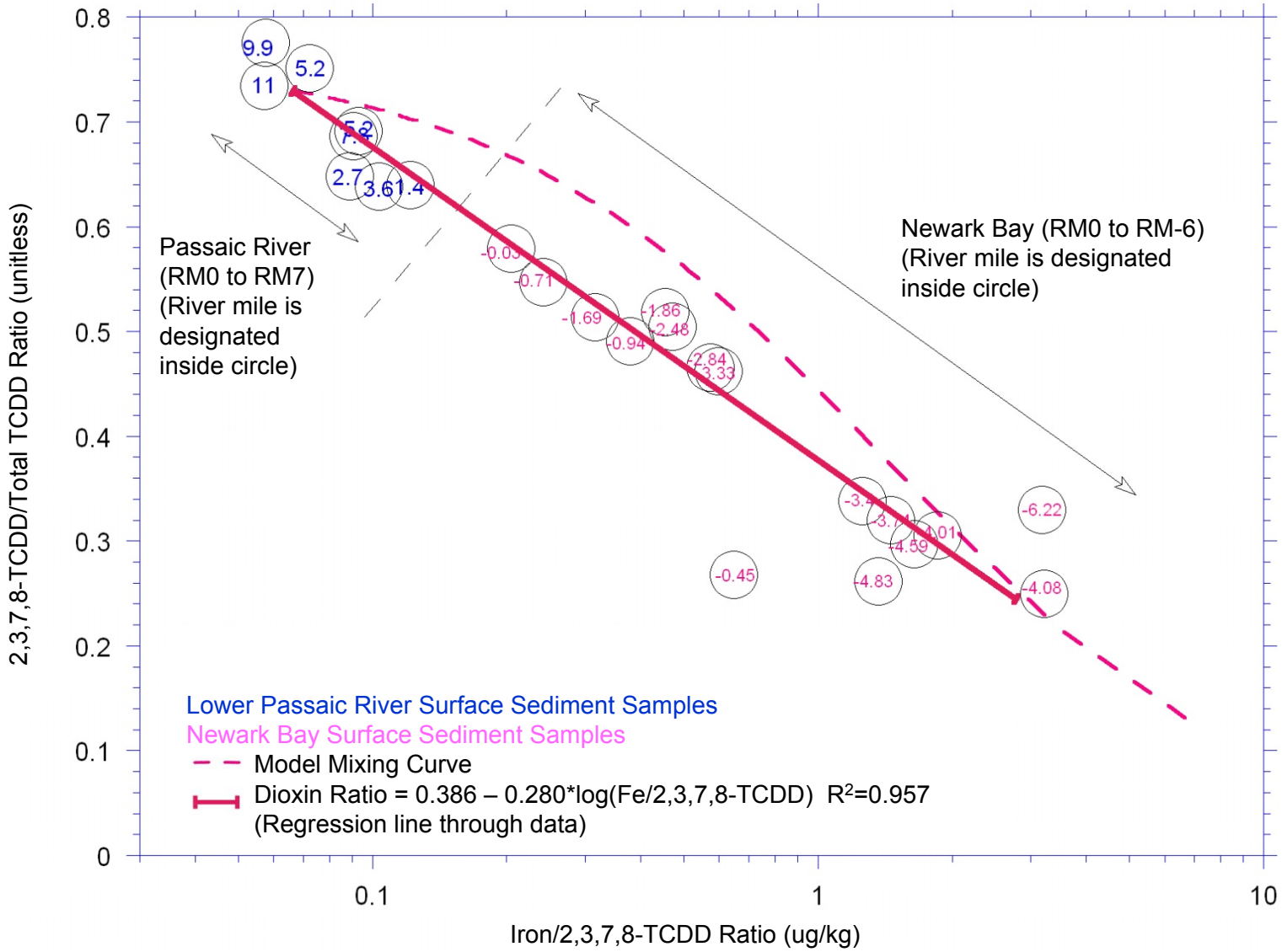
R2-0026638



	Example Two-End-Member Mixing Curve *Lower Eight Miles of the Lower Passaic River*	Figure 4-30 2014

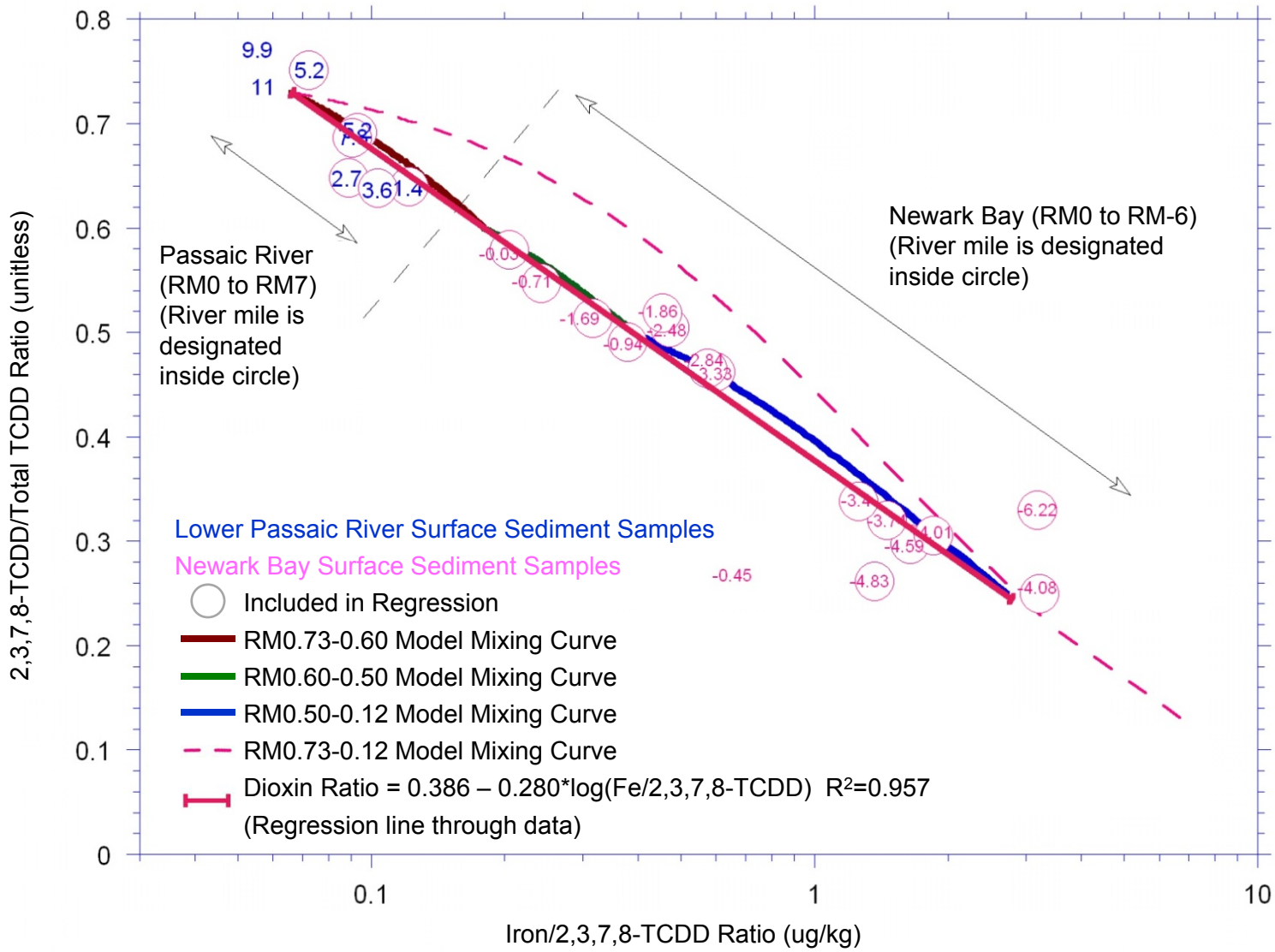


	Example Mixing Curve With Reciprocal Concentration *Lower Eight Miles of the Lower Passaic River*	Figure 4-31 2014



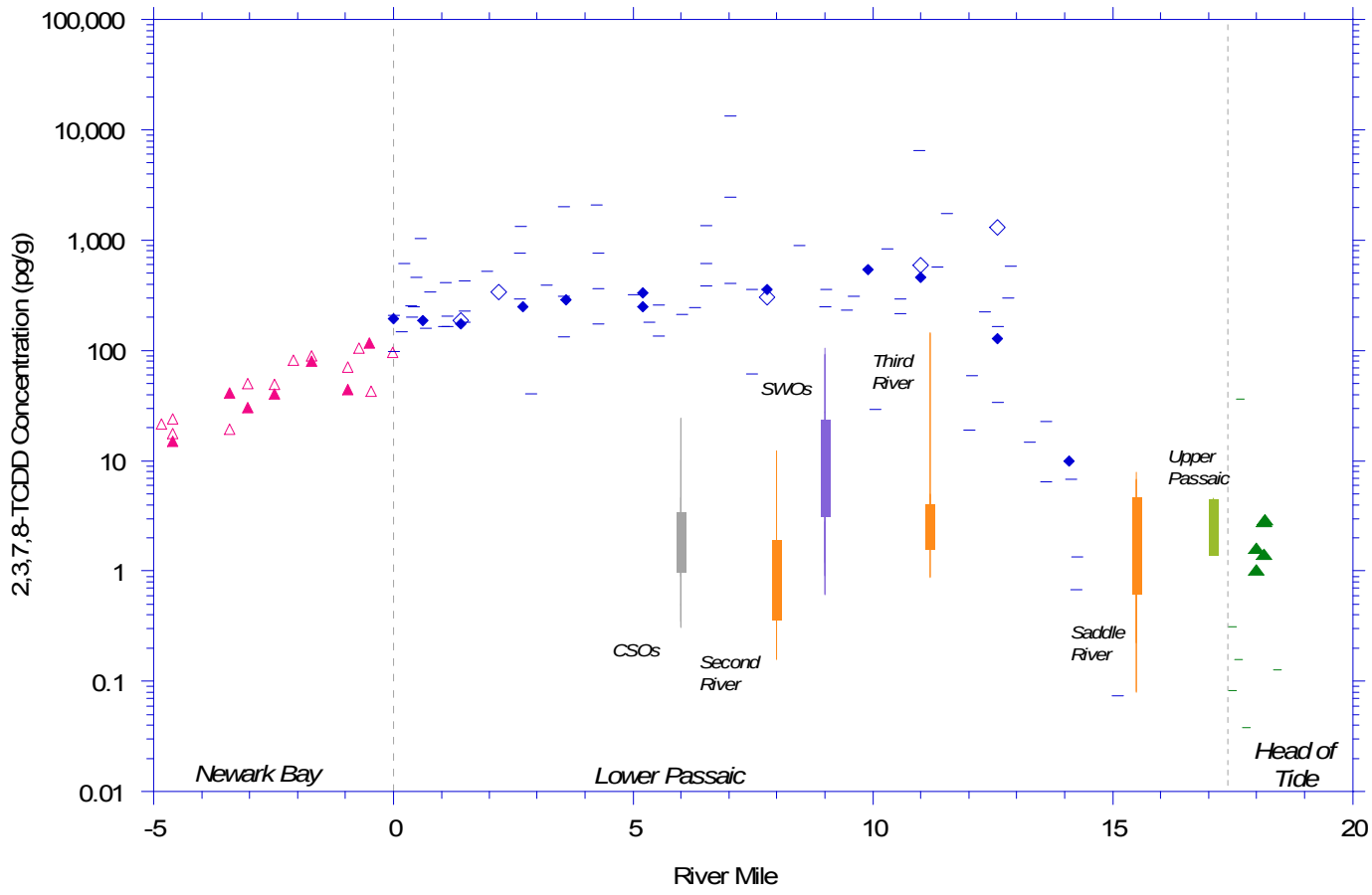
	2,3,7,8-TCDD/Total TCDD Results and Two-End-Member Mixing Curve for the Lower Passaic River and Newark Bay *Lower Eight Miles of the Lower Passaic River*	Figure 4-32 2014

R2-0026641



	2,3,7,8-TCDD/Total TCDD Results and Multiple Mixing Curves for the Lower Passaic River and Newark Bay *Lower Eight Miles of the Lower Passaic River*	Figure 4-33 2014

R2-0026642



Legend*

Water Body

- Lower Passaic
- Upper Passaic above HoT
- Newark Bay Main Channel
- CSOs
- SWOs
- Tributaries
- Upper Passaic

Sample Type

- 2007-2008 Surficial Sediment Be-7 Bearing
- 2005 Surficial Sediment Be-7 Bearing
- 2008 CPG Surficial Sediment Be-7 Bearing

Distribution of CSOs, SWOs, Tributaries and Upper Passaic Samples

- Maximum
- 75th Percentile
- 25th Percentile
- Minimum

*See Notes on Figure 5-1b

2,3,7,8-TCDD Concentrations Measured in Recently-Deposited Material at Various Boundary Conditions

Lower Eight Miles of the Lower Passaic River

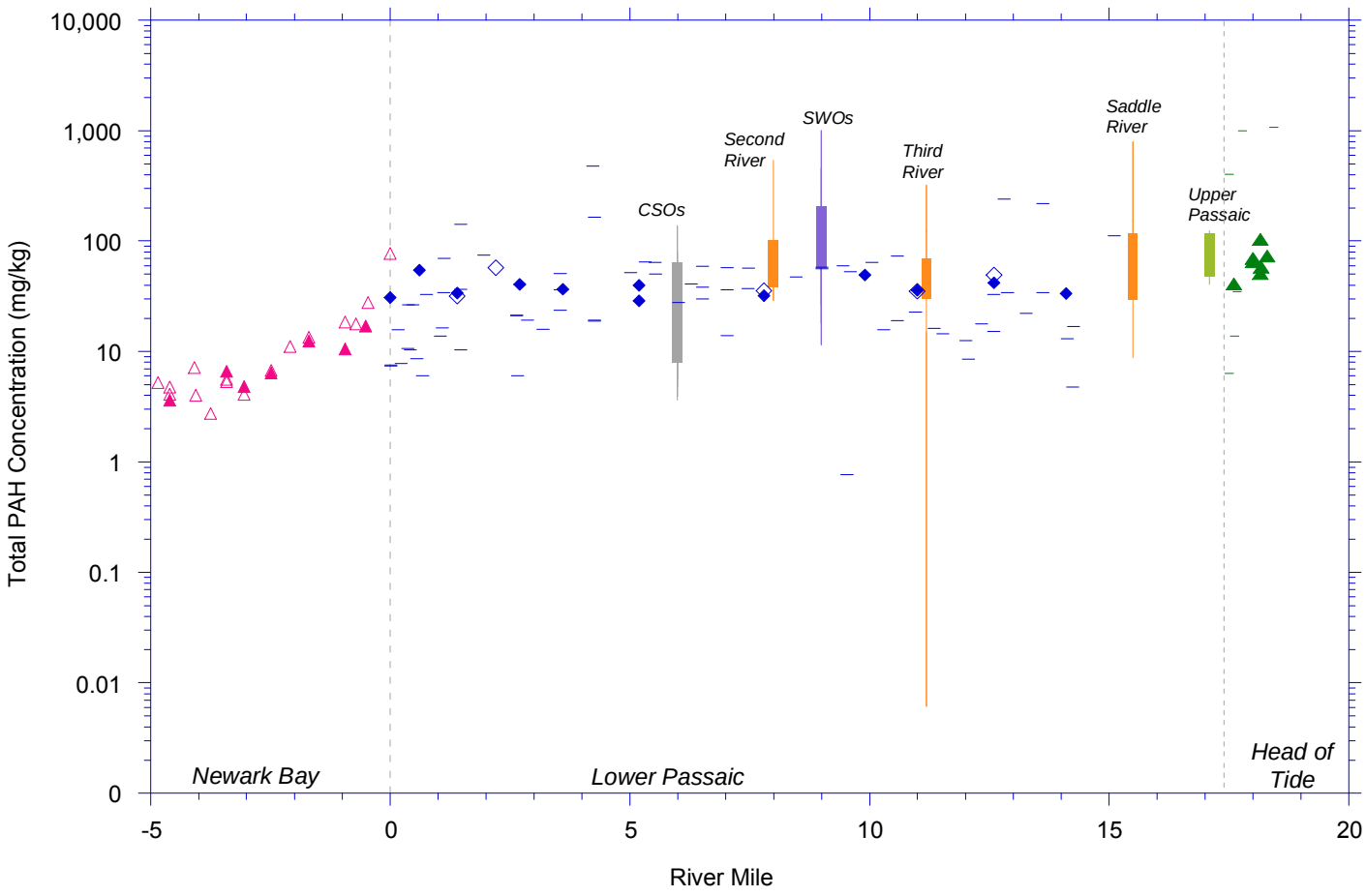
Figure 5-1a

2014

Notes:

1. CSOs and SWOs samples are suspended matter.
2. The tributaries (Second, Third and Saddle Rivers) samples are from sediment traps and Be-7 bearing sediment.
3. Upper River samples are from sediment trap and suspended matter. The green triangle indicates the Be-7 bearing sediment samples.
4. The 2005 and 2007-2008 Lower Passaic River samples are from Be-7 bearing sites.
5. Newark Bay samples are Be-7 bearing from navigational channel.
6. Box and whiskers plot represents tributaries, CSOs and SWOs.

	2,3,7,8-TCDD Concentrations Measured in Recently-Deposited Material at Various Boundary Conditions *Lower Eight Miles of the Lower Passaic River*	Figure 5-1b 2014



Legend*

Water Body

- Lower Passaic
- Upper Passaic above HoT
- Newark Bay Main Channel
- CSOs
- SWOs
- Tributaries
- Upper Passaic

Sample Type

- 2007-2008 Surficial Sediment Be-7 Bearing
- 2005 Surficial Sediment Be-7 Bearing
- 2008 CPG Surficial Sediment Be-7 Bearing

Distribution of CSOs, SWOs, Tributaries and Upper Passaic Samples

- Maximum
- 75th Percentile
- 25th Percentile
- Minimum

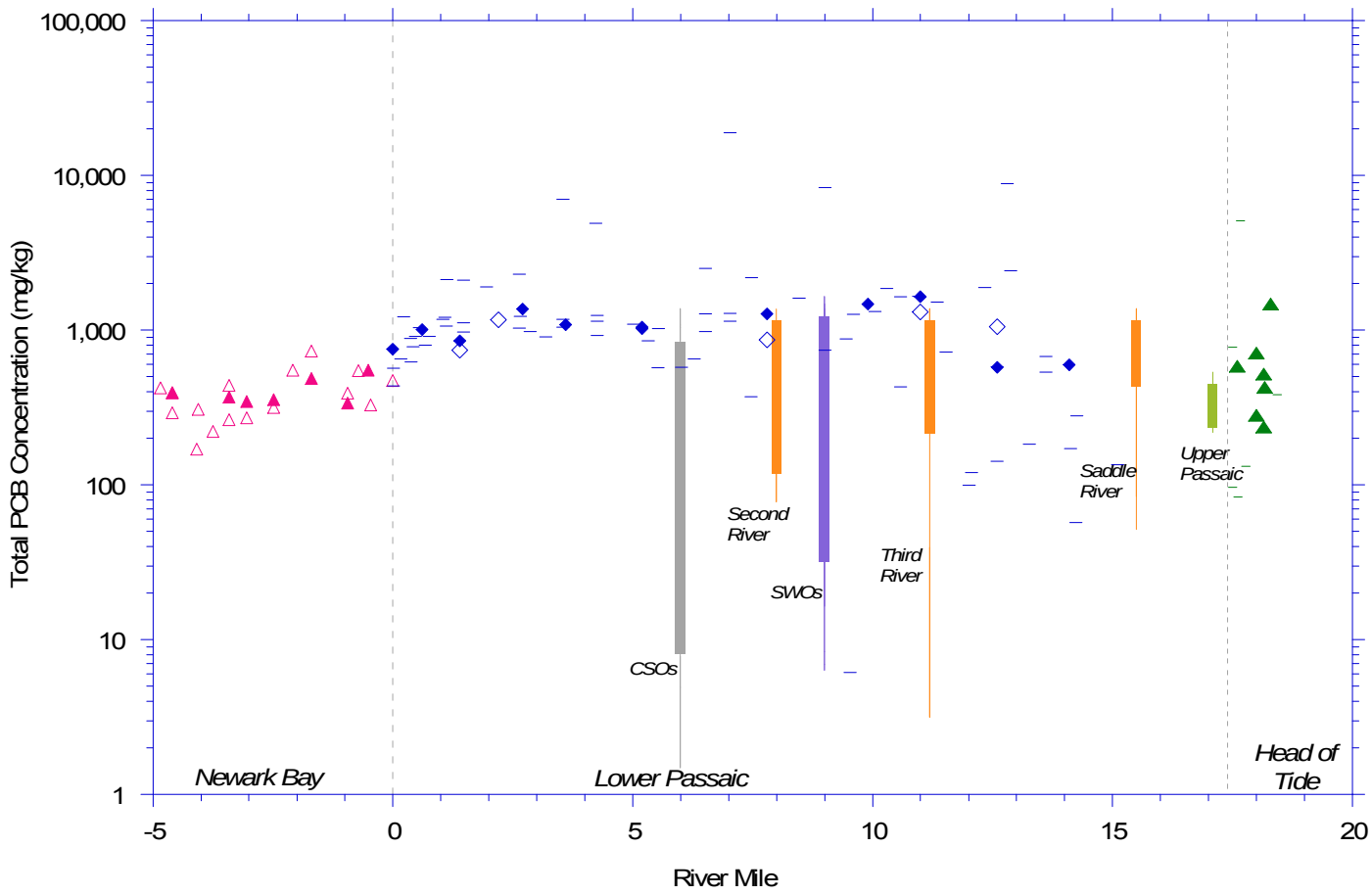
*See Notes on Figure 5-1b

Total PAH Concentrations Measured in Recently-Deposited Material at Various Boundary Conditions

Lower Eight Miles of the Lower Passaic River

Figure 5-2

2014



Legend*

Water Body

- Lower Passaic
- Upper Passaic above HoT
- Newark Bay Main Channel
- CSOs
- SWOs
- Tributaries
- Upper Passaic

Sample Type

- 2007-2008 Surficial Sediment Be-7 Bearing
- 2005 Surficial Sediment Be-7 Bearing
- 2008 CPG Surficial Sediment Be-7 Bearing

Distribution of CSOs, SWOs, Tributaries and Upper Passaic Samples

- Maximum
- 75th Percentile
- 25th Percentile
- Minimum

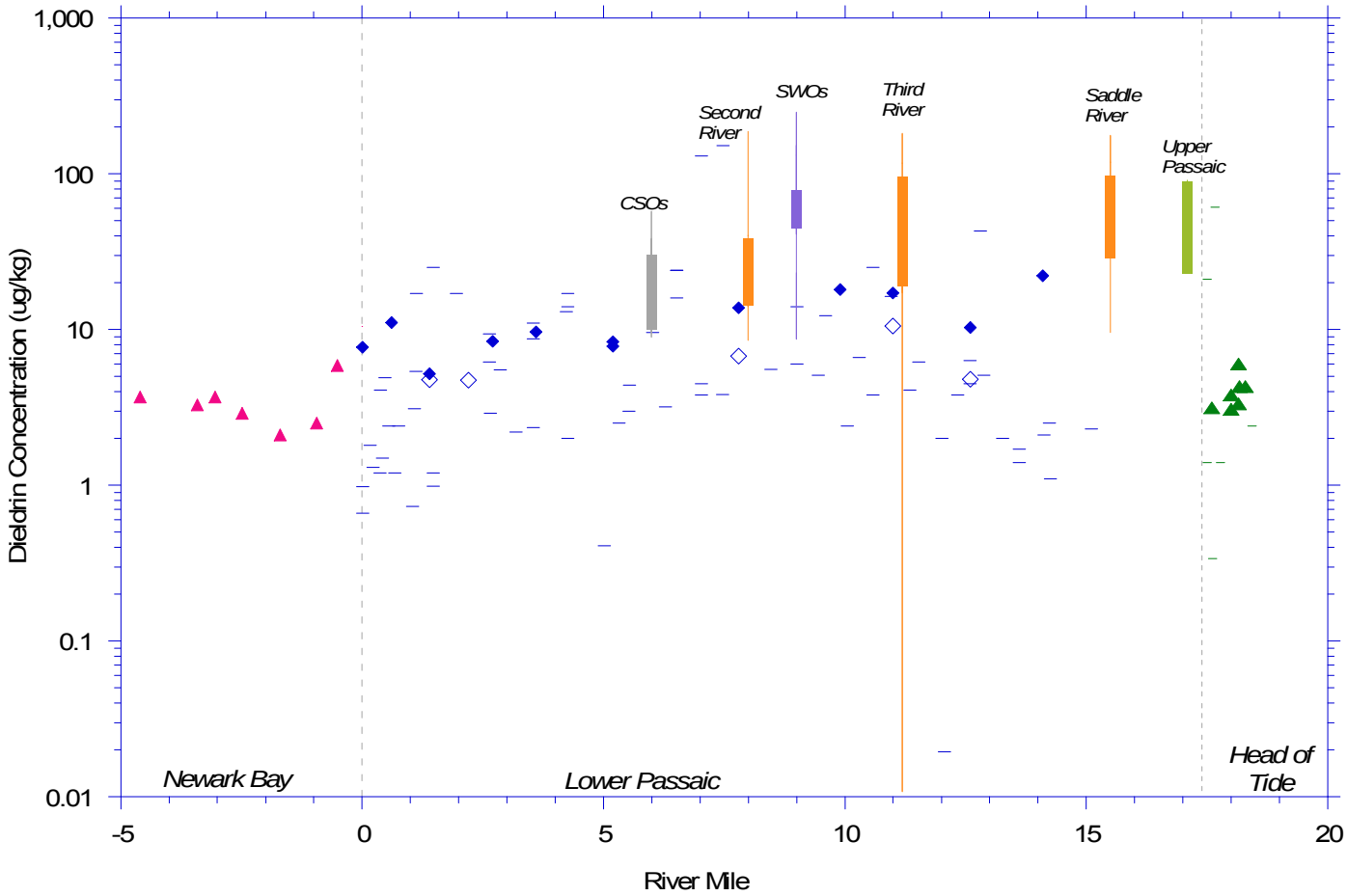
*See Notes on Figure 5-1b

Total PCB Concentrations Measured in Recently-Deposited Material at Various Boundary Conditions

Lower Eight Miles of the Lower Passaic River

Figure 5-3

2014



Legend*

Water Body

- Lower Passaic
- Upper Passaic above HoT
- Newark Bay Main Channel
- CSOs
- SWOs
- Tributaries
- Upper Passaic

Sample Type

- 2007-2008 Surficial Sediment Be-7 Bearing
- 2005 Surficial Sediment Be-7 Bearing
- 2008 CPG Surficial Sediment Be-7 Bearing

Distribution of CSOs, SWOs, Tributaries and Upper Passaic Samples

- Maximum
- 75th Percentile
- 25th Percentile
- Minimum

*See Notes on Figure 5-1b

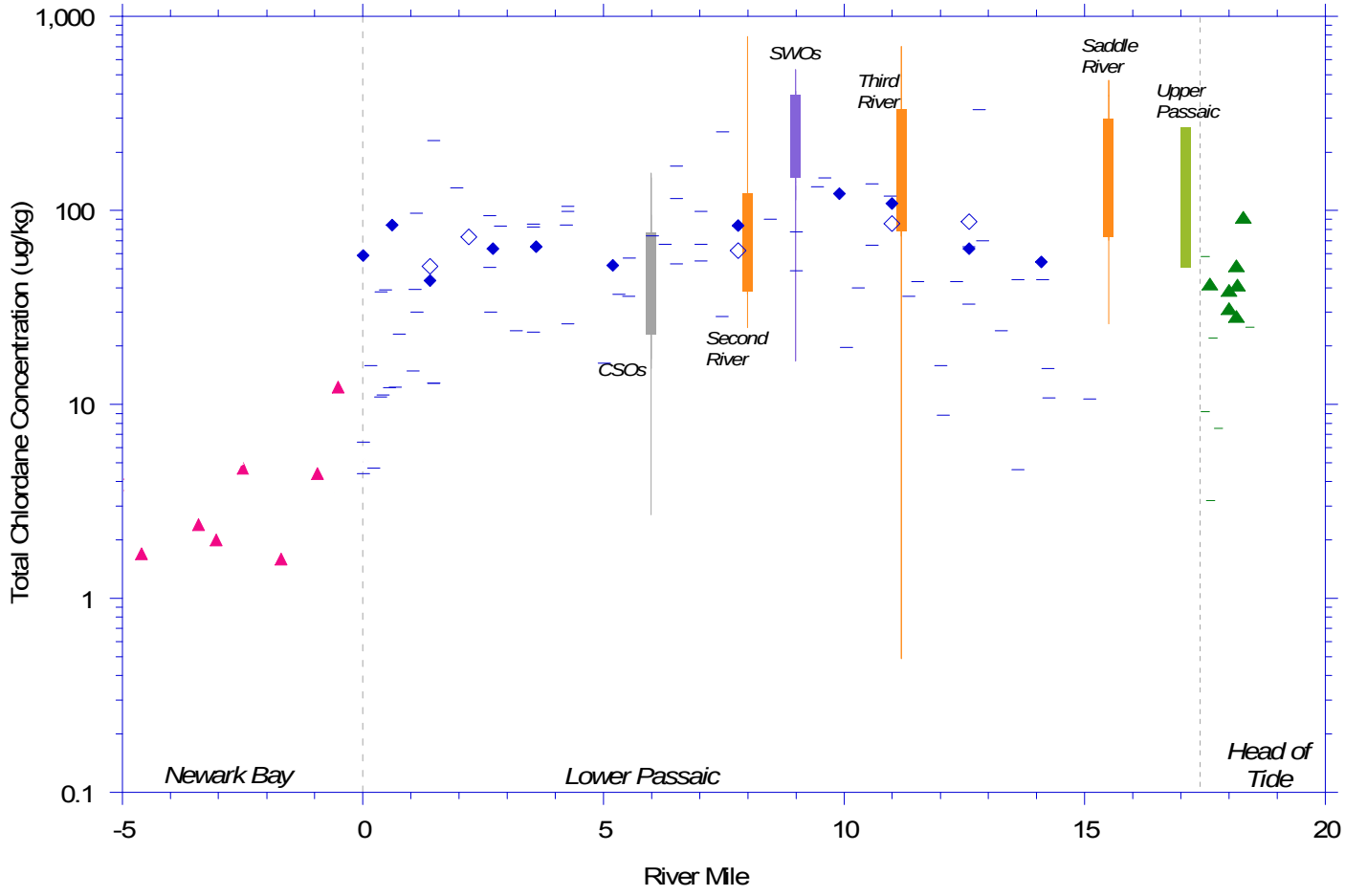
Dieldrin Concentrations Measured in Recently-Deposited Material at Various Boundary Conditions

Lower Eight Miles of the Lower Passaic River

Figure 5-4a

2014

R2-0026647



Legend*

Water Body

- Lower Passaic
- Upper Passaic above HoT
- Newark Bay Main Channel
- CSOs
- SWOs
- Tributaries
- Upper Passaic

Sample Type

- 2007-2008 Surficial Sediment Be-7 Bearing
- 2005 Surficial Sediment Be-7 Bearing
- 2008 CPG Surficial Sediment Be-7 Bearing

Distribution of CSOs, SWOs, Tributaries and Upper Passaic Samples

- Maximum
- 75th Percentile
- 25th Percentile
- Minimum

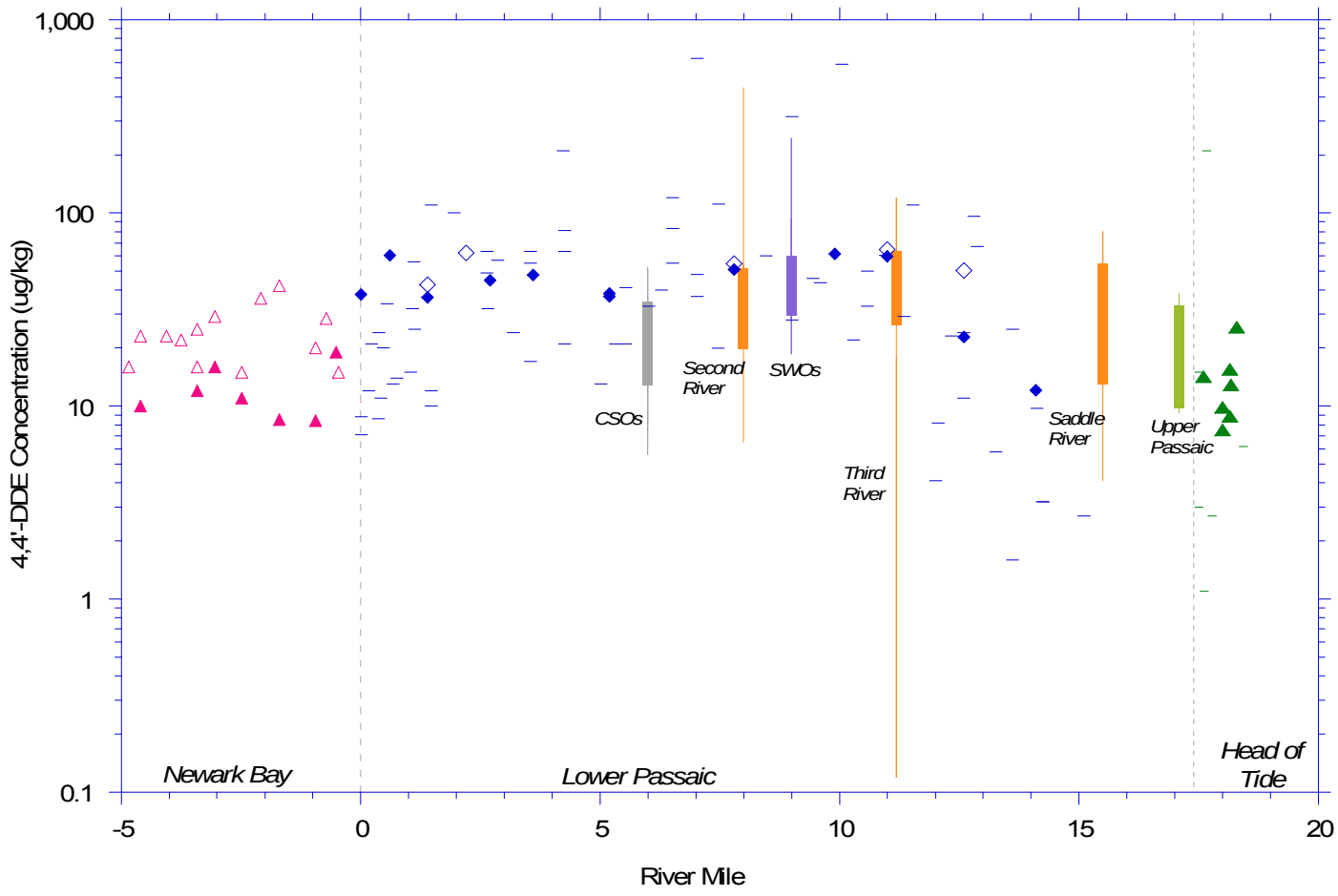
*See Notes on Figure 5-1b

Total Chlordane Concentrations Measured in Recently-Deposited Material at Various Boundary Conditions

Lower Eight Miles of the Lower Passaic River

Figure 5-4b

2014



Legend*

Water Body

- Lower Passaic
- Upper Passaic above HoT
- Newark Bay Main Channel
- CSOs
- SWOs
- Tributaries
- Upper Passaic

Sample Type

- 2007-2008 Surficial Sediment Be-7 Bearing
- 2005 Surficial Sediment Be-7 Bearing
- 2008 CPG Surficial Sediment Be-7 Bearing

Distribution of CSOs, SWOs, Tributaries and Upper Passaic Samples

- Maximum
- 75th Percentile
- 25th Percentile
- Minimum

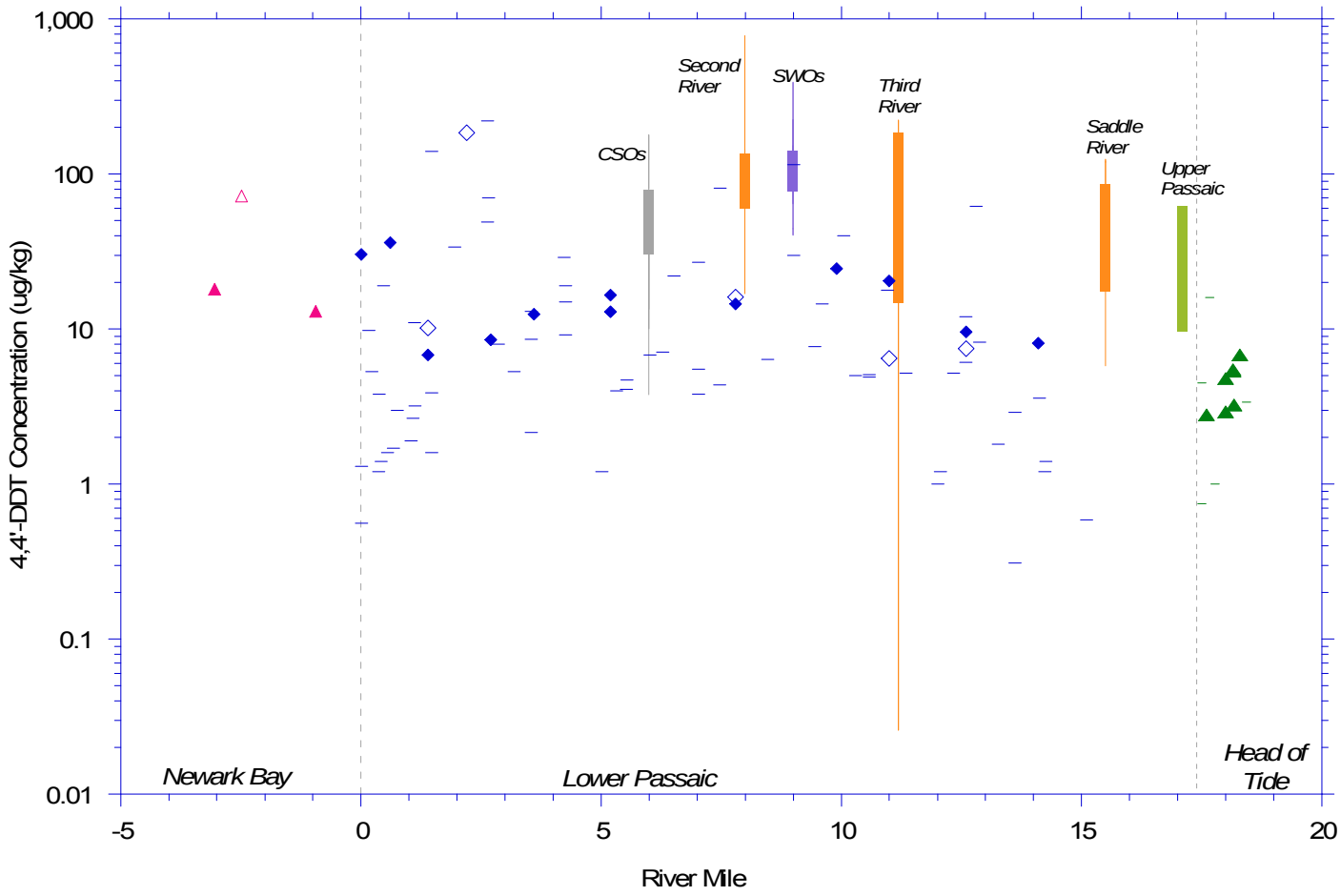
*See Notes on Figure 5-1b

4,4'-DDE Concentrations Measured in Recently-Deposited Material at Various Boundary Conditions

Lower Eight Miles of the Lower Passaic River

Figure 5-4c

2014



Legend*

Water Body

- Lower Passaic
- Upper Passaic above HoT
- Newark Bay Main Channel
- CSOs
- SWOs
- Tributaries
- Upper Passaic

Sample Type

- 2007-2008 Surficial Sediment Be-7 Bearing
- 2005 Surficial Sediment Be-7 Bearing
- 2008 CPG Surficial Sediment Be-7 Bearing

Distribution of CSOs, SWOs, Tributaries and Upper Passaic Samples

- Maximum
- 75th Percentile
- 25th Percentile
- Minimum

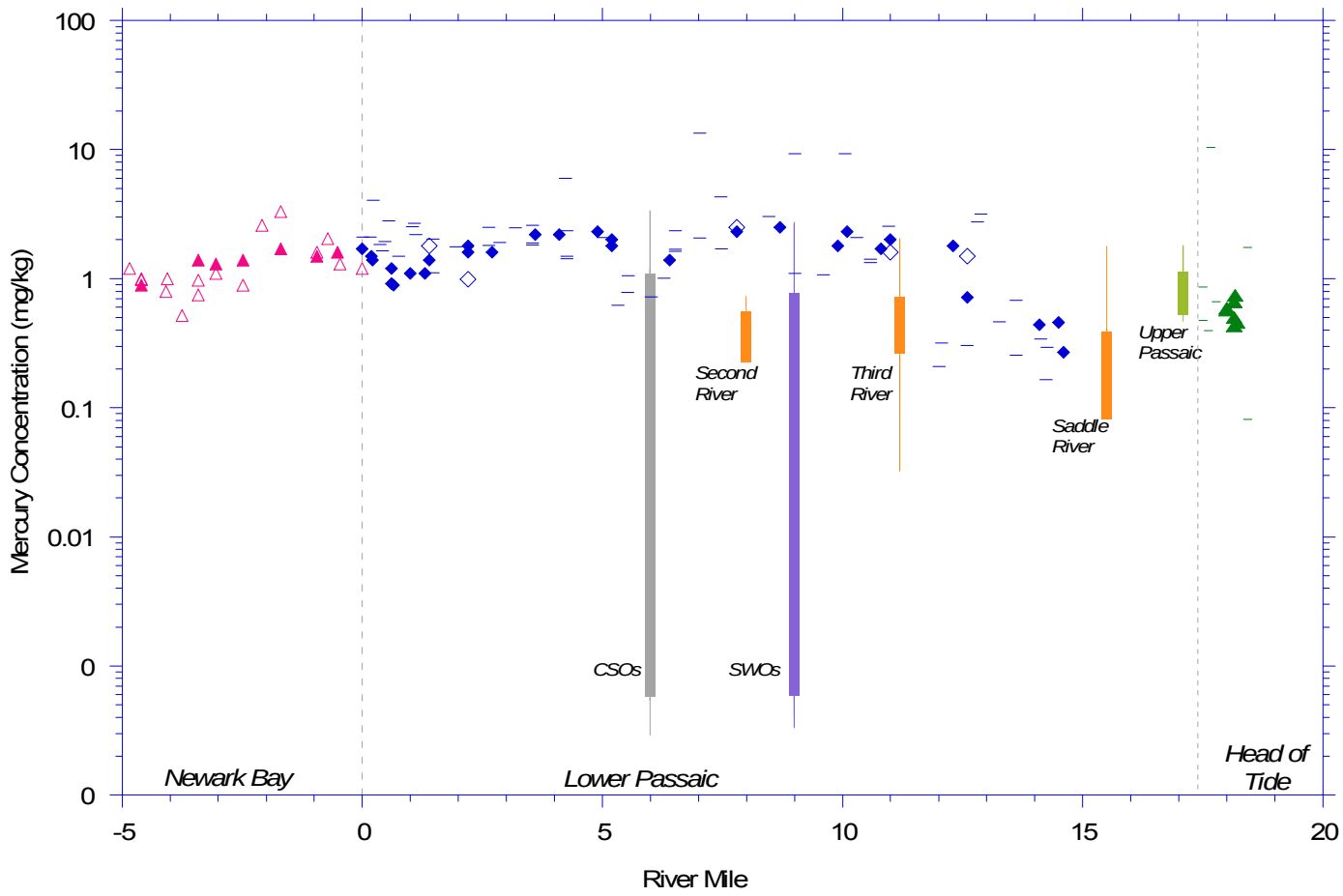
*See Notes on Figure 5-1b

4,4'-DDT Concentrations Measured in Recently-Deposited Material at Various Boundary Conditions

Lower Eight Miles of the Lower Passaic River

Figure 5-4d

2014



Legend*

Water Body

- Lower Passaic
- Upper Passaic above HoT
- Newark Bay Main Channel
- CSOs
- SWOs
- Tributaries
- Upper Passaic

Sample Type

- 2007-2008 Surficial Sediment Be-7 Bearing
- 2005 Surficial Sediment Be-7 Bearing
- 2008 CPG Surficial Sediment Be-7 Bearing

Distribution of CSOs, SWOs, Tributaries and Upper Passaic Samples

- Maximum
- 75th Percentile
- 25th Percentile
- Minimum

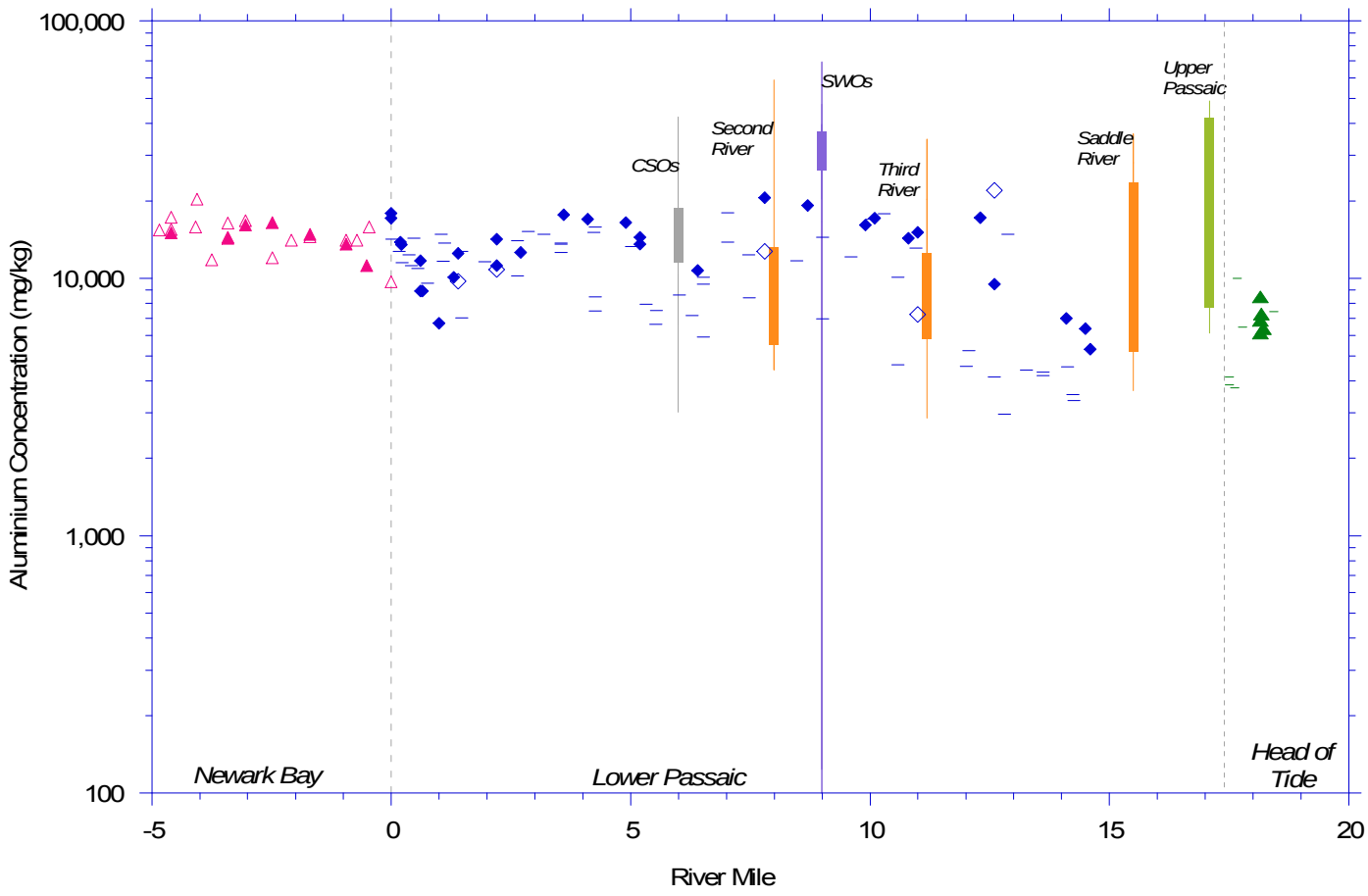
*See Notes on Figure 5-1b

Mercury Concentrations Measured in Recently-Deposited Material at Various Boundary Conditions

Lower Eight Miles of the Lower Passaic River

Figure 5-5a

2014



Legend*

Water Body

- Lower Passaic
- Upper Passaic above HoT
- Newark Bay Main Channel
- CSOs
- SWOs
- Tributaries
- Upper Passaic

Sample Type

- 2007-2008 Surficial Sediment Be-7 Bearing
- 2005 Surficial Sediment Be-7 Bearing
- 2008 CPG Surficial Sediment Be-7 Bearing

Distribution of CSOs, SWOs, Tributaries and Upper Passaic Samples

- Maximum
- 75th Percentile
- 25th Percentile
- Minimum

*See Notes on Figure 5-1b

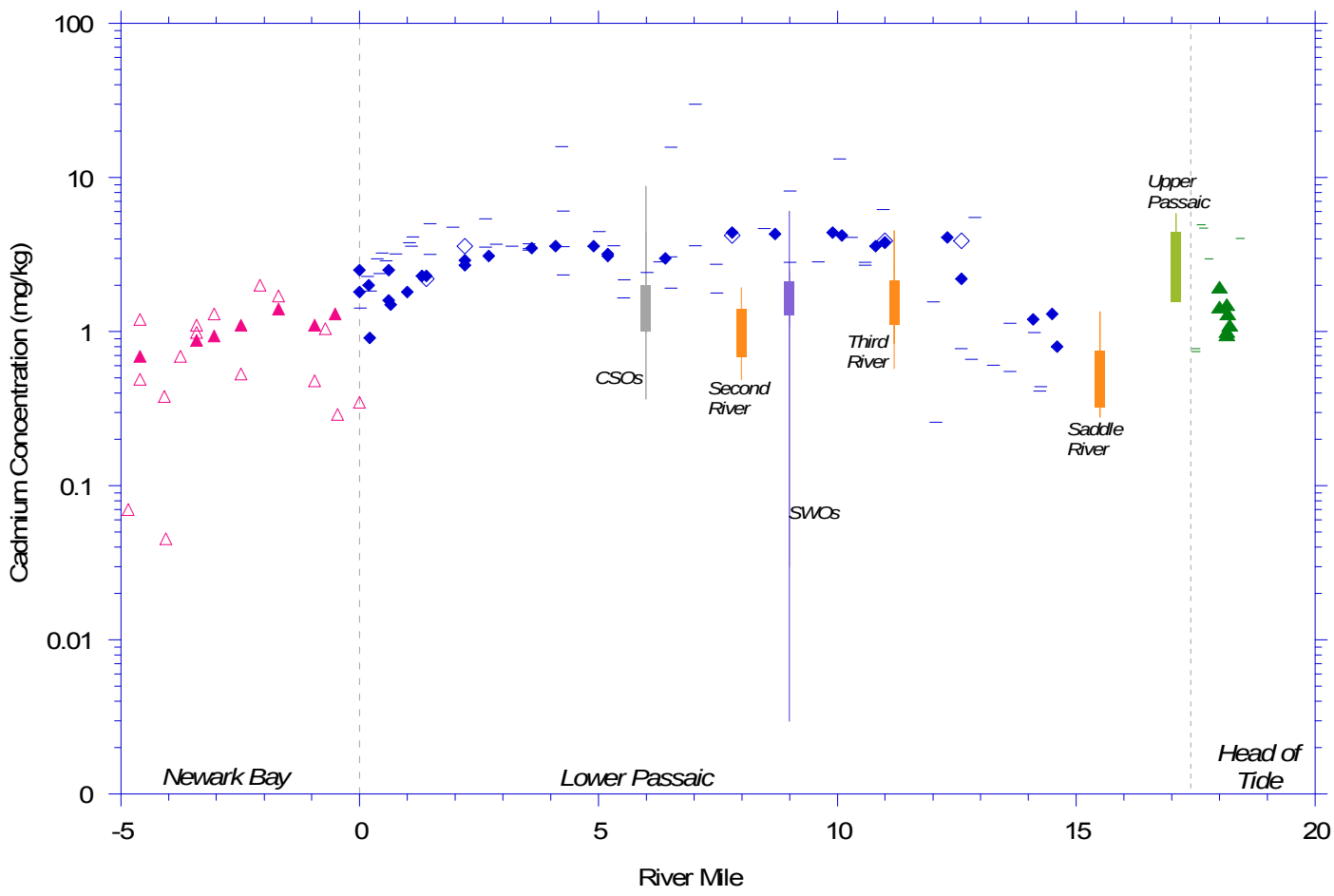
Aluminum Concentrations Measured in Recently-Deposited Material at Various Boundary Conditions

Lower Eight Miles of the Lower Passaic River

Figure 5-5b

2014

R2-0026652



Legend*

Water Body

- Lower Passaic
- Upper Passaic above HoT
- Newark Bay Main Channel
- CSOs
- SWOs
- Tributaries
- Upper Passaic

Sample Type

- 2007-2008 Surficial Sediment Be-7 Bearing
- 2005 Surficial Sediment Be-7 Bearing
- 2008 CPG Surficial Sediment Be-7 Bearing

Distribution of CSOs, SWOs, Tributaries and Upper Passaic Samples

- Maximum
- 75th Percentile
- 25th Percentile
- Minimum

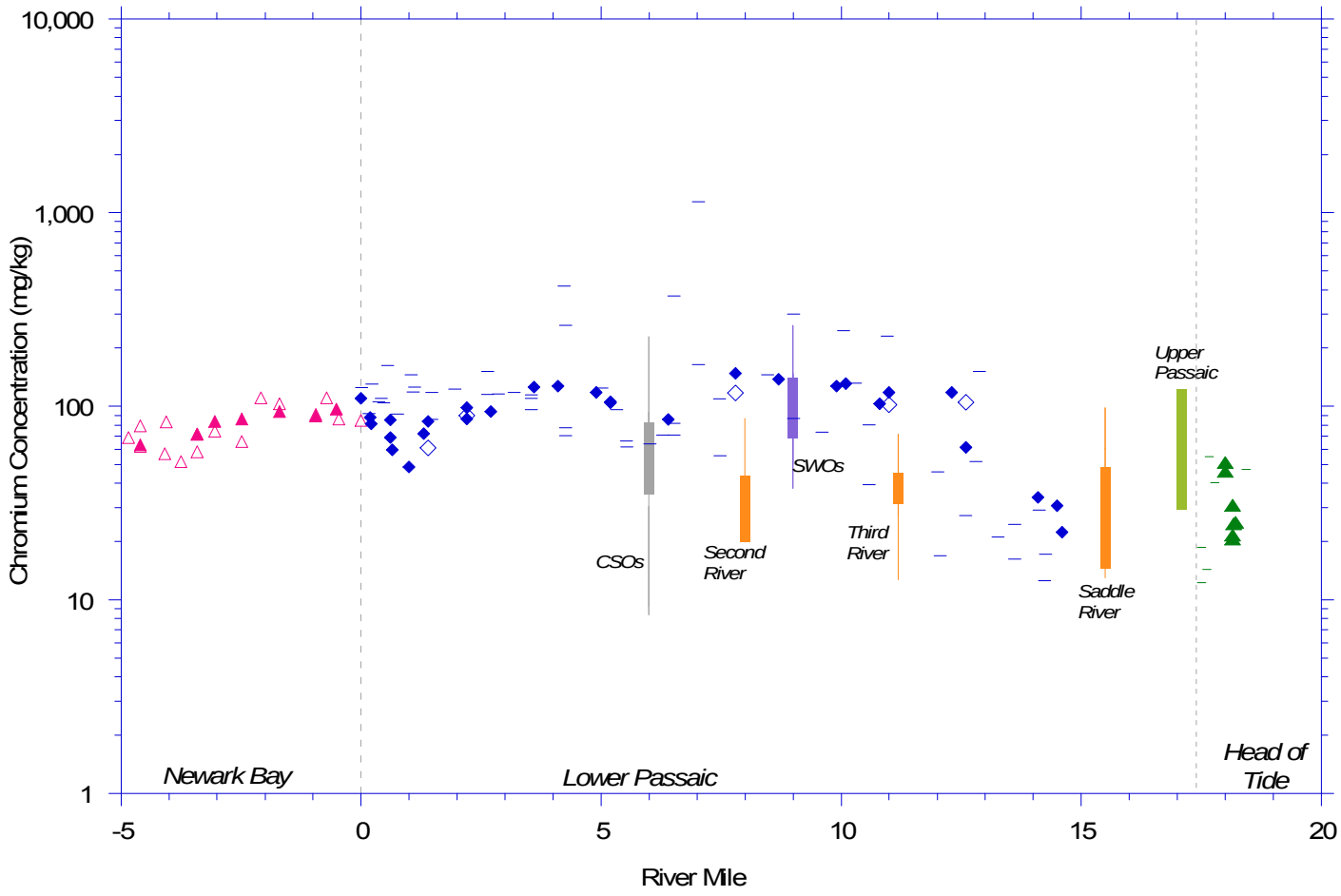
*See Notes on Figure 5-1b

Cadmium Concentrations Measured in Recently-Deposited Material at Various Boundary Conditions

Lower Eight Miles of the Lower Passaic River

Figure 5-5c

2014



Legend*

Water Body

- Lower Passaic
- Upper Passaic above HoT
- Newark Bay Main Channel
- CSOs
- SWOs
- Tributaries
- Upper Passaic

Sample Type

- 2007-2008 Surficial Sediment Be-7 Bearing
- 2005 Surficial Sediment Be-7 Bearing
- 2008 CPG Surficial Sediment Be-7 Bearing

Distribution of CSOs, SWOs, Tributaries and Upper Passaic Samples

- Maximum
- 75th Percentile
- 25th Percentile
- Minimum

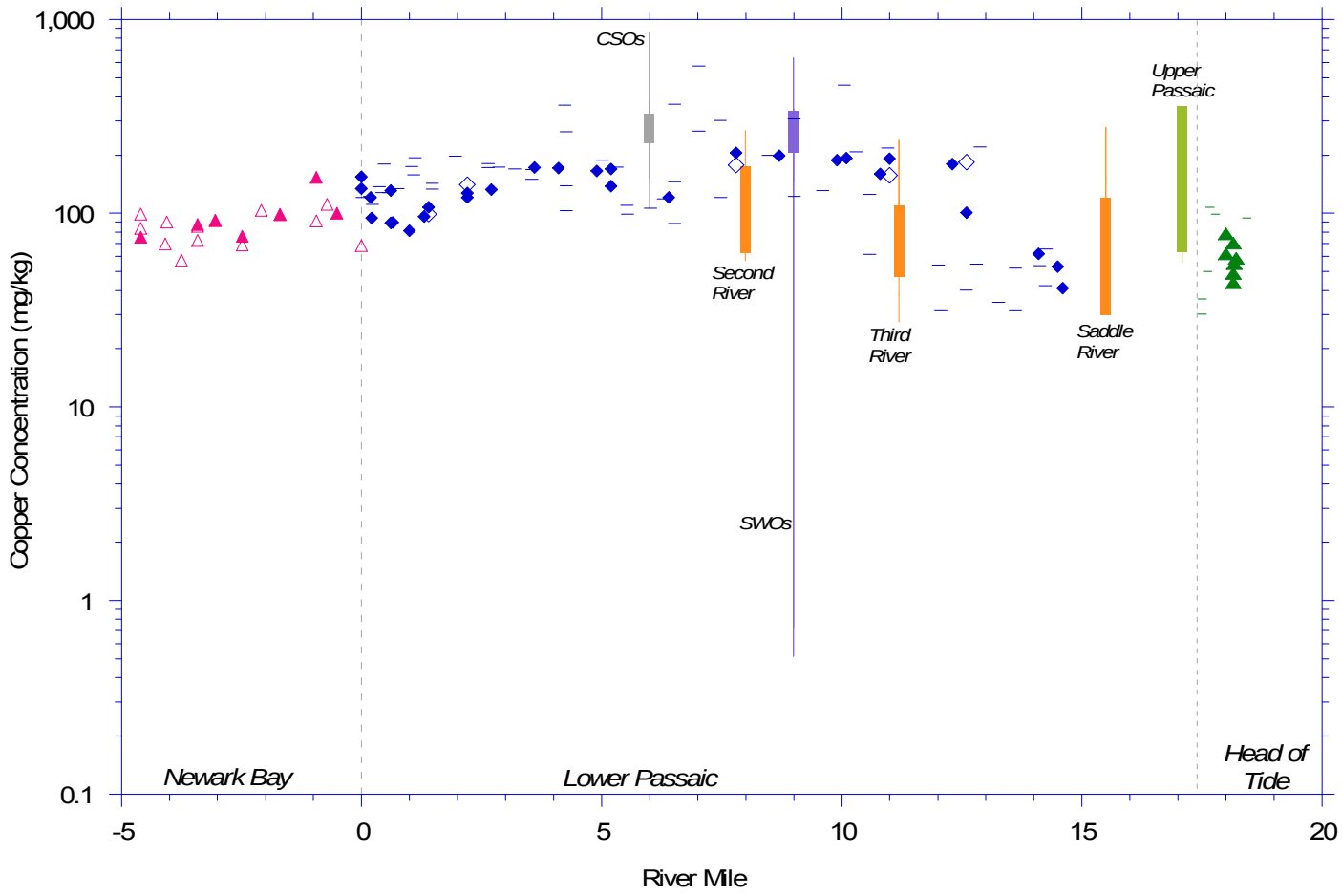
*See Notes on Figure 5-1b

Chromium Concentrations Measured in Recently-Deposited Material at Various Boundary Conditions

Lower Eight Miles of the Lower Passaic River

Figure 5-5d

2014



Legend*

Water Body

- Lower Passaic
- Upper Passaic above HoT
- Newark Bay Main Channel
- CSOs
- SWOs
- Tributaries
- Upper Passaic

Sample Type

- 2007-2008 Surficial Sediment Be-7 Bearing
- 2005 Surficial Sediment Be-7 Bearing
- 2008 CPG Surficial Sediment Be-7 Bearing

Distribution of CSOs, SWOs, Tributaries and Upper Passaic Samples

- Maximum
- 75th Percentile
- 25th Percentile
- Minimum

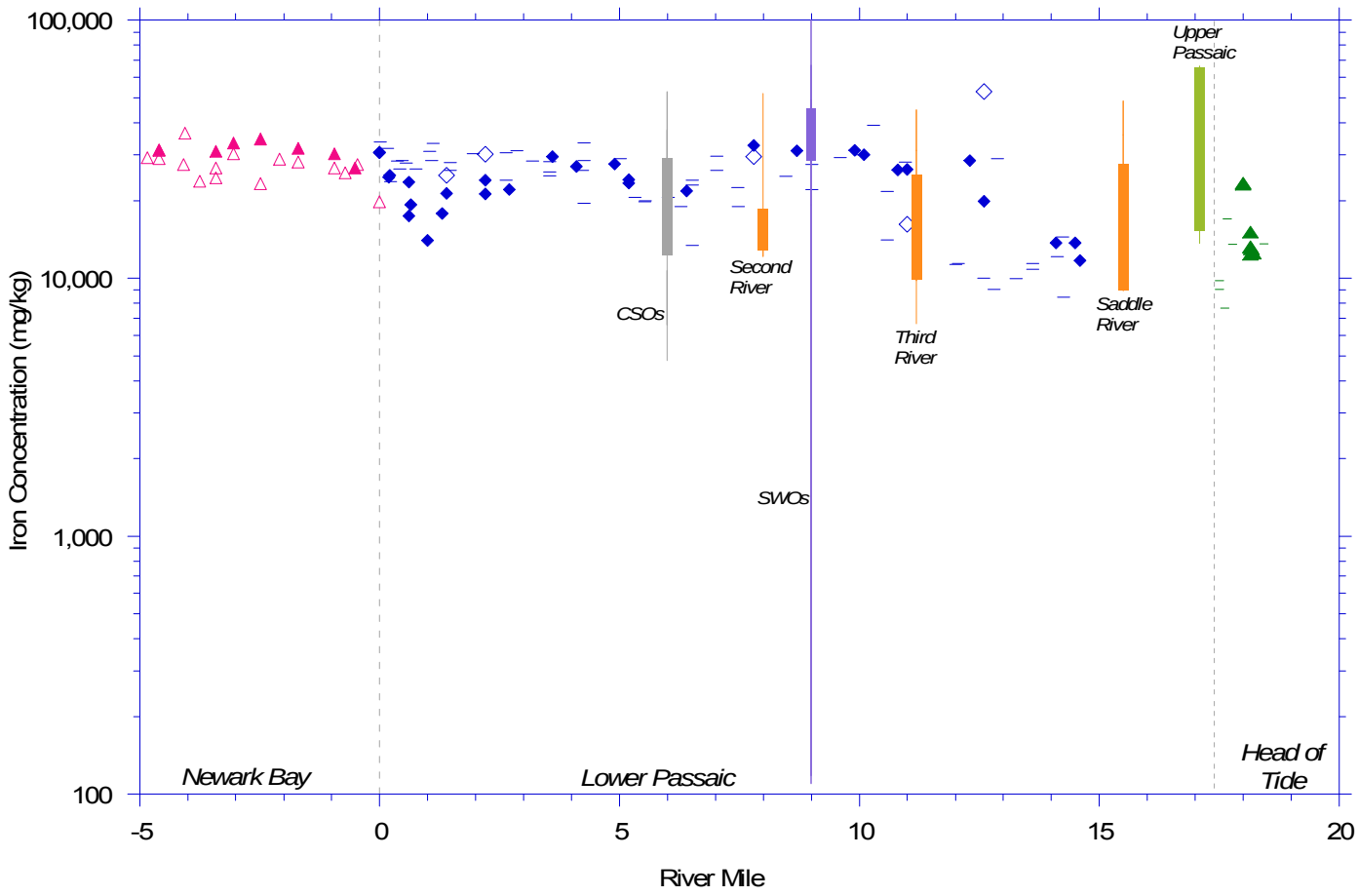
*See Notes on Figure 5-1b

Copper Concentrations Measured in Recently-Deposited Material at Various Boundary Conditions

Lower Eight Miles of the Lower Passaic River

Figure 5-5e

2014



Legend*

Water Body

- Lower Passaic
- Upper Passaic above HoT
- Newark Bay Main Channel
- CSOs
- SWOs
- Tributaries
- Upper Passaic

Sample Type

- 2007-2008 Surficial Sediment Be-7 Bearing
- 2005 Surficial Sediment Be-7 Bearing
- 2008 CPG Surficial Sediment Be-7 Bearing

Distribution of CSOs, SWOs, Tributaries and Upper Passaic Samples

- Maximum
- 75th Percentile
- 25th Percentile
- Minimum

*See Notes on Figure 5-1b

Iron Concentrations Measured in Recently-Deposited Material at Various Boundary Conditions

Lower Eight Miles of the Lower Passaic River

Figure 5-5f

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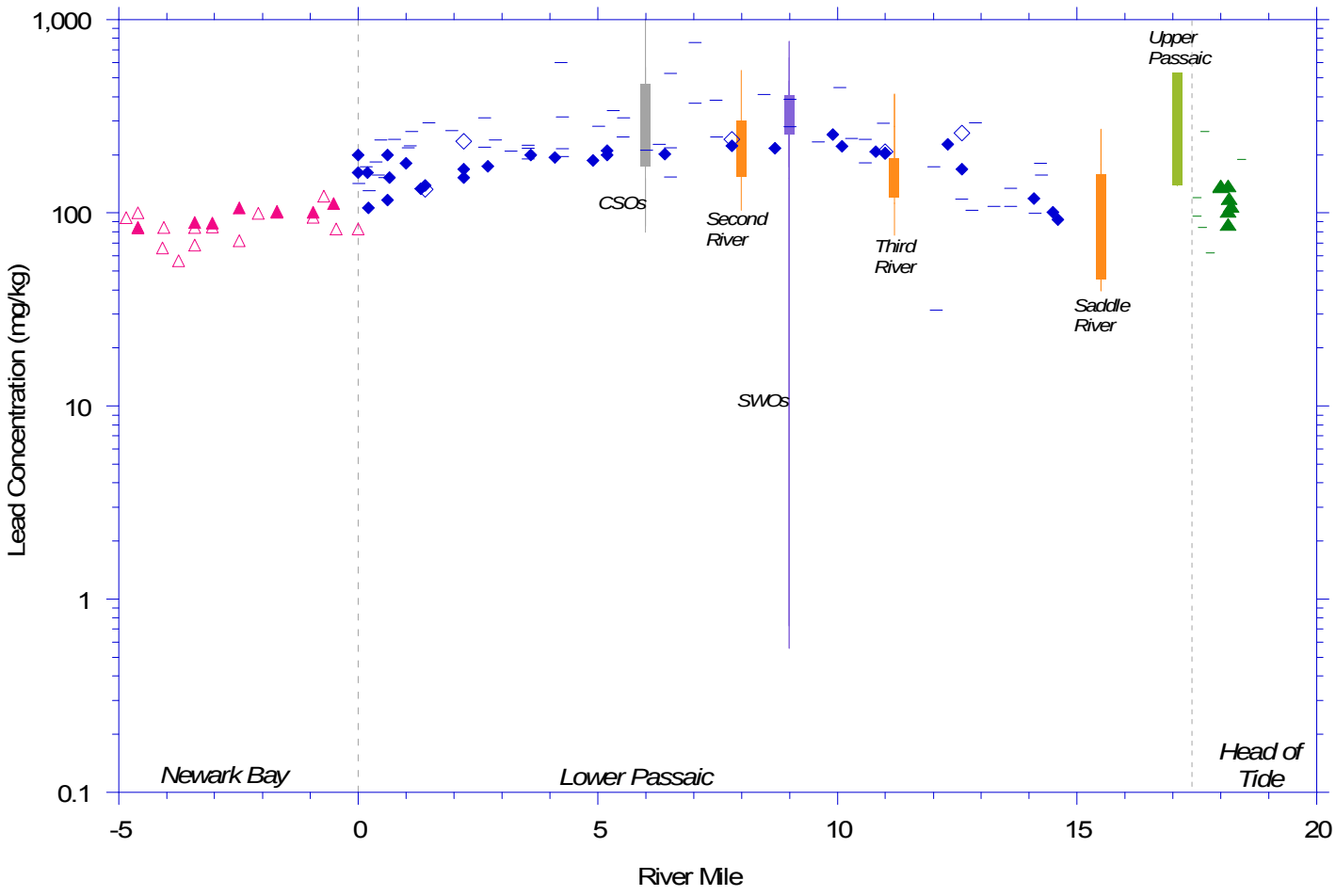


Legend*

Water Body

- Lower Passaic
- Upper Passaic above HoT
- Newark Bay Main Channel
- CSOs
- SWOs
- Tributaries
- Upper Passaic

Sample Type

- 2007-2008 Surficial Sediment Be-7 Bearing
- 2005 Surficial Sediment Be-7 Bearing
- 2008 CPG Surficial Sediment Be-7 Bearing

Distribution of CSOs, SWOs, Tributaries and Upper Passaic Samples

- Maximum
- 75th Percentile
- 25th Percentile
- Minimum

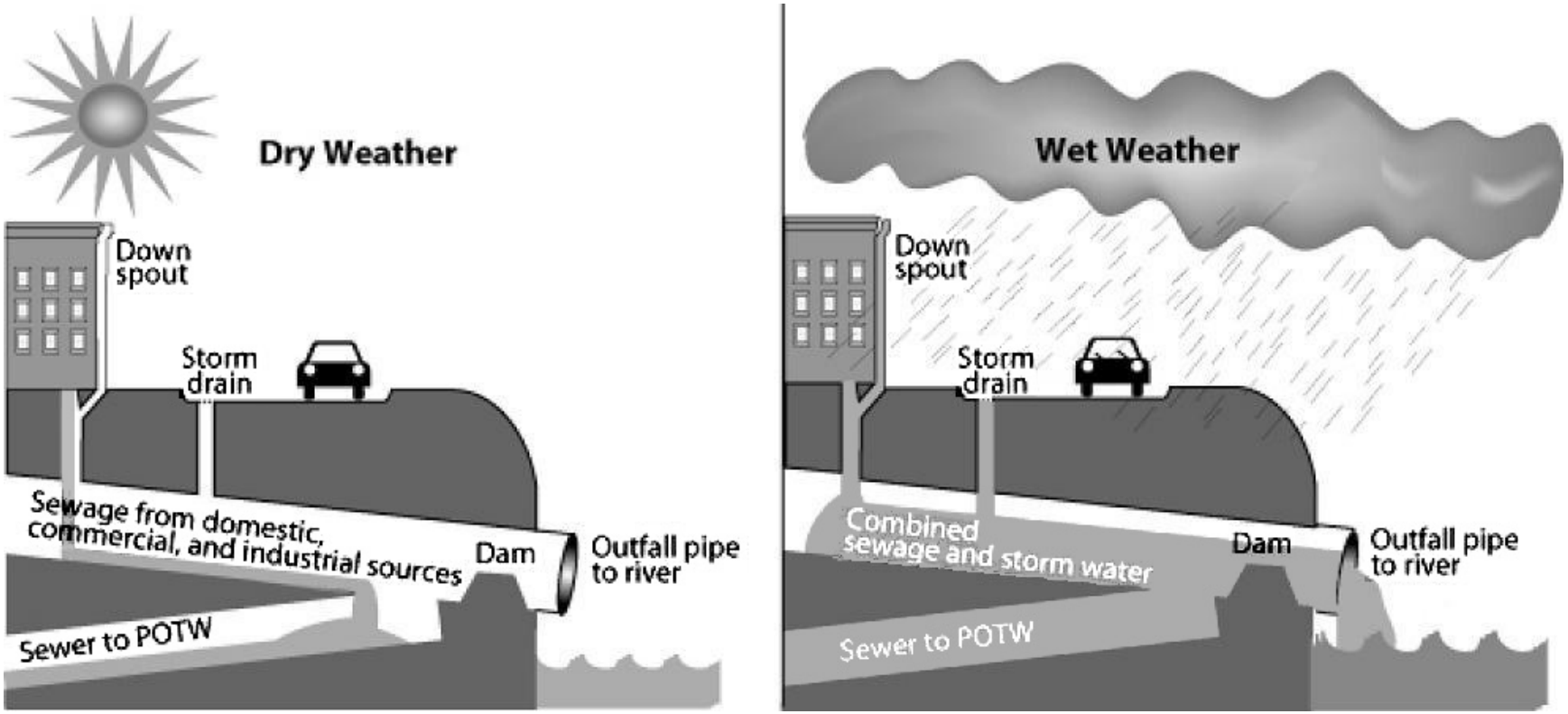
*See Notes on Figure 5-1b

Lead Concentrations Measured in Recently-Deposited Material at Various Boundary Conditions

Lower Eight Miles of the Lower Passaic River

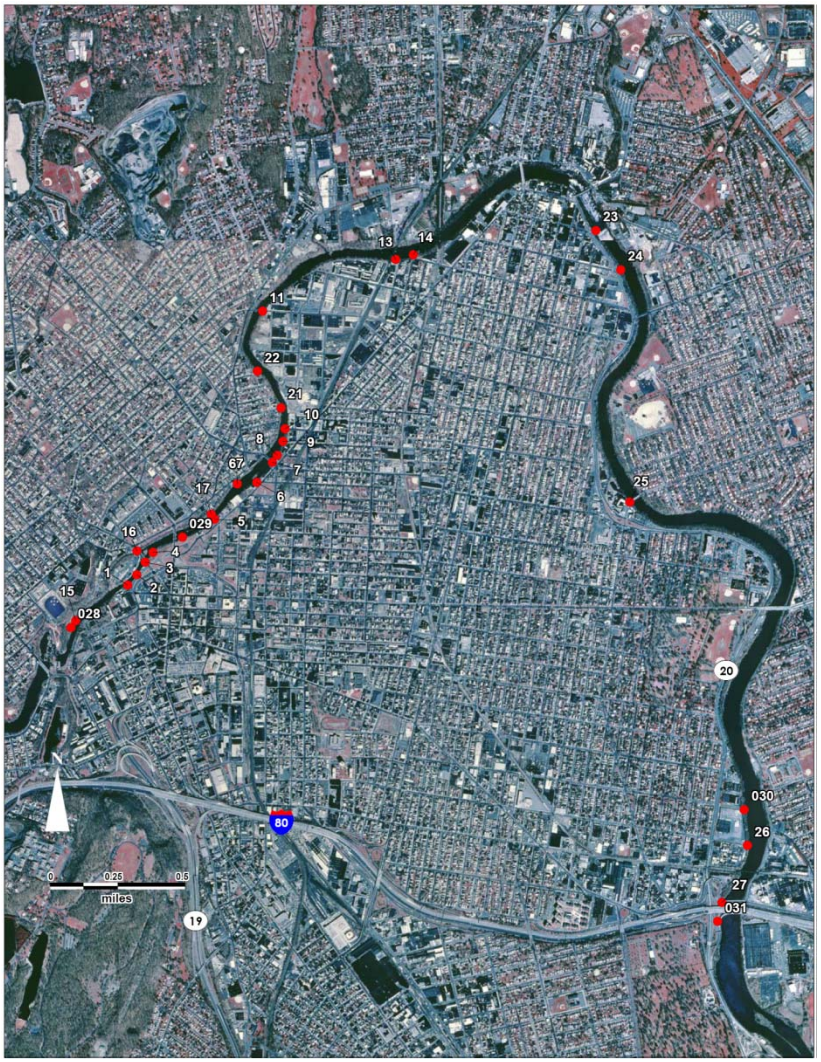
Figure 5-5g

2014

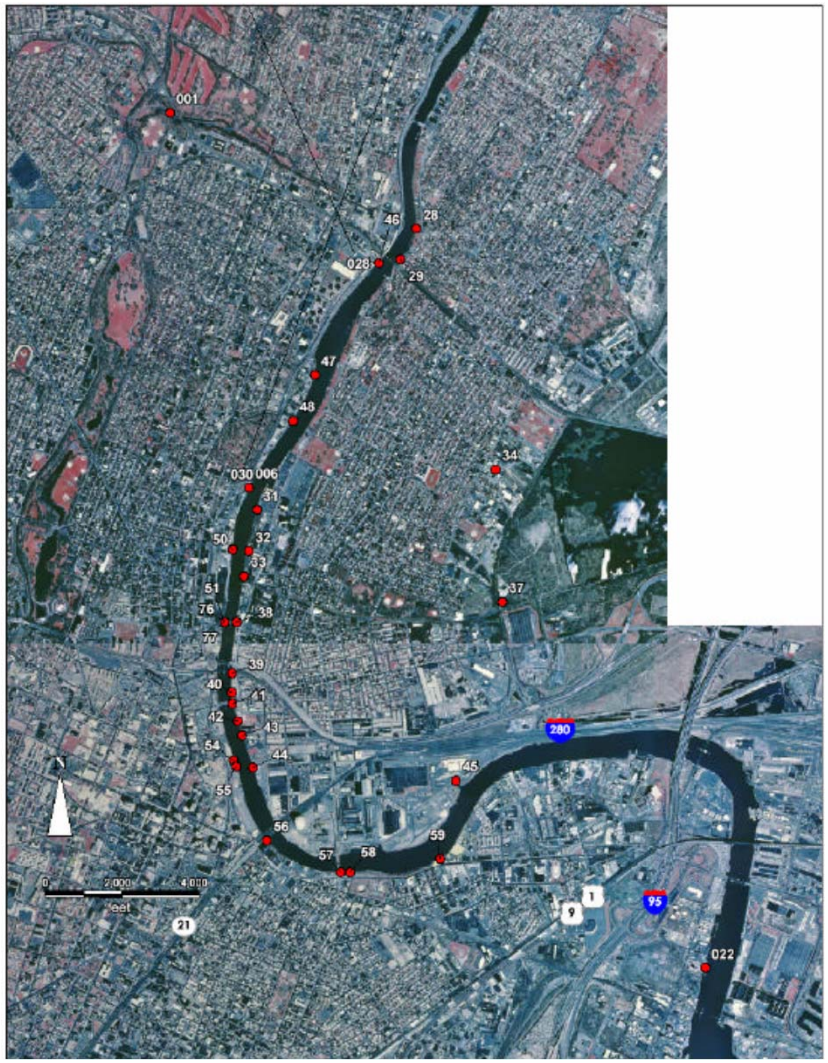


Source: U.S. Environmental Protection Agency, Washington, D.C. August 2004

	Illustration of a Combined Sewer Outfall System *Lower Eight Miles of the Lower Passaic River*	Figure 6-1 2014



Paterson Area Outfalls



Newark Area Outfalls

	Lower Passaic River CSO Locations *Lower Eight Miles of the Lower Passaic River*	Figure 6-2 2014

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CSO Locations for the 2007-2008 USEPA/Malcolm Pirnie, Inc. and 2001-2004 CARP Programs

Lower Eight Miles of the Lower Passaic River

Figure 6-3a

2014

CSO Locations for the 2007-2008 USEPA/Malcolm Pirnie, Inc. and 2001-2004 CARP Programs

Lower Eight Miles of the Lower Passaic River

Figure 6-3b

2014

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SWO Locations for the 2007-2008 USEPA/Malcolm Pirnie, Inc. and 2001-2004 CARP Programs

Lower Eighte Miles of the Lower Passaic River

Figure 6 - 4a

2014

SWO Locations for the 2007-2008 USEPA/Malcolm Pirnie, Inc. and 2001-2004 CARP Programs

Lower Eight Miles of the Lower Passaic River

Figure 6 - 4b

2014

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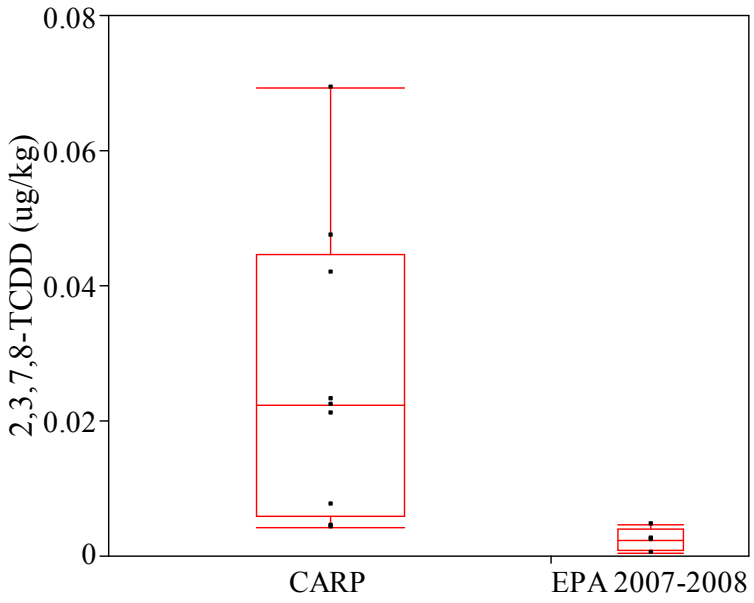
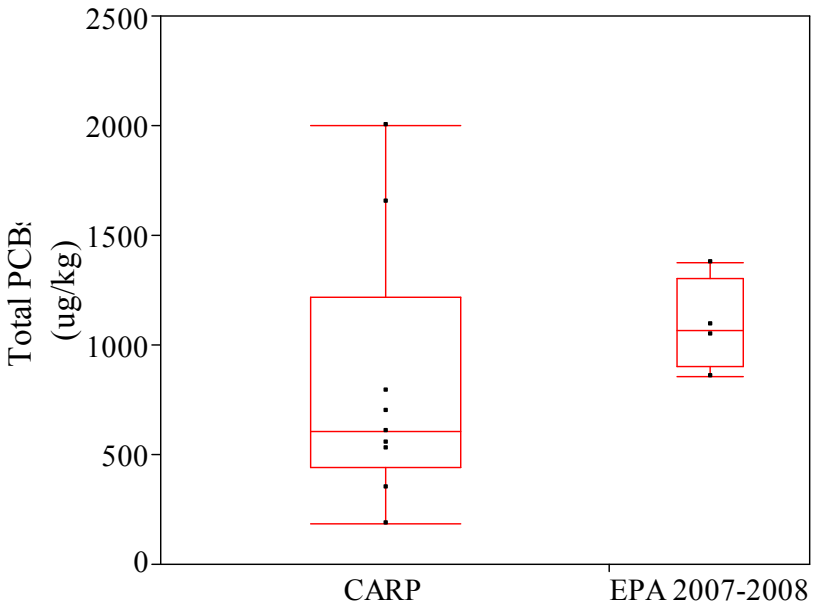


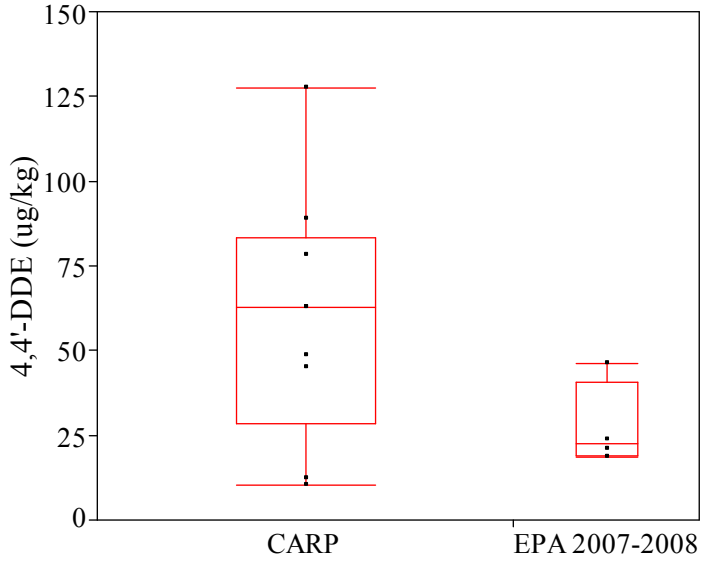


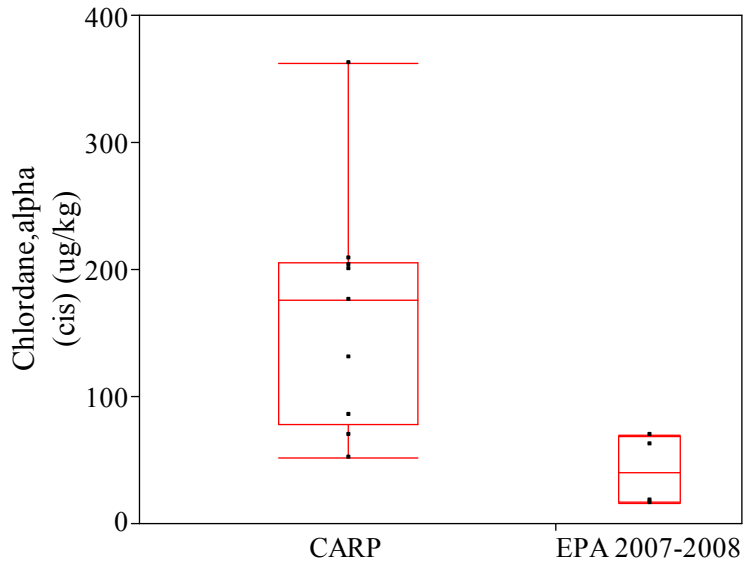
Comparison of Contaminant Data Collected at CSO Sites for the 2007-2008 USEPA/Malcolm Pirnie, Inc. and 2001-2004 CARP Programs
2,3,7,8-TCDD and Total PCB

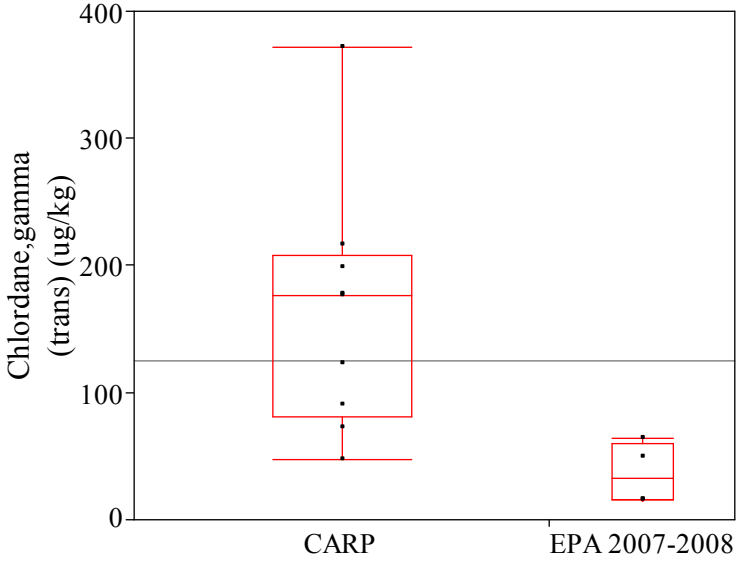
Lower Eight Miles of the Lower Passaic River

Figure 6-5a

2014





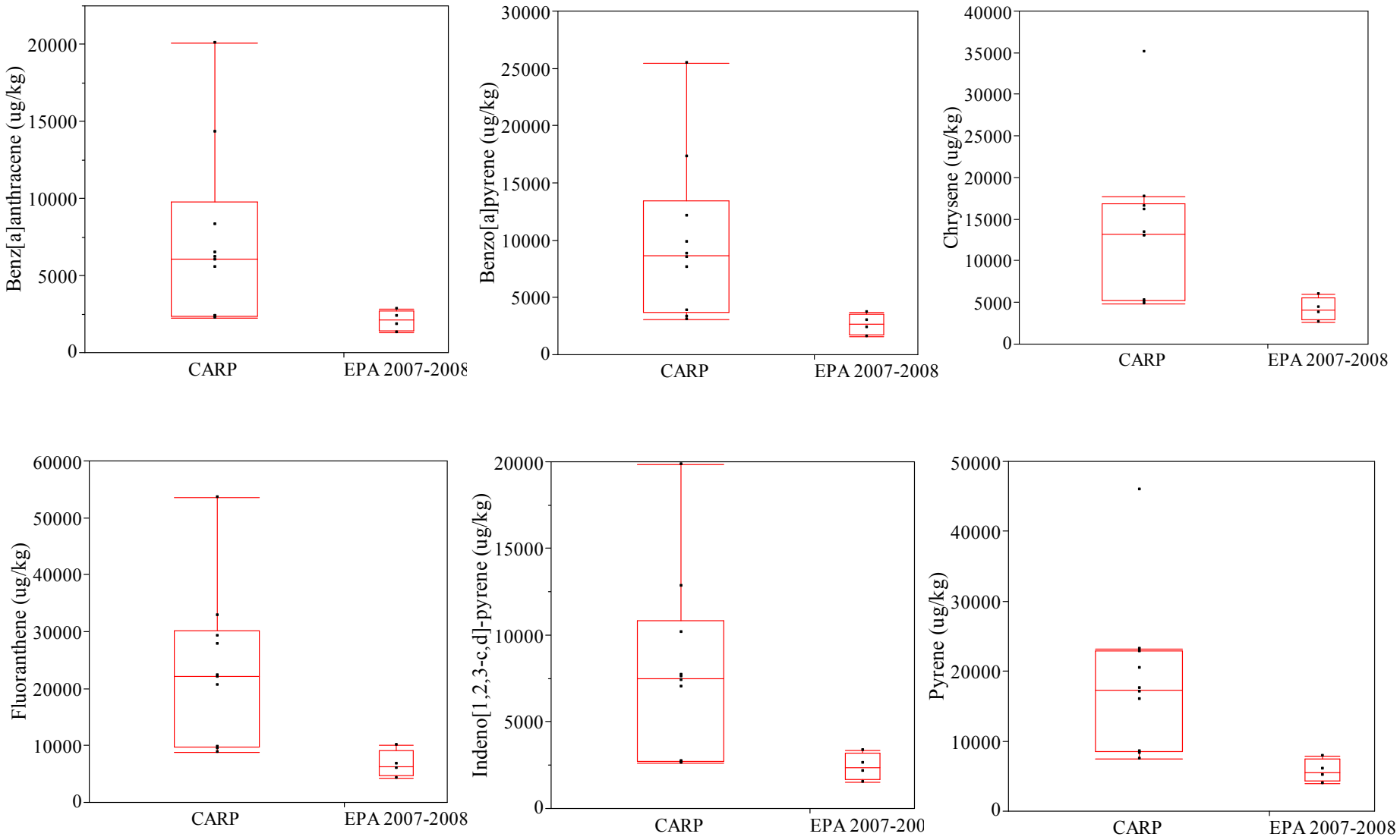


Comparison of Contaminant Data Collected at CSO Sites for the 2007-2008 USEPA/Malcolm Pirnie, Inc. and 2001-2004 CARP Programs
Pesticides

Lower Eight Miles of the Lower Passaic River

Figure 6-5b

2014



	Comparison of Contaminant Data Collected at CSO Sites for the 2007-2008 USEPA/Malcolm Pirnie, Inc. and 2001-2004 CARP Programs PAH Compounds *Lower Eight Miles of the Lower Passaic River*	Figure 6-5c 2014

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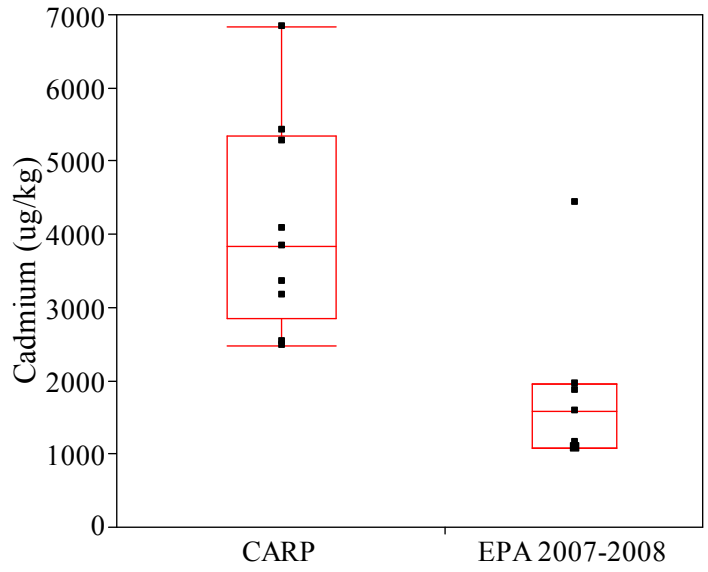

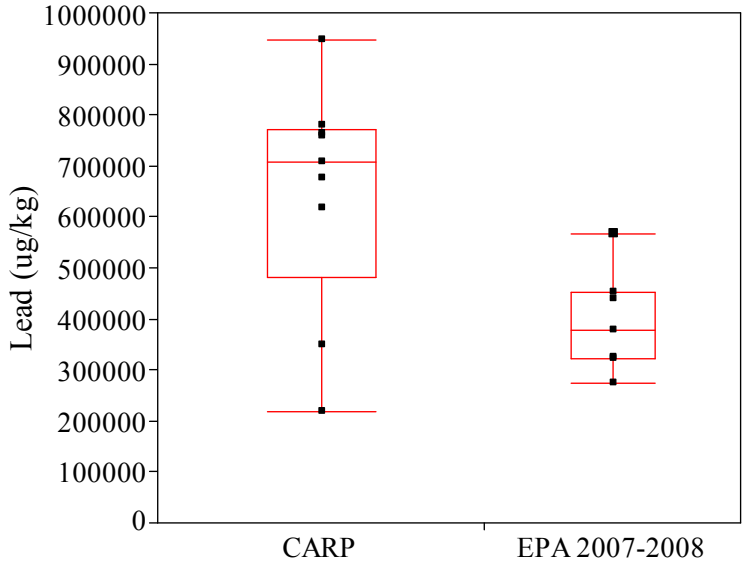

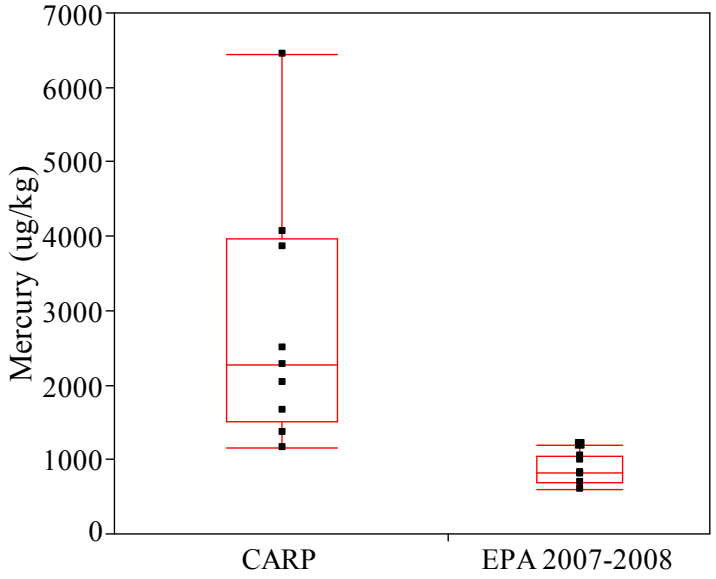

Comparison of Contaminant Data Collected at CSO Sites for the 2007-2008 USEPA/Malcolm Pirnie, Inc. and 2001-2004 CARP Programs
Metals

Lower Eight Miles of the Lower Passaic River

Figure 6-5d

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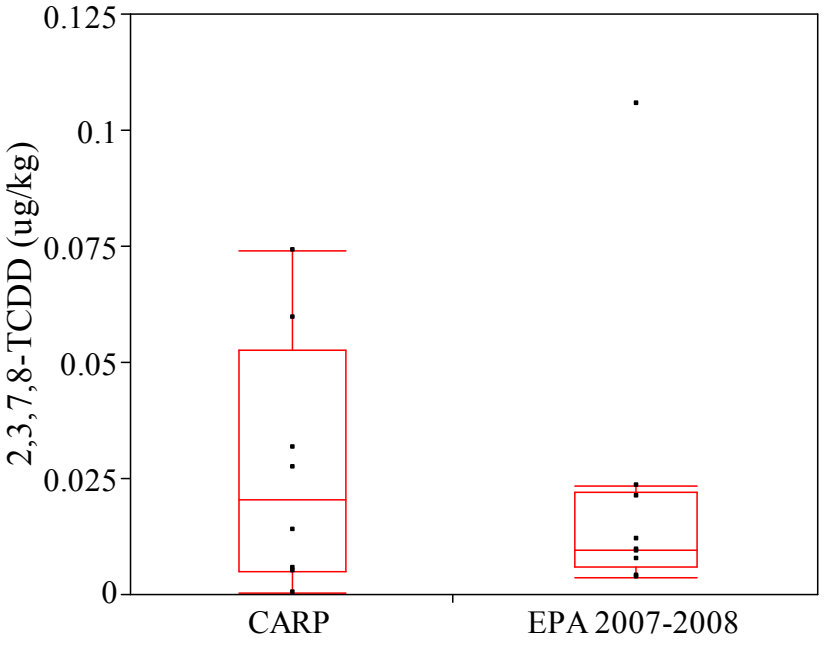

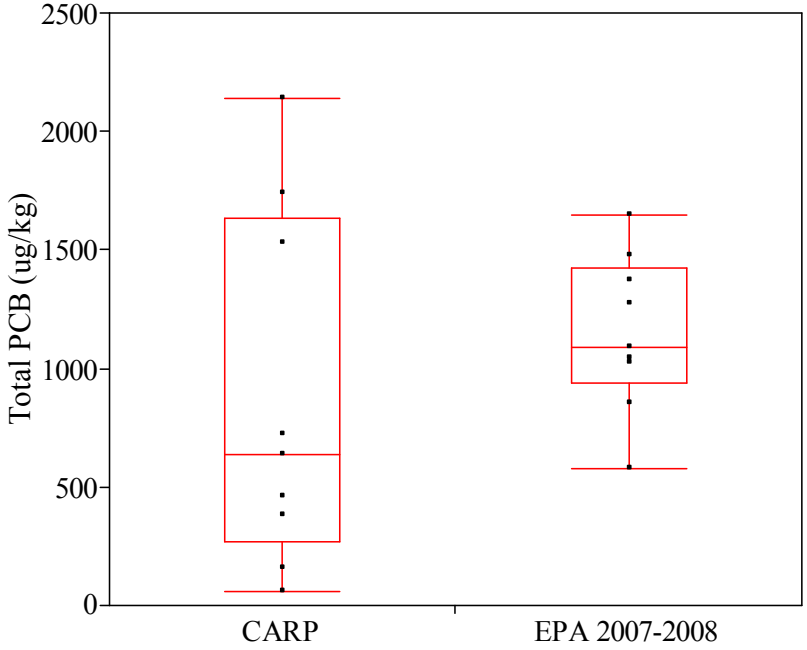

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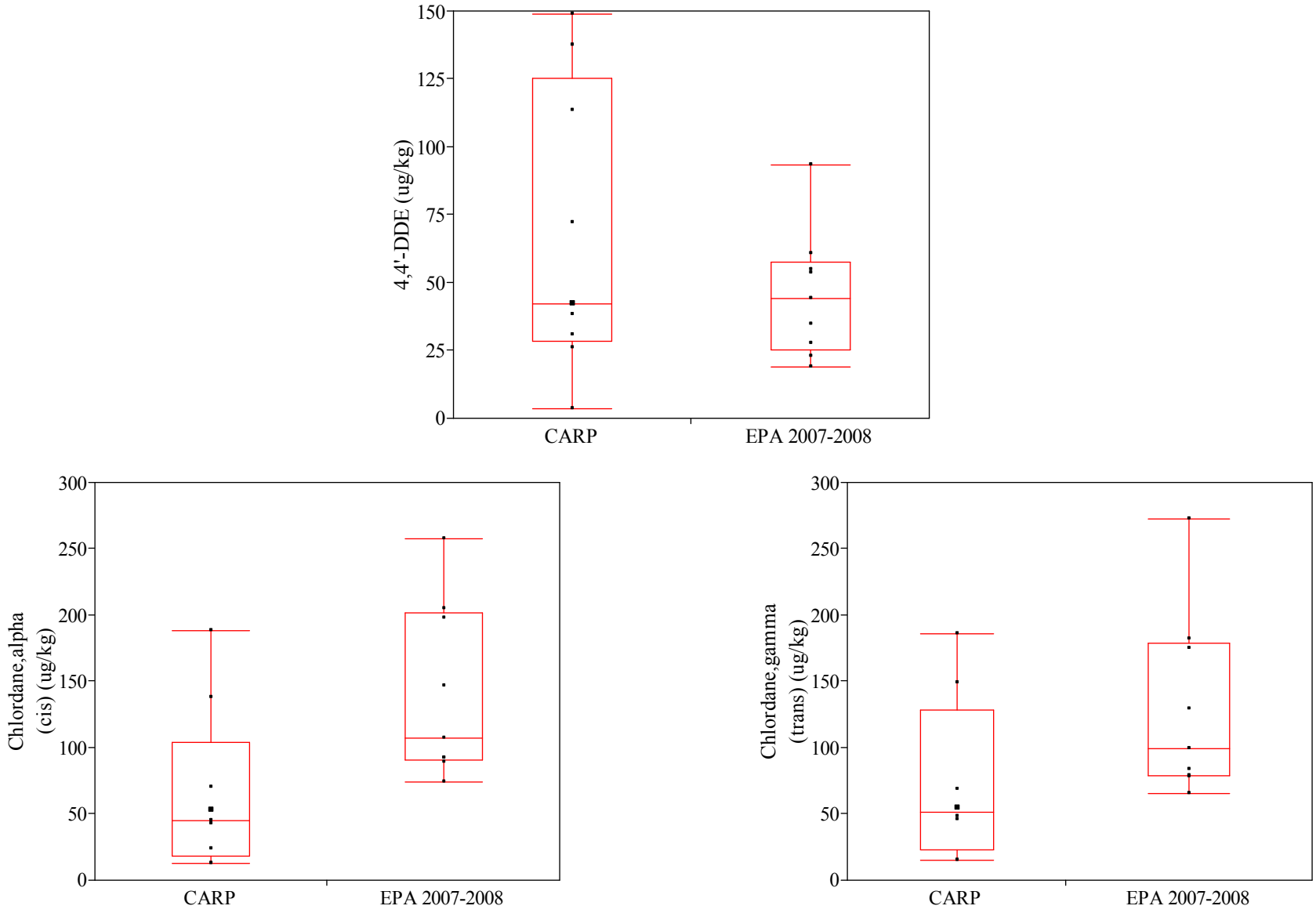
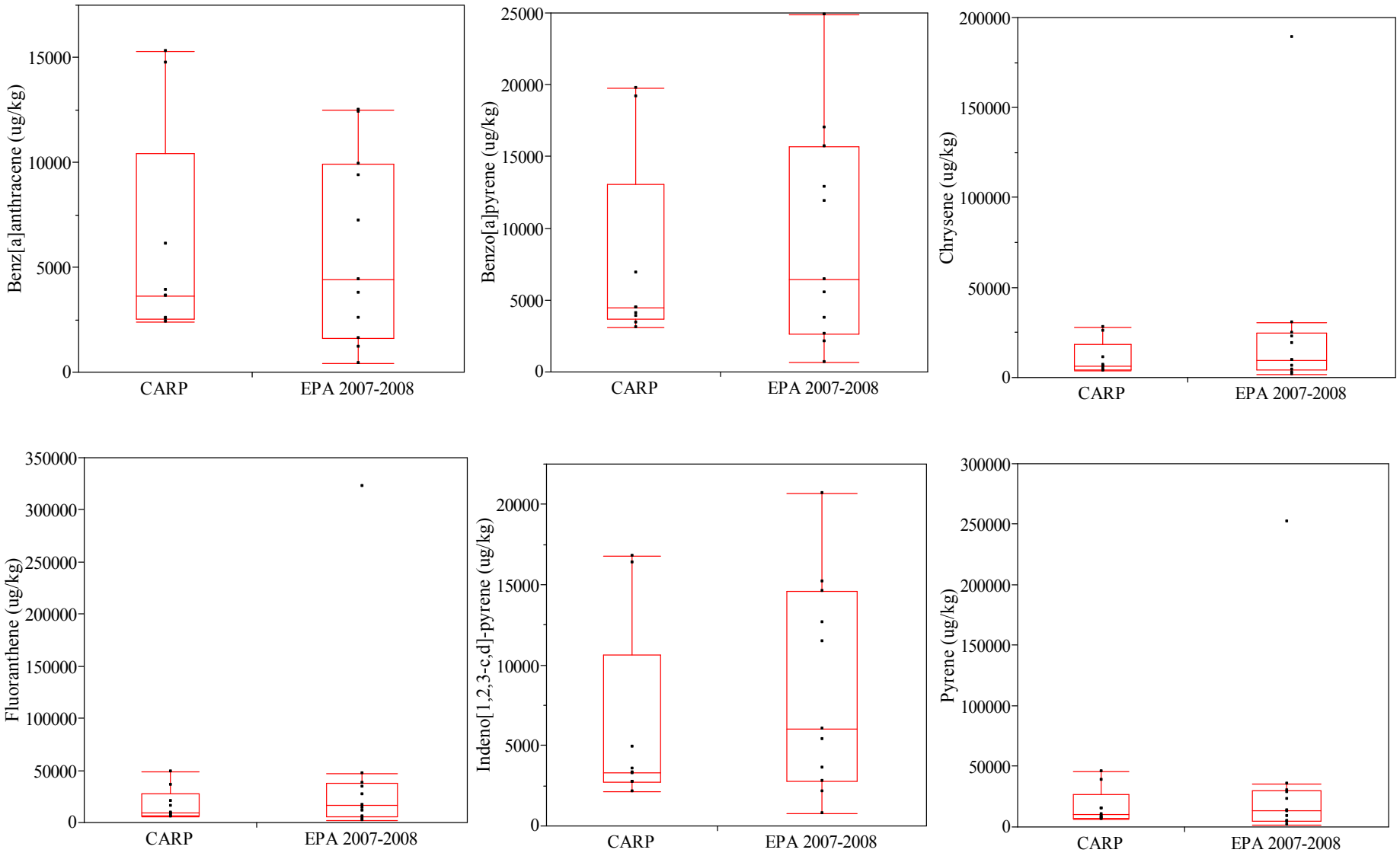


	Comparison of Contaminant Data Collected at SWO Sites for the 2007-2008 USEPA/Malcolm Pirnie, Inc. and 2001-2004 CARP Programs Pesticides *Lower Eight Miles of the Lower Passaic River*	Figure 6-6b 2014

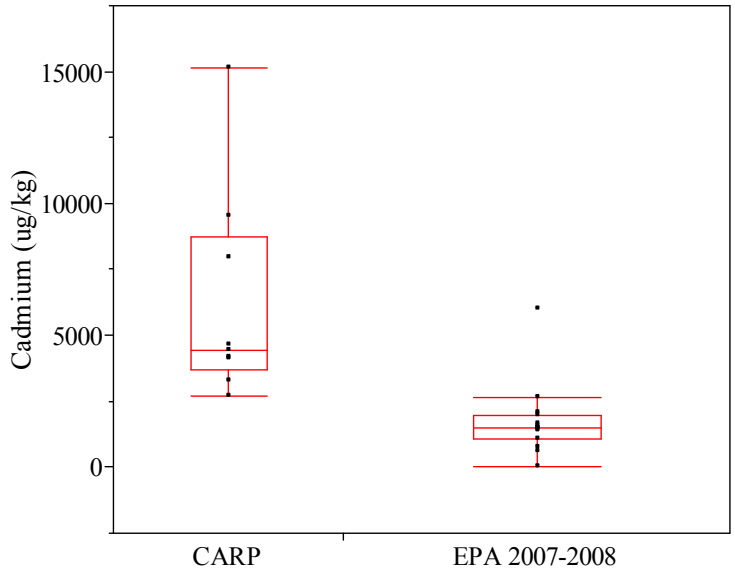


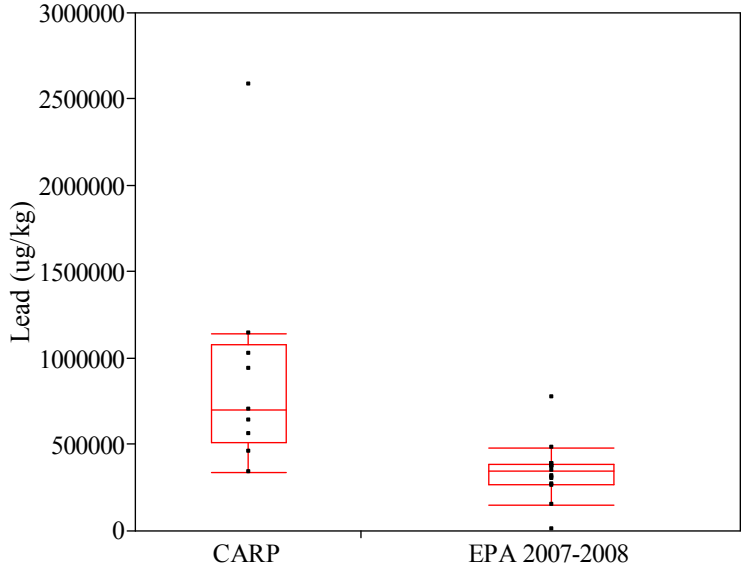
Comparison of Contaminant Data Collected at SWO Sites for the 2007-2008 USEPA/Malcolm Pirnie, Inc. and 2001-2004 CARP Programs
PAH Compounds

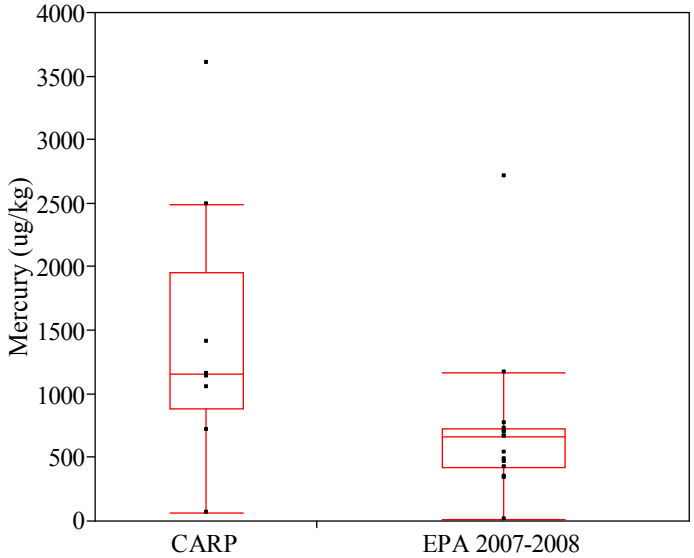
Lower Eight Miles of the Lower Passaic River

Figure 6-6c

2014







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Data Evaluation Report No. 3:

“Contaminant History as Recorded in the Sediments”

LOWER EIGHT MILES OF THE LOWER PASSAIC RIVER
DATA EVALUATION REPORT NO. 3: CONTAMINANT HISTORY AS RECORDED IN THE SEDIMENTS

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1 INTRODUCTION

This document is part of a series of data evaluation reports, which were prepared to support the Remedial Investigation (RI) and Focused Feasibility Study (FFS). Reports in this series describe different aspects of the Lower Passaic River. Where necessary, data evaluation reports are cross-referenced to direct the reader to another report that contains further explanation. Topics discussed in this series include boundary conditions for the river, historical sediment contamination, surface sediment contamination, contaminant inventory calculations, and biota analysis. The following data evaluation report examines the historical concentrations of contaminants of potential concern (COPCs) and contaminants of potential ecological concern (COPECs) on suspended solids in the river as recorded in the sediments and their implications for the history of contaminant discharges to the river.

1.1 Overview of the FFS Study Area

The FFS Study Area is located within the Lower Passaic River Study Area (LPRSA), which is the 17-mile, tidal portion of the Passaic River from Dundee Dam [located at River Mile (RM[1]) 17.4] to the confluence with Newark Bay at RM0 and the watershed of this river portion, including the Saddle River (RM15.6), Third River (RM11.3) and Second River (RM8.1) [Figure 1-1]. During a comprehensive study of the Lower Passaic River, the sediments of the lower eight miles were found to be a major source of contamination to the rest of the river and Newark Bay. Therefore, the United States Environmental Protection Agency (USEPA) completed the FFS to evaluate alternatives to address those sediments in the lower eight-mile stretch from RM0 to RM8.3, near the border between the City of Newark and Belleville Township. The entire 17-mile Lower Passaic River is the subject of another Remedial Investigation/Feasibility Study (RI/FS)

[1] The FFS uses the "River Mile" (RM) system developed by the United States Army Corps of Engineers (USACE), which follows the navigation channel of the Lower Passaic River. The Data Evaluation Reports (Appendix A), Empirical Mass Balance (Appendix C) and Lower Passaic River-Newark Bay model (Appendix B) were initially developed at the beginning of the 17-mile Remedial Investigation and Feasibility Study (RI/FS), and thus follow a RM system developed for that RI/FS, which follows the geographic centerline of the River. RM0 is defined by an imaginary line between two marker lighthouses at the confluence of the Lower Passaic River and Newark Bay: one in Essex County just offshore of Newark and the other in Hudson County just offshore of Kearny Point. River miles then continue upriver to the Dundee Dam (RM17.4). The two RM systems are about 0.2 miles apart.

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being implemented by the Cooperating Parties Group (CPG; a group of approximately 70 potentially responsible parties who signed an agreement with USEPA in 2007), under USEPA oversight. The Upper Passaic River watershed (the portion of the Passaic River located above the Dundee Dam) contributes solids, water, and contaminants that cross over the head-of-tide, which is represented by the Dundee Dam[2], into the Lower Passaic River.

1.2 Overview of the Contaminant History

This document examines contaminants in dated sediment cores as an indication of historical water quality changes and sediment contamination in the Lower Passaic River. A common approach for evaluating trends is to apply statistical tests to historical water quality data. However, determining water-quality trends using historical data is often subject to several limitations, such as lack of sufficient data, changing sampling techniques through time, and variations in analytical methods and detection levels. These limitations can be crucial when dealing with trace elements and hydrophobic organic compounds, which normally occur at very small concentrations in the water column. Detecting trends for some minor elements and compounds often is further complicated by large variability in aqueous concentrations over short time intervals.

An alternative approach for evaluating water-quality trends for some constituents is paleolimnology, the use of age-dated sediment cores to reconstruct water-quality histories (Van Metre, *et al.*, 2004; Callender and Van Metre, 1997; Davis, 1980; Eisenreich *et al.*, 1989; Hites *et al.*, 1981; Van Metre, *et al.*, 1997). Historical water-quality records can be partly reconstructed using dated sediment cores collected from receiving water bodies, such as reservoirs, lakes, and estuaries. Water quality trends that reflect urbanization and industrial discharges can be established from contaminant concentrations on particles that were originally suspended in the water column, deposited on the sediment bed and subsequently captured in the dated sediment cores.

[2] The Dundee Dam represents a hydraulic boundary. The head-of-tide actual location is downstream of the dam because even though the tides can influence the water level near the dam, the upper-most extent of saltwater (*i.e.*, the salt front) typically stops several miles below the Dundee Dam (refer to Lower Passaic River System Understanding of Sediment Transport [HQI and Sea Engineering Inc, 2011] for further details on the salt front migration).

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The Lower Passaic River is a dynamic environment, experiencing both periods of net erosion and net deposition, with daily tidal exchanges and periodic high flow events. Solids that enter the Lower Passaic River at Dundee Dam, tributary confluences, and local discharge points are blended and re-worked through tidal mixing and erosional/depositional events. Eventually, some of these solids are transported downstream and deposited in Newark Bay. Solids also enter the river via tidal exchange from Newark Bay, only to be reworked and blended with the solids from the other sources and either deposited in the river or exchanged back to Newark Bay. These processes are further described in Appendix B of the FFS.

As solids are deposited on the river bottom, they largely retain their burden of particle-reactive and persistent contaminants, reflecting the suspended solid water quality conditions at the time of deposition. In some sheltered locations, the deposition is steady and undisturbed enough to create a nearly continuous record of settling solids and associated contaminants through time. Cores obtained from these areas provide a means to construct these records.

By examining the levels of well-documented radionuclides in the core, the approximate year of deposition can be established for various depths within the core. In turn, the contaminant levels in these dated layers are then considered reflective of the mean concentrations of contaminants associated with suspended solids present in the river during the deposition period. In this manner, a dated sediment core can be considered a record of historical water column conditions at the collection site and the surrounding area, in the same way that a fossilized fish embedded in sedimentary rock provides data regarding its prior life in the water column. For the purposes of the FFS, deposition over the last 50 to 100 years is of greatest interest. The core intervals reflecting this period of deposition were established based on the depth distribution of radioactive Cesium-137 (Cs-137), which is discussed in Section 2.

By obtaining cores from locations distributed along the river, the spatial and temporal distribution of solids-borne contaminants can be discerned. A dated sediment core at RM1.4 can provide a record of suspended solids contamination in the saline waters near the mouth of the Lower Passaic River; whereas a core at RM12.6 provides a record of suspended solids associated contamination in the largely fresh waters of this area of the river. Cores obtained between these locations can be used to document changes along the main axis of the river.

This data evaluation report examines downcore profiles collected in the Lower Passaic River by both the USEPA and Tierra Solutions, Inc. (TSI) [under USEPA oversight]. The analysis is focused on the chronologies obtained from five dated sediment cores collected in 2005 by the USEPA, which provide the greatest detail concerning the long-term trends of contamination in the Lower Passaic River. In 2007, the USEPA reoccupied the locations of the 2005 high resolution cores and obtained a 0 to 2 centimeter (cm) sample using a shallow box core. The 2007 surface sediment concentrations will be presented and discussed to extend the contaminant trends obtained from the dated cores. In addition, a comparison to 1995 TSI cores, specifically the longest 1995 sediment cores with interpretable Cs-137 profiles, is also presented. Figure 1-2 shows the location of the 1995 and 2005 cores examined in this data evaluation report.

This data evaluation report is composed of the following sections in addition to the introduction:

- *Section 2.0, Conceptual Model of Sediment Core Dating and the FFS Coring Program:* presents the theoretical and practical considerations for collection and dating of sediment cores as well as a description of the USEPA's dated sediment core collection efforts.
- *Section 3.0, Examining the Sediment Record of Historical Contamination:* characterizes the historically-deposited sediments in the river and presents a geochronology of contaminant loading.
- *Section 4.0, Acronyms*: defines the acronyms used in this report.
- *Section 5.0, References*: lists the references used in this report.

2 CONCEPTUAL MODEL OF SEDIMENT CORE DATING AND THE FFS CORING PROGRAM

Before discussing the high resolution sediment core results, it is useful to outline the basic concepts on which core collection and analysis are based. The first assumption is that sediments that accumulate at a given location reflect the water column conditions at the time of deposition at that location (*i.e.*, the sediments are effectively a time-integrated sample of the water column suspended matter). Sediments best retain the concentrations and patterns of particle-reactive contaminants, such as polychlorinated dibenzodioxins/ furans (dioxins), polychlorinated biphenyls (PCBs), heavier polycyclic aromatic hydrocarbons (PAHs), and heavy metals. Highly soluble compounds such as volatile organics are not well conserved in the sediments and usually cannot be examined by this approach.

High resolution cores must be collected from areas that exhibit specific attributes in order to yield a core with an interpretable chronology and associated contaminant history (Olsen, 1979, Olsen *et al.*, 1981, and Bopp *et al.*, 2006). Sediment accumulation at the core location must occur continuously or almost continuously over time. Cores collected from rivers and estuaries where hydrodynamic energies are relatively high and surface sediments are frequently scoured and redeposited do not yield profiles that reflect steady annual deposition and obtaining datable cores is unlikely. The techniques used to verify continuous or almost continuous sediment accumulation are discussed below.

To translate the layers of deposited sediments into a geochronology of contaminant loading, several additional criteria must be satisfied. Several key criteria follow.

- Sediment accumulation is relatively constant on an annual basis although varying seasonally with flow. Long term variations in annual deposition rate can be addressed when multiple radionuclide indicators are available.
- Little resuspension occurs subsequent to sediment deposition (*i.e.*, few or no erosional events).

- Biological stirring (bioturbation) of the sediments occurs only minimally, typically mixing only a few years of deposition.
- The effects of human activities on sediment accumulation are minimal or can be documented (*e.g.*, a known dredging event).

When these criteria are satisfied then the factors governing contaminant concentrations on water column suspended matter will also be reflected in sediment concentrations (*e.g.*, contaminant concentrations in the sediment will decrease downstream of a major tributary relatively free of contamination, mimicking the contaminant water column concentrations upstream and downstream of the tributary).

2.1 Establishing Sediment Core Chronologies: Radionuclide Dating Principles

Radionuclides serve either as event markers or as "clocks" in establishing core chronologies. A radionuclide used as an event marker has a well-defined input history, such that minimum or maximum concentrations in the core sediments can be ascribed to known events. A radionuclide clock is a radionuclide whose rate of input to the sediments is approximately constant over long periods of time. Input to the sediment by other processes after deposition must be minimal and/or measurable. The decline in the concentration of the radionuclide with depth due to radioactive decay can then be ascribed to the approximate age of the sediments, similar to a clock counting the elapsed time since deposition. In order to understand how radionuclides serve these purposes, it is first necessary to define radionuclides, their properties and their origins.

A radionuclide is an atom with an unstable nucleus that will eventually decay to a more stable state, releasing radiation in the process. Each radionuclide has its own atomic form and amount of radioactivity released over a time period. Radionuclides can be detected at extremely low concentrations. For example, the detection limit for Cs-137 is about one part in 10^{15} by weight (1 femtogram/gram), which is 0.06 picocuries per gram (pCi/g) or about 6 disintegrations per minute in a 50-g sample. Radionuclides decay exponentially over time. The rate of decay is characterized in terms of a half-life ($t_{1/2}$), which is defined as the time for a radionuclide concentration to decay to half of its original concentration.

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In general, it is difficult to detect environmental levels of a radionuclide after about five half-lives have passed (*i.e.*, when only about 3 percent of the initial concentration remains). In this report, measurements of radioactivity for individual radionuclides are reported in pCi/g.

Radionuclides are produced by many different processes. Some are generated naturally, such as beryllium-7 (Be-7) and carbon-14 (C-14), which are produced by solar radiation in the upper atmosphere. Some radionuclides are man-made, such as Cs-137, which is produced during detonation of a nuclear weapon or as a by-product in a nuclear reactor. Most of the Cs-137 present on the earth's surface was produced as a result of the atmospheric nuclear weapons testing that took place between 1954 and 1963.

For a radioisotope to be useful in sediment core dating, it must be strongly sorbed to fine particles, so it remains with the sediment after deposition. It must also have a half-life that is appropriate for the period to be examined. Cs-137 and lead-210 (Pb-210) have half-lives of 30.2 and 22.3 years, respectively, making them useful for sediment dating over the last 50 to 100 years. Be-7 has a half-life of 53.4 days, making it a useful indicator of very recent sediment deposition (6 to 12 months or less). In contrast, C-14 has a half-life of about 5,700 years, too long for use in this FFS. All three isotopes, Cs-137, Pb-210, and Be-7 associate strongly to particles and have been successfully used to date sediments in estuarine environments.

2.1.1 Interpretation of Cs-137 in the Sediments

Because of its well-known input history and its residual levels in soils and sediments across the planet, Cs-137 is used as an event marker rather than a sedimentological "clock." Most of the historical release of Cs-137 to the environment has been the result of atmospheric weapons testing, which occurred almost exclusively between 1954 and 1963. The historical input of Cs-137 to the New York area has been summarized by Bopp *et al*. (1982) and Olsen (1979). Cs-137 provides two known time horizons, as indicated by:

(1) The appearance of Cs-137 in 1954 as a consequence of the onset of atmospheric atomic weapons testing; and

(2) A Cs-137 release maximum in 1963 corresponding to an extensive amount of atmospheric weapons testing just prior to the implementation of the Partial Test Ban Treaty (PTBT) in October 1963 (CIA, 2009).

These two horizons are detectable around the planet, with a somewhat stronger signal in the northern hemisphere. However, there are also local Cs-137 inputs that can serve as local time horizon markers. Much of Europe has a second Cs-137 maximum in the sediments, corresponding to the 1986 Chernobyl nuclear power accident. In the Hudson, there is a second Cs-137 maximum in the sediments, corresponding to releases from the nuclear reactor site at Indian Point, Buchanan, New York in 1971 (Bopp *et al*, 1982). Only the 1954 and 1963 Cs-137 horizons have been noted in Passaic River sediments (Bopp *et al.*, 1991 and Chaky, 2003).

In addition to the two horizons in the Cs-137 record, Cs-137 provides a third line of evidence related to sediment age. Since essentially no environmental levels of Cs-137 existed prior to 1954, fine-grained sediment lacking Cs-137 is considered deposited pre-1954. As a result of the atmospheric atomic weapons testing, a residual Cs-137 burden remains in soils throughout planet and in particular, in the northern hemisphere. Ongoing erosion of soils into receiving waters such as the Lower Passaic River continues to deliver suspended solids that contain measureable levels of Cs-137 to the present day. Thus, essentially all post-1954 fine-grained deposition contains measureable levels of Cs-137.

In establishing the age of sediments in this FFS, the 1963 Cs-137 maximum and the 1954 appearance of Cs-137 are the primary marker horizons. The sediment depth corresponding to the bottom of the first core segment with detectable levels of Cs-137 is assigned the year 1954. The mid-point of the core segment with the maximum Cs-137 value in the core is assigned the year 1963. The deepest Cs-137-bearing layer in a sediment core can be ascribed to about 1954 as long as deeper sediments are shown to be free of Cs-137 and the dredging history of the area is known.

To establish the approximate year of deposition for any depth within the core, the year is estimated by interpolating between the 1954 and 1963 horizons or by interpolating between the 1963 horizon and the top of the core, which is assigned the year of core collection. In the best of conditions, the number of centimeters of sediment accumulation per year is a constant for the two intervals but this is not essential to interpret a core chronology. More sophisticated means of core interpolation can be applied, which consider solids mass deposited per year rather than centimeters per year (cm/yr). However, for the purpose of this FFS, the approach described above provides sufficient accuracy for the needs of the project.

2.1.2 Interpretation of Be-7 in the Sediments

In contrast to Cs-137, Be-7 is serves as a sedimentological clock to identify very recently-deposited sediments. Be-7 is continuously produced in the upper atmosphere by cosmic radiation and as a result, has a fairly constant fallout rate at any given location (Lal *et al.*, 1958). As Be-7 settles to the earth's surface, either as particles or in rainfall, it enters receiving water bodies such as the Lower Passaic River. This occurs directly at the air-water surface and by surface runoff delivered from the tributaries. Once in the water column of the Lower Passaic River, Be-7 quickly associates with the suspended matter. Thus, settling solids will contain measurable amounts of this isotope. Because of its short half-life, (53.4 days), Be-7 will be limited to sediments deposited within the last 6 to 12 months.

While it is theoretically possible to use this radionuclide to examine very short term variations in deposition rates (less than 6 months), its use in this manner is limited by the physical conditions of the river. Specifically, annual sediment deposition rates, the expected thickness of biological mixing and the minimum thickness of a measurable sediment layer are all on the order of 1 cm or more. Thus, the uppermost layer in a core in a depositional setting will typically represent 1 to 2 years of deposition, will be relatively well mixed and contain Be-7. The next layer down will be 2 to 4 years old and free of Be-7. Based on this, the presence of Be-7 in the top layer of a core is taken to indicate very recent deposition (sediments deposited within the last 6 to 12 months).

Deeper layers are generally free of Be-7 except in areas of very high deposition rates. Because of its limited presence in deeper sediments, Be-7 concentrations were not determined for samples deeper than eight centimeters.

2.1.3 Consideration of Pb-210

Samples were also analyzed for Pb-210 as part of the USEPA coring investigation of the Lower Passaic River. However, these data were subject to analytical issues such as method blank contamination and did not meet the data quality objectives. As a result, these results were not used in the interpretation of the cores. Since these results were not used in this report, no further discussion of the Pb-210 dating process is warranted.

2.1.4 Definition of a High Resolution Sediment Core

The term *high-resolution* sediment coring refers to the method by which sediment cores are collected and sliced for analysis. High-resolution sediment cores are collected from the river bottom, preferably from a relatively undisturbed region of fine-grained sediments. The sediment from the core is carefully extruded from the end of the coring tube and sliced into relatively thin segments, typically 2 to 4 cm intervals. Each slice is then sub-sampled for COPC and COPEC analysis and radionuclide analysis, among other parameters. These intervals, which generally represent only a few years of deposition, reflect the characteristics of suspended matter in the river at the time that they were deposited. Typical deposition rates of 0.5 to 2 cm/yr permit the analysis of one to four years of sediment accumulation per slice. This technique produces a *highly resolved* sediment deposition chronology, hence the name.

2.2 Core Suitability for Dating

Beginning with the data quality objectives (DQOs) developed for the Lower Passaic Restoration Project Quality Assurance Project Plan (QAPP) (Malcolm Pirnie, Inc., 2005b) several criteria were developed to select suitable cores for dating purposes. These criteria are listed below. If a core met these criteria, then the approximate year of

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deposition was estimated for the appropriate depths based on the various time horizons recorded in the core. The core selection criteria for dating are presented below:

Criterion No. 1: Enough Cs-137 (*e.g.*, 0.2 pCi/g at the surface and a maximum of at least 1 pCi/g at depth) must be present in core sediments for a core chronology to be established.

Criterion No. 2: A clear Cs-137 peak (*i.e.*, highest Cs-137 concentration) must be present relating to the 1963 or 1971 event.

Criterion No. 3: Be-7 must be present in the surface layer.

As noted previously, the objective of the sediment dating program was to examine water-borne contaminant transport as recorded in the sediments of the river. The sediments of the river record this transport when they are derived from the suspended matter carried by the river. The sediments suitable for dating must be fine-grained since the radionuclides (used in this FFS), as well as several contaminants have a greater affinity for these materials than for coarse-grained sediments such as sand and gravel. Fine-grained sediments are also carried and deposited on a more continuous basis, thus increasing the potential for a continuous, steady record of the river's suspended-matter conditions.

In light of the above, enough Cs-137 must be present in core sediments for a core chronology to be established (Criterion No. 1). In general, the higher the Cs-137 levels in a given core, the greater the fine-grained sediment content and the higher the sediment deposition rate relative to cores with lower levels of Cs-137. In addition to the presence of Cs-137, a clear Cs-137 peak defining 1963 is imperative for using Cs-137 as an event-marker (Criterion No. 2). If there is no clear maximum, the core is considered not dateable, since this implies either lack of steady deposition, extensive biological mixing or a man-made disturbance such as dredging.

The presence of Be-7 in the surface layer (Criterion No. 3) confirms the presence of sediment that has been deposited within a year from the time of collection. In a core lacking Be-7, the age of the surficial sediments cannot be determined with accuracy. The

location may have been disturbed by scour processes or it may simply represent a currently non-depositional environment.

The ability to assign ages to various sediment layers in a core based on radionuclides is affected by factors like sediment deposition rate variation, sediment scour, biological activity, and anthropogenic activities. These factors alter the amount of sediment present in a core for a given interval or mix sediments across intervals and so affect the certainty of the assigned dates of deposition. The uncertainty of the assigned dates is also not constant over the length of the core, but rather is a function of the distance from "known" time points (*e.g.*, the top layer is 2005 or the Cs-137 maximum at 1963).

2.3 Application of Be-7 in the Lower Passaic River

For the purposes of the FFS, an activity of Be-7 greater than 0.5 pCi/g was used as the minimum value in classifying sediments as “recently depositional.” Detection limits for Be-7 were on the order of 0.3 pCi/g. In several instances Be-7 activity was much higher, indicating that the samples were very recently-deposited and/or contained a higher fraction Be-7 bearing, recently-deposited particles (Figure 2-1). The highest Be-7 levels were obtained from tributary suspended sediment trap samples. The Third River suspended matter had Be-7 activity as high as 30 pCi/g (Figure 2-1). These high values identify the tributaries and the Upper Passaic River as a major means of delivery of Be-7 to the Lower Passaic River. Analysis of Be-7 in both surface sediments and suspended sediment traps confirmed that Be-7 bearing surficial sediments obtained by various coring techniques were similar to suspended matter captured in suspended sediment traps. Thus Be-7 in surface sediments indicates the presence of recently-deposited material, as noted previously. This close link between Be-7 bearing surface sediments and suspended matter was further demonstrated near the head of tide. Recently-deposited Be-7 bearing sediment samples collected from above Dundee Dam were found to contain similar Be-7 activity and contaminant concentrations as those found in sediments from sediment traps deployed just below the Dundee Dam (at RM17.1).

Besides its use in sediment core dating and its identification of the link between suspended matter and recently-deposited sediments, Be-7 was also used to identify possible candidate sites for high resolution core collection. Specifically, since a criterion for a datable core is the presence of Be-7 at the surface, then a coring site must have detectable Be-7. A survey of site locations to identify recently-deposited surface samples with Be-7 activity was conducted by USEPA prior to core collection (Malcolm Pirnie, Inc., 2005a).

In further support of the results from the high resolution cores collected in 2005, Be-7 bearing sediments and sediment traps were used to characterize the current properties of suspended matter carried by the tributaries, the Upper Passaic River, and main stem of the Lower Passaic River. Targeted fine-grained surface sediment sampling by Malcolm Pirnie, Inc. in 2007-2008 yielded surface sediment Be-7 concentrations of up to 10 pCi/g. Figure 2-1 presents the Be-7 levels for surface sediment of the Lower Passaic as well as Newark Bay, the Upper Passaic River and the tributaries. Notably the Be-7 levels of the main stem of the Lower Passaic River are comparable to those observed in the tributaries and higher than observations in Newark Bay and the Upper Passaic River. The results indicate the occurrence of many recently depositional sites, whose properties can be used to characterize mean water column suspended matter properties over the 2005 to 2007 period. Further discussion on the application of Be-7 to identify recently-deposited sediment contamination can be found in Data Evaluation Report No. 4.

2.4 FFS High Resolution Coring Program

2.4.1 2005 High Resolution Sediment Coring Program for the Lower Passaic River

High resolution sediment cores were collected by Malcolm Pirnie, Inc. for USEPA from 14 candidate locations in the Lower Passaic River and Upper Passaic River in September and October 2005 to assess historical contaminant loading to the river and current surface sediment concentrations. These candidate locations were identified by the Be-7 surface sediment collection survey described above. The details of the coring locations selection and samples selection are described in Data Evaluation Report No. 1.

Radiological data indicated that five cores (located at RM1.4, RM2.2, RM7.8, RM11.0, and RM12.6) had acceptable Cs-137 profiles. These cores also provided a spatially well-distributed set of coring sites. Samples from the selected cores were analyzed for a suite of inorganic and organic parameters. Samples from every interval of the cores were analyzed for Target Analyte List (TAL) metals, including mercury, through USEPA's Contract Laboratory Program (CLP) by Sentinel, Inc. (Huntsville, Alabama). For organic compounds (analyses conducted by Axys Analytical Services Ltd. in British Columbia, Canada), sediment samples were defrosted[3] and manually combined (every two intervals, consecutively, to yield approximately 20 samples per core) prior to submittal to the laboratory. The organic compound classes included dioxin congeners, PCB congeners, PAHs, and pesticides.

For the cores at RM1.4, RM2.2, and RM11, organic analyses for dioxins, PCBs and pesticides were conducted in the same manner, also yielding about 20 samples per core. For the locations at RM7.8 and RM12.6, only a subset of the organic samples for dioxins, PCBs, and pesticides were analyzed due to the budget limitations, with samples primarily analyzed near the top of the core and at the 1963 Cs-137 maximum. A few additional samples were analyzed along the length of the core at RM12.6. The latter two cores at RM7.8 and RM12.6 were analyzed in this fashion to support the information obtained from the well-resolved core record recovered at RM11.

With approximately 20 samples per core, this segmentation process resulted in the first four segments in each core representing approximately two-year time intervals (with the top interval representing the 2005-2003 time horizon), and the remainder of the segments (approximately 16 segments) each representing approximately a four-year time interval (or approximately 64 years total). The total time period represented in each core was approximately 1940 to 2005, or about 65 years. Given the use of Cs-137 as the primary dating basis, the temporal assignments of the various core layers is considered most accurate from about 1954 to 2005. For more information on the high resolution sediment

[3] See Data Evaluation Report No. 1 for more details on sample archiving prior to analysis of organic compounds.

sampling program, refer to the *Field Sampling Plan, Volume 1* (Malcolm Pirnie, Inc., 2006).

Before analyzing the results of the high resolution coring program, the qualifiers assigned to the results by the laboratory and data validator were reviewed. Due to the additional analytical cleanup methods employed in the Lower Passaic River sampling programs, method detection limits were relatively low, which resulted in few samples being reported as not detected (qualifiers containing a "U"). No rejected data were reported in this dataset.

The 2005 high resolution sediment core dataset can be summarized as follows:

- The analysis of bathymetric surveys, side-scan sonar surveys, and historical coring work helped to identify potential sites for high resolution core collection. A subsequent field reconnaissance survey using Be-7 further reduced the candidate sites to 14 locations. Cores were obtained at all 14 locations. Of these, 5 sites were selected for chemical analysis based on the quality of the radionuclide profile and the location in the river, providing information on contaminant levels over the last 50 to 60 years at locations from RM1.4 to RM12.6, encompassing nearly two-thirds of the Lower Passaic River.
- Radionuclide levels were readily quantified and provide a sound basis for establishing contaminant chronologies at each of the 5 coring locations.
- Chemical analyses were obtained from each of the dated sediment cores to provide well resolved contaminant histories at each location. The interpretation of these analyses is the subject of Section 3 of this data evaluation report.

2.4.2 2005 and 2007 Upper Passaic Coring Program

A description of the 2005 and 2007 Upper Passaic Coring Programs and a summary of the resulting datasets are described in the subsequent subsections.

2.4.2.1 2007 Dundee Lake Coring Program

Additional sediment cores were collected by USEPA from nine locations in the Upper Passaic River, between the Dundee Dam and the Interstate Route 80 Bridge, for dating and analysis. These cores were intended to assess historical and current contaminant loading to the Lower Passaic River from the Upper Passaic River. Locations were identified based on bathymetric data, historical satellite photographs showing shoreline development, literature references, and field reconnaissance conducted on December 14, 2006. These data resources were used to select coring locations with potentially undisturbed silt deposits in net depositional areas.

Dated sediment samples from above the head of tide, along with estimates of the suspended solid load, were used to determine the load of particle-borne contaminants contributed from the Upper Passaic River to the Lower Passaic River at the time corresponding to the dated core interval. To confirm that this approach was appropriate, filtered suspended matter samples and sediment trap samples obtained just below Dundee Dam (RM17.1, representing Upper Passaic River water that had not been mixed with Lower Passaic River water) were compared and were found to contain similar contaminant concentrations to the Be-7 bearing sediment core locations occupied above Dundee Dam (north of RM17.4). Refer to Data Evaluation Report No. 2 for further discussion of the Upper Passaic River loads.

At each location, a geological boring and co-located high resolution sediment core were collected. The geological boring was split horizontally to examine geologic sequences and determine if the core was collected from a silt deposit location. Four locations were classified as potentially depositional, and the corresponding co-located high resolution sediment cores were divided vertically into 2 cm and 4 cm intervals, yielding approximately 20 samples per core. Samples were shipped to a laboratory immediately for analysis for the following parameters: dioxin congeners, PCB congeners, PAH compounds, pesticides, metals including mercury and titanium, total organic carbon (TOC), particle size distribution, Cs-137, and Be-7 (core top sample only).

Based on an analysis of the resulting radiological data, two cores were eliminated from further consideration because the core top segment was not Be-7 bearing, indicating that the location did not contain recently-deposited sediments. As such, it was unlikely that the cores contained a continuous depositional history that could be accurately dated using radiological data from each interval of the core. As a result, the corresponding chemical analyses for these cores were halted. Chemical analyses were completed on the two remaining cores that possessed a Be-7 bearing core top. However, further evaluation of the Cs-137 data indicated that the radiological profile was discontinuous, suggesting that the sediments had been disturbed and that the core was not representative of a continuous depositional location. As a result, the 2007 Dundee Lake sediment core dataset addressed only a subset of its original goals and can be summarized as follows:

- Be-7 bearing surface sediments from two locations represent recent suspended matter concentrations on solids entering the Lower Passaic River from the Upper Passaic River in 2006.
- The dataset provides evidence of the scale of historical contaminant concentrations on suspended matter, based on the presence of Cs-137 in the deeper layers of one core. The Cs-137 levels were too low to establish a core chronology.

2.4.2.2 2005 Dundee Lake Coring Program

In addition to the cores obtained by USEPA in 2007, several cores were obtained by scientists from Rensselaer Polytechnic Institute (RPI) and Lamont-Doherty Earth Observatory (L-DEO) in September 2005. These cores were initially segmented and dried to permit long term storage while awaiting subsequent analysis. Two of the cores were shown to contain Be-7 and were subsequently successfully radiologically dated using Cs-137. Given that the 2007 Upper Passaic River program only partially achieved its goals, segments from the 2005 cores obtained by RPI and L-DEO were then analyzed for the USEPA Lower Passaic River investigation in 2007 and 2008, following the same protocols used for the USEPA high resolution sediment cores. In addition, a separate analysis was conducted to demonstrate the viability of the sample collection and processing procedures used by the RPI and L-DEO scientists. This was done on a series of separate sediment sample splits that were handled by both USEPA processing

procedures as well as the drying procedures used by RPI and L-DEO. The samples were chemically analyzed following the standard Lower Passaic River procedures, thereby creating sample pairs differing only by the processing procedure. Note that all processing procedures described in this paragraph were performed in accordance with the USEPA-approved QAPP (Malcolm Pirnie, Inc., 2005b).

The 2005 Dundee Lake dated sediment cores provide the following information, satisfying the major goals for the Upper Passaic River coring.

- Be-7 bearing surface sediments were obtained from two locations to represent contaminant concentrations on suspended matter delivered to the Lower Passaic River at the Dundee Dam in 2005.
- The dataset provides a radionuclide-dated sediment core profile documenting historical contaminant concentrations on suspended matter entering the Lower Passaic River. In particular, the profile provides a basis to estimate the historical loads of all major contaminants to the Lower Passaic River going back to the 1960s.

3 EXAMINING THE SEDIMENT RECORD OF HISTORICAL CONTAMINATION

As described above, radionuclide chronologies for the sediment cores of the Lower Passaic River were established based on Cs-137 and Be-7. The following discussion describes the interpolation process to assign an approximate year of deposition to each depth in the core as well as the interpretation of the sediment record for several major contaminants of the Lower Passaic River.

3.1 Radiological Profiles for the 2005 High Resolution Cores from the Lower Passaic River

The sedimentation rate and a core chronology were established for five sediment cores from the Lower Passaic River collected in 2005, located at RM1.4, RM2.2, RM7.8, RM11, and RM12.6. As described previously, Cs-137 profiles were used to determine the depositional nature of the sediment cores and to place chronological tie-points between cores, the historical timeline and contamination events. Figure 3-1 illustrates the Cs-137 profile for the core located at RM11. This core represents the best Cs-137 profile among the five cores and has the highest Cs-137 peak (approximately 6 pCi/g), indicating it contains a large fraction of fine grained sediment and represents a consistently depositional area. The peak Cs-137 concentration is found at the depth of approximately 100 cm in the core. This point in the core was assigned a date of 1963, following the dating procedures described above. Be-7 was not measured in the surface layer of the core. However, since the core was collected from a Be-7 bearing location based on the 2005 reconnaissance survey conducted just 2 weeks prior, the upper-most core section was considered to be recently-deposited and the core surface was assigned a date of 2005 (the year of the core collection).

The sediment thickness between the core surface and the depth of the Cs-137 maximum was divided by the time between the two intervals (42 years) to determine a sedimentation rate (cm/yr), assuming a constant rate of sediment accumulation during

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this period. For the core located at RM11, the sedimentation rate between 1963 and 2005 is approximately 2.3 cm/yr. Sediment sample intervals between these horizons were assigned an approximate year of deposition based upon this rate. A second deposition rate was determined for the deeper segments in the core, using the 1954 and 1963 horizons (the difference in the sedimentation rates between the upper and lower portions of the core will be discussed later in this section). Specifically the distance between the mid-point of the interval containing the Cs-137 maximum (1963) and the bottom of the first segment with detectable levels of Cs-137 (1954) represented the total amount of deposition that occurred over this time period, approximately 70 cm. The elapsed time between the intervals is 9 years. These values yield a deposition rate of about 8 cm/yr or about 4 times greater than the post-1963 period in this core. Applying these deposition rates to the appropriate core segments provides an approximate year of deposition for all depths in the core. Plotting the Cs-137 profile as a function of approximate year of deposition rather than depth yields the profile shown on the right side of Figure 3-1.

The purpose of this figure is to show how the use of the multiple Cs-137 event horizons adjusts the core chronology to account for variable deposition rates. These adjustments provide a more accurate interpolation of the conditions captured by the core with respect to time. When done across multiple cores, these adjustments help to ensure that cross-core comparisons are made for relatively well defined periods of time, *i.e.*, that a cross-core comparison of 1970s-age sediments is in reality a comparison of sediments of this period. Given the variation of sedimentation rates both within and among cores, these horizons provide an accurate basis for consistent comparisons across the core chronologies.

The other four cores were dated in a similar fashion to the RM11 core. The 1963 time horizon can be identified in all five cores (dashed black line in Figure 3-2). In each core, the Cs-137 maximum is found relatively deep within the core, with a gradual decrease in the Cs-137 concentration in the overlying layers moving to the top of the core. Note the absolute difference in the depth of this horizon across the cores; the range is from about 90 to 420 cm. Yet because of the consistent presence of the Cs-137 maximum in each

core, the profiles can be accurately normalized to a consistent timeframe, as will be evident in later discussions.

The 1954 time horizon can be identified in only three out of the five cores (dotted gray line in Figure 3-2). Cores at RM7.8 and RM12.6 did not capture pre-1954 material. In the case of the core at RM12.6, the sediment record suggests that little or no pre-1963 material was present at the location given that the peak Cs-137 concentration of approximately 3 pCi/g lies directly above coarse-grained, non-Cs-137 bearing material. It is presumed that this underlying sediment is quite old given the absence of Cs-137.

Also notable among the cores containing the 1954 horizon is the change in the sediment deposition rate from the period 1954 to 1963 versus the period 1963 to present day (the core top). In each instance, the 1954 to 1963 deposition rate is 3 to 4 times greater than the post-1963 period. While the reason for this change is not known, it is likely the reduction in sedimentation rate reflects the rapid changes in the Lower Passaic River channel geometry following the effective cessation of maintenance dredging around 1950. Specifically, during the first decade or so after dredging ceased, sediments deposited rapidly throughout the river due to the slow water velocities that would have existed with the deep navigation channel. As the channel filled in during later years, the shallower channel would have caused water velocities to increase and deposition rates would have slowed in response. The well-known input history of Cs-137 to the river system provides a high degree of accuracy in dating sediment layers during this period and lends a high degree of confidence to the adjustment in deposition rates.

All five locations were shown to have Be-7-bearing material present at the coring site based on the field reconnaissance survey conducted just a few weeks prior to core collection. Based on this survey, all five cores were thought to contain recently-deposited sediments (*i.e.*, circa 2004-2005) at the core top. However, for the core at RM12.6, the age assignment of the top segment of the core was adjusted to align more closely with the upper portion of the 2,3,7,8-Tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) concentration profiles of the cores at RM11 and RM7.8. The two latter cores both exhibit a multi-fold

increase in the 2,3,7,8-TCDD concentration on the second segment from the top of the core, corresponding to an apparent circa 2000 2,3,7,8-TCDD release event. A similar increase in the 2,3,7,8-TCDD concentration occurs in the uppermost layer of the core at RM12.6.

Since the uppermost layer of the RM12.6 core and the second interval from the RM7.8 and RM11 cores all displayed the 2,3,7,8-TCDD concentration change as well as a corresponding change in the mixture of dioxin congeners[4], it was inferred that the very top layer of the core at RM12.6 was either very thin or missing, so that the uppermost layer found in the RM12.6 core can be assumed to correspond in age to the second interval of the RM7.8 and RM11 cores. The surface of the RM12.6 core was assigned an age of 2002, thereby placing the large 2,3,7,8,-TCDD event at circa 2000 in all three cores. Figure 3-3 shows a detailed plot of 2,3,7,8-TCDD concentrations for the last 25 years of deposition at each coring site based on the Cs-137 dating described above. The plot trace for RM12.6 has been adjusted as described above. The three- to four-fold increase in 2,3,7,8-TCDD concentrations relative to the 1995 interval is evident in all three cores above RM7. This change in concentration and the change in the relative distribution of the dioxin congeners are the basis for the adjustment in the year assignment for the core at RM12.6. Also of note in the plot is the essentially complete recovery to 1995 concentrations for Be-7 bearing sediments collected at these coring sites in 2007 (described further below). This is considered direct evidence for the cessation of the release. It can be observed that no other contaminants show an increase in concentration at the circa 2000 horizon (as can be seen in Figures 3-7 through 3-13).

A detailed discussion of the spike of 2,3,7,8-TCDD concentration at RM7.8, RM11, and RM12.6 in circa 2000 is outside the scope of this report. Its inclusion here is solely for the purpose of improving the dating agreement across cores.

[4] Described in Section 3.2.1.2 and shown in the right-hand panel in Figure 3-6.

3.2 Downcore Profiles and Contaminant History

As described in the preceding section, the five cores obtained by the USEPA each have an interpretable radionuclide chronology that permits the assignment of the approximate year of deposition to each segment in the core. The cores also have sufficient vertical resolution to provide a detailed chronology of contaminant concentrations on settling solids, which in turn can be used to infer historical loads borne by the river. This section discusses the contaminant chronologies of the 2005 high resolution cores along with some more recently collected samples and some of the results of the 1995 Tierra Solutions, Inc. (TSI) coring survey.

The period of interest captured by the five cores, between 2005 and approximately 1940, has been augmented by a subsequent 2007 sampling event. In 2007, a survey of recently-deposited sediments over the entire Lower Passaic River was conducted by obtaining Be-7 bearing sediments (0 to 2 cm) at locations throughout the 17-mile stretch of the Lower Passaic River as well as from above Dundee Dam. As part of this survey, Be-7-bearing samples were collected at or close to the five high resolution coring sites, effectively providing an additional sediment layer above the 2005 horizon in each core.

In addition to the interpretation of the five cores described above, USEPA also evaluated a subset of the cores obtained by TSI in 1995. The survey conducted by TSI was limited to RM1 to RM7. USEPA identified 14 cores (see Table 3-1) with Cs-137 profiles that partially satisfied the criteria described in Section 2.2. While the TSI cores yielded Cs-137 profiles that were considered indicative of steady sediment accumulation, the core segmentation for chemical analysis was much coarser and so can only provide limited resolution of contaminant histories at the coring locations. Nonetheless, the cores provide supporting evidence that can be interpreted in the context of the more detailed 2005 cores. This discussion will use the five longest cores of the 14 TSI core locations, extending from RM2.7 to RM6.3 in a comparison with the 2005 observations. These cores provide information on the entire post-1954 period as documented by their Cs-137

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profiles, as well as some time prior to 1954. The locations of the five TSI cores used in the comparison are shown on Figure 1-2.

As noted previously, this data evaluation report is focused on the history of contamination as recorded in the sediments, and so only examines a limited number of cores where conditions preserved the history in a "readable" form. However, extensive sediment core data from the 1991, 1993, and 1995 sampling programs are available to characterize the general level of sediment contamination throughout much of the region between RM1 and RM7. As part of the preparation of this report, the chemical profiles of each historical core were plotted to evaluate the depositional environment at the core locations. Cadmium, copper, lead, mercury, total petroleum hydrocarbons (TPH), low molecular weight (LMW) PAHs, high molecular weight (HMW) PAHs, dieldrin, Total PCBs, 2,3,7,8-TCDD, Total DDx [the sum of 4,4'- dichlorodiphenyltrichloroethane (4,4'-DDT) and its metabolites 4,4'-dichlorodiphenyldichloroethane (4,4'-DDD), and 4,4'-dichlorodiphenyldichloroethylene (4,4'-DDE)], and Cs-137 were plotted for 120 historical cores. These plots can be found in Attachment A.

In the following discussion, example compounds from four major contaminant groups are examined, including dioxins (2,3,7,8-TCDD), PCBs, pesticides, and heavy metals. In each discussion, the 2005 results are provided first, followed by the additional results for the 2007 program. For one compound in each contaminant group, an additional comparison is made between the 2005 core results and the five TSI locations mentioned above.

3.2.1 Tetrachlorodibenzo-p-dioxin (TCDD) Profiles

The results for 2,3,7,8-TCDD for the five dated sediment cores collected in 2005 are presented as downcore profiles versus approximate year of deposition in Figure 3-4. The year assignments for these and all subsequent representations of these cores were derived as described in Section 3.1. The downcore profile for the core at RM11, which provides the most well-resolved core chronology, is shown on the left-most panel of Figure 3-4. The middle panel of the figure shows the results from all the five 2005 high resolution

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cores superimposed on the same chart. While there are some differences among the profiles, the most important observation is that they all show similar trends and magnitude of contaminant concentration despite the distances that separate the cores. This observation, that contaminant concentrations and trends through time, particularly post-1975, are consistent from RM1.4 to RM12.6, forms the foundation for the geochemical understanding of the Lower Passaic River and is further discussed below.

In all five cores, the highest 2,3,7,8-TCDD concentration occurs between the mid-1950s and the mid-1960s. The maximum value is between 6 and 20 micrograms per kilograms of sediment (µg/kg) across all five cores, despite their distances from each other and the known sources[5] of 2,3,7,8-TCDD contamination to the river. The occurrence of the maximum concentrations during this period is consistent with Bopp *et al.* (1991) who showed that the highest TCDD concentration occurs in sediment dating to the 1950s and 1960s, based on the geochronology of a sediment core from Newark Bay. This peak concentration was attributed by Bopp *et al.* (1991) to coincide with the peak production and discharge of TCDD into the Passaic River in the 1950s and 1960s. The two downstream-most cores (RM1.4 and RM2.2) show 2,3,7,8-TCDD maxima that occur earlier and are less broad than those indicated by the three more upstream locations. Some of these differences may reflect differences in short term deposition rates.

While all five cores document the period of greatest 2,3,7,8-TCDD discharge, the recent conditions are more pertinent to the FFS since current trends form the basis for estimating future conditions. Notably for all five cores, the concentration of 2,3,7,8-TCDD is slowly declining from 1980s to the present. The rate of decline, as suggested by the roughly parallel trends on these log-scale plots, is approximately the same at all five locations, indicating that the recovery rate throughout the river is closely linked. During this period, the 2,3,7,8-TCDD concentrations tracked quite closely (approximately a factor of two variation[6] among the 5 cores) for the last 20 years. The rate of decline during this period

[5] Although the 80 Lister Avenue site represents a well-documented discharge of 2,3,7,8-TCDD to the river, historically another herbicide manufacturer, Montrose Chemical, was located immediately adjacent to the Diamond Alkali Company.

[6] The concept of a factor of two variation is used extensively throughout this discussion as measure of the agreement across cores. The term "a factor of two" refers to the ratio of the maximum value over the minimum value in a set of values. If only two values were involved (as in a split sample duplicate pair), this would be equivalent to a relative percent difference of 66 percent. However, when

(exclusive of the circa 2000 event) is quite slow. As can be seen in the right hand panel of Figure 3-4 (or in Figure 3-3), concentrations in 2007 [150 to 500 nanograms per kilograms of sediment, (ng/kg)] are roughly half of what was observed in 1980 (400 to 800 ng/kg), suggesting a "half time" for the decline of 2,3,7,8-TCDD concentrations on the order of 30 years.[7]

A closer look at the core profiles shows that the concentrations for the cores at RM1.4 and RM12.6 are consistently lower than that of the other cores, especially post-1990 (right-most panel of Figure 3-4). These two cores represent the downstream-most (near Newark Bay) and upstream-most locations. As such, they are the first locations to be affected by solids entering the Lower Passaic River from Newark Bay and from the Upper Passaic River, respectively. The three sediment cores located between these two locations show still greater similarity among concentrations and trends than the entire group of five cores.

This observation was further supported by the Be-7 bearing surface sediment concentrations obtained in 2007, some of which are plotted in the right hand panel of Figure 3-4. The locations at RM1.4 and RM12.6 are in areas where steep concentration gradients occur as solids from the main part of the Lower Passaic River are mixed with Newark Bay solids (RM1.4) and Upper Passaic River solids (RM12.6) (see Data Evaluation Report No. 4). Between these locations, the 2,3,7,8-TCDD concentrations for the other three cores, which are located at RM2.2, RM7.8, and RM11, have been in very close agreement since 1980, excluding the event circa 2000 previously discussed. Similarly close agreement is

this degree of variability is observed across multiple cores, a much higher level of agreement can be inferred. Specifically when used in the context of this analysis, all values (typically five) fall within this factor of two range, meaning that most value pairs differ by much less and agree more closely than the two extreme values. Typical coefficients of variance (defined as the standard deviation over the mean) are the order of 25 percent or less. For example, the Total PAH values for the year 2000 differ by slightly less than a factor of two (maximum/minimum = 1.7, see Figure 3-9a, right panel) with a coefficient of variance of 21 percent. Given that the comparison is among samples from cores located miles apart and from variable depths assigned only by radionuclide dating, this is constitutes a very high degree of agreement and bears out the robustness of the radionuclide-based core dating technique. Note that the typical acceptable level of agreement among split sample duplicates (*i.e.,* two allotments from the same mixing bowl) as suggested by USEPA guidance is an RPD of 40 percent, equivalent to a factor of 1.5.

[7] The use of the term "half time" in this sense is not to imply decay or destruction of 2,3,7,8-TCDD over time, akin to the decay of a radionuclide. Rather, the term here is used to simply express a rate for the decline of 2,3,7,8-TCDD concentrations in the solids accumulating at each coring location. Specifically, "half time" is the time necessary for the 2,3,7,8-TCDD concentration to decline to half of its current value. The processes that affect the decline are multifold, including many of the fluxes and processes that occur in an urban estuary. The "half time" expression is just a means to encompass these processes and note their net effect on concentration through time.

observed for all of the other contaminants examined in this FFS, as discussed below. This indicates that tidal energies have been and continue to be sufficient to minimize concentration gradients and maintain a narrow range in concentration for settling suspended solids at these three locations over the 27-year period ending in 2007. The analysis of Be-7-bearing sediments presented in Data Evaluation Report No. 4 indicates that this area extends from RM2 to RM12.

3.2.1.1 Other Lines of Evidence Regarding 2,3,7,8-TCDD

The observations based on the five 2005 cores are supported by other lines of evidence: 1) 2007 Be-7-bearing surface sediment data (see Data Evaluation Report No. 4); and 2) the historical data collected by TSI from RM1 to RM7 in 1995, discussed below.

As part of the 1995 investigation conducted by TSI under USEPA oversight, TSI obtained cores from about 95 sites. Of these, 14 cores had detectable levels of Be-7, direct evidence for the presence of recently-deposited sediments at these locations. The cores from these sites were reviewed for their Cs-137 profiles as potentially dateable cores. Of these, five were selected based on the quality of their Cs-137 profile (satisfying the criteria in Section 2.2) and having a declining 2,3,7,8-TCDD profile near the core bottom, indicating that the core had captured pre-1940 conditions. These five cores are located at RM2.7, RM3.1, RM4.0, RM4.5, and RM6.3.

Figure 3-5 compares the results from the 2005 coring effort with the profiles from these five cores. While the 2005 cores were sufficiently well resolved to permit useful approximate year of deposition assignments to individual core segments, the 1995 TSI cores had thicker core segments and so approximate year of deposition assignments were not made. This reflects the coarser resolution of the chemical analyses relative to the radionuclide analyses within these cores, as described above. Nonetheless, the 1995 TSI cores are consistent with the observations made from the 2005 cores.

In all five cases, the 2,3,7,8-TCDD maximum occurs with or before the Cs-137 maximum. This is similar to the 2005 cores, in particular to the closest of the 2005 cores at RM1.4 and RM2.2, which both showed pre-1963 2,3,7,8-TCDD maxima. (Note that the 2005 core at RM7.8 was not fully analyzed for this period.) Additionally, four of the five 1995 core maximum values were in the range of 5 to 20 µg/kg, similar to that of the 2005 cores (6 to 20 µg/kg). Only the core at RM2.7 fell outside this range. Its maximum value of nearly 100 µg/kg is not surprising given its proximity to the known discharge from the 80 Lister Avenue facility,

Like the 2005 USEPA cores, the 1995 TSI cores also show a decline from the maximum to the surface. While the 1995 TSI cores do not provide sufficient resolution to permit an accurate assessment of the post-1980 period for comparison against the 2005 cores (the 1995 cores typically only have four samples from the circa 1960 maximum to the surface), three of the 5 show a slowing rate of recovery, similar to the 2005 cores.

Lastly, all five TSI cores show a surface concentration of 0.15 to 0.3 µg/kg 2,3,7,8-TCDD, well within the range of the 2007 Be-7-bearing surface sediments collected at or near the 2005 coring sites. This is also within the range of circa 1995 values obtained from the 2005 core profiles (0.1 to 0.3 µg/kg). The observation that Be-7-bearing surface sediments in 1995 are essentially the same as those obtained in 2007 indicates a very slow rate of recovery for 2,3,7,8-TCDD concentrations. This is entirely consistent with the estimated rate of decline derived from the dated 2005 cores alone.

3.2.1.2 Ratio of 2,3,7,8-TCDD to Total Tetrachlorodibenzo-p-dioxin (Total TCDD)

The dated sediment cores also provide information on 2,3,7,8-TCDD in addition to the trend of concentration with time. A study by Chaky (2003) showed the usefulness of examining the ratio of 2,3,7,8-TCDD to Total TCDD in tracing the impact of Passaic River dioxins throughout metropolitan New York City harbor. Following this lead, downcore profiles of the ratio of 2,3,7,8-TCDD/Total TCDD were generated for each of the USEPA 2005 cores. The results are shown in Figure 3-6. Note that the layout is the

same as that of Figure 3-4. This layout will be used for the presentation of the 2005 core results throughout this data evaluation report.

The left hand panel shows that the ratio of 2,3,7,8-TCDD/Total TCDD has been around 0.7 for three of the five post-1990 core intervals, with the exceptions associated with the core segments closest to the year 2000. As noted previously, the discussion of the circa 2000 event is outside the scope of this FFS. The value of 0.7 indicates that for the dated sediment core at RM11.6, 2,3,7,8-TCDD represents 70 percent of the Total TCDD concentration in most of the post-1990 deposition. The second panel in the figure shows the ratio for the other dated cores in addition to the core at RM11.6. The profiles show that throughout the Lower Passaic River, the ratio has remained within the range of 0.58 to 0.82 since 1980. The profiles also show that a high ratio of 2,3,7,8-TCDD/Total TCDD (greater than 0.58) has persisted throughout the Lower Passaic River since the 1950s, as recorded by these cores. These high values should be contrasted against the Chaky (2003) observations for urban runoff, sewage discharges, and atmospheric deposition, all of which yield ratios of 0.04 to 0.06 (more than an order of magnitude lower)[8]. The observations of low 2,3,7,8-TCDD/Total TCDD ratios by Chaky (2003) in potential external loads to the Lower Passaic River were borne out by the USEPA 2007-2008 field program which sampled tributaries, combined sewer overflows (CSOs) and stormwater outfalls (SWOs) throughout the Lower Passaic River area and obtained ratios typically less than 0.1 (discussed in Data Evaluation Report No. 2).

The consistency and uniqueness of this ratio through time as documented by the 2005 cores shows that Lower Passaic River 2,3,7,8,-TCDD contamination has been dominated by industrial sources for the last 50 years. It is evident in the pre-1950 deposition in these cores (see the middle panel of Figure 3-6) that the 2,3,7,8-TCDD/Total TCDD ratio prior to 1950 was at or close to the range of 0.04 to 0.06, commensurate with 2,3,7,8-TCDD concentrations on the order of 0.01 µg/kg (see Figure 3-4). These values are characteristic of conditions prior to the onset of major discharges of 2,3,7,8-TCDD, and can be

[8] Note that a 2,3,7,8-TCDD/Total TCDD ratio of 0.04 indicates that 2,3,7,8-TCDD comprises just 4 percent of the Total TCDD concentration in a sample.

attributed to sources like atmospheric deposition and urban runoff, based on Chaky (2003). The observation that the ratio has been so consistent since about 1980 is indicative of the extensive tidal mixing of suspended solids prior to deposition. The close agreement among the cores with respect to concentration during this period, as discussed above, supports this indication as well.

3.2.2 Integration of Observations Concerning 2,3,7,8-TCDD

The observations of 2,3,7,8-TCDD concentrations and the 2,3,7,8-TCDD/Total TCDD ratio in the 2005 dated sediment cores are supported by the 2007-2008 USEPA surveys and the 1995 TSI coring results. The 2005 coring results provide both the spatial and temporal variation of 2,3,7,8-TCDD concentrations, which in turn lead to several very significant observations concerning the Lower Passaic River. As mentioned previously, the observation that surface contaminant concentrations and trends through time are consistent from RM1.4 to RM12.6 forms the foundation for the geochemical understanding of the Lower Passaic River. Specifically, these observations can only be explained by a very hydrodynamically active river, where suspended solids are mixed over long distances prior to permanent deposition. This can be accomplished by either extensive mixing within the water column prior to deposition or by extensive settling and redeposition combined with water column mixing, repeatedly reworking settled solids. In either case, concentration gradients are largely eradicated over relatively short periods of time. The close agreement of Be-7 bearing sediments over long distances suggests this process may work as rapidly as a few Be-7 half-lives (6 months to a year).

An upper bound on the mixing timeframe is suggested by the older, less resolved core segments. In this instance, the core records from the late 1960s show substantive differences in 2,3,7,8-TCDD concentrations between the upstream and downstream cores. However, by 1975, or less than 10 years later, concentrations at all coring locations are in close agreement, indicating an eradication of the concentration gradient from RM1.4 to RM12.6 within that time (see Figure 3-4, middle panel). Thus the observation that recently-deposited surface sediments exhibit similar levels of contamination between

RM2 and RM12 is attributed to mixing within the RM2 to RM12 interval, with gradients due to local discharges dissipated in roughly 10 years or less.

The history of contamination recorded by the dated sediment cores was also used to estimate the rate of decline of the concentration of 2,3,7,8-TCDD since about 1980, when industrial loads to the Lower Passaic River are thought to have subsided. All five cores yield consistent chronologies that suggest a “half time” on the order of 30 years for 2,3,7,8-TCDD concentrations on recently-deposited sediments, indicative of very slow recovery.

3.2.3 PAH Profiles

Downcore profiles for Total PAHs are presented in Figure 3-9a for the 2005 high resolution cores. Total PAHs were present in nearly all sediment samples at nearly all depths. In all five cores, Total PAH concentrations increase slightly with depth. However, maximum core concentrations are achieved at the core bottom, with no decline for the deepest sediments, unlike 2,3,7,8-TCDD and Total PCBs. Also unlike 2,3,7,8-TCDD and Total PCBs, the Total PAH concentration from 1980s to the present does not decline measurably. Within-year Total PAH concentrations typically vary by a factor of two from 1980 to 2005 (Figure 3-9a) but with no particular trend with time, suggesting that the Total PAH contaminant load to the Lower Passaic River has not changed significantly over this period.

Higher Total PAH concentrations are observed in the 1960s with typical concentrations near 90,000 µg/kg, roughly two times greater than those observed post-1980, with a median concentration near 40,000 µg/kg (Figure 3-9a). HMW PAHs account for approximately 80 percent of the Total PAH concentration. Upon closer inspection of the HMW PAH profiles and the LMW PAH profiles (Figures 3-9b and 3-9c), it is apparent that the relative relationships among cores have remained constant since about 1970, and all five cores show little trend in their absolute concentrations (right hand panel of Figures 3-9b and 3-9c). The lack of trend within the cores and consistent relationship among the cores can be attributed to the extent of tidal mixing and the observation that

PAH concentrations in solids delivered by Upper Passaic River and Newark Bay are similar to those found in the Lower Passaic River. Thus, unlike 2,3,7,8-TCDD, there is no large source of low PAH solids to the Lower Passaic River that might serve to lower PAH concentrations over time. This is confirmed by the results from the Be-7-bearing sediments collected in 2007 from the entire length of the Lower Passaic River, which show little difference between Lower Passaic and Upper Passaic River samples, and only minor differences between Newark Bay and the Lower Passaic River (see Data Evaluation Report No. 4). Without differences among these solids sources, there is no basis to create concentration gradients like those observed for 2,3,7,8-TCDD and to a lesser extent, Total PCBs. The latter two contaminants both have measureable gradients along the Lower Passaic River, higher concentration in the surface sediments of the Lower Passaic River relative to the external sources, and declining concentrations with time in the high resolution cores.

Select individual PAH compounds are presented, one from the LMW PAH group (Phenanthrene) and two from the HMW PAH group (Benzo[a]pyrene and Fluoranthene), in Figures 3-9d to 3-9f. The individual PAH compounds show similar trends to the Total PAH profile. These profiles further reinforce the similarity of PAH concentrations and PAH patterns among the five coring sites since both the trend of the individual concentrations and the relationships among the cores are consistent across PAH compounds.

The five 2005 high resolution cores were plotted adjacent to the five deep 1995 TSI cores for comparison in Figure 3-10. An important aspect of the sediment history is captured by the deeper TSI cores, which extend fairly far below the 1954 horizon and are generally deeper than the 2005 USEPA cores. The observation of the PAH maximum at the bottom of several of the 2005 USEPA cores is consistent with that observed in four of the five TSI cores. The exceptions in the 2005 USEPA cores occur in both of the upstream locations (RM11 and RM12.6). While the reason for the exception at RM11 is not known, the sedimentological evidence at RM12.6 indicates that the lowest layer in this core is physically very different from the overlying sediments and probably very old. The

age of the underlying layer based on its physical properties suggests it may be glacial in age, so low levels of PAHs would be expected in this layer. In all of the other USEPA and TSI cores, which are located below RM8, the bottom core maxima suggest that maximum PAH discharges to the Lower Passaic River took place prior to 1950. This suggestion is supported by the core at RM4.5 which shows a clear PAH maximum about 3 feet below the Cs-137 maximum, followed by a decline to nominal concentrations below 13 ft, more than twice the depth of the Cs-137 maximum in the core. The TSI cores also confirm the other important observation from the 2005 USEPA cores concerning post-1970 deposition. In four of the five TSI cores, there has been little decline in the PAH concentration since the 1963 Cs-137 maximum.

Overall, the profiles of Total PAH concentrations in the cores are consistent with the inferences drawn from the 2,3,7,8-TCDD and PCB profiles regarding sources and tidal mixing within the Lower Passaic River. However, PAH concentration differences among solids sources are so small that little concentration differences among areas or over the last 35 years are observed. However, this has one other implication, specifically that the sources of PAH contamination to the Lower Passaic River are not abating.

3.2.4 Pesticide Profiles

The evaluation of the 2005 high resolution core pesticide data focuses on the following pesticide compounds: DDE, dieldrin, and trans-chlordane, which have been identified as COPECs. Dated sediment core profiles for these compounds are provided in Figures 3-11a through 3-11c.

DDE is examined in detail here as a surrogate for the sum of DDT and its metabolites. Analytical interferences often affect quantitation of these pesticide forms and DDE was the least impacted by analytical issues based on the data quality review and its consistent behavior in the profiles. DDE concentrations are shown in Figure 3-11a. The distribution of the core maxima are similar to those of Total PCBs and 2,3,7,8-TCDD. Notably the maximum values extend over a greater period than those for Total PCBs and 2,3,7,8-TCDD, with high values as late as 1970.DDE concentrations have slowly declined over

the past 25 years. Since 1990, the range of concentrations within a given year have generally varied by about a factor of two, similar to the observations for Total PCBs and 2,3,7,8-TCDD during this period. The slowly declining concentration trend is confirmed by the 2007 surface sediment concentrations, where concentrations are only slightly lower than 2005.

The dated core results for dieldrin (shown in the left and center panels of Figure 3-11b) show peak concentrations in the 1960s with concentrations at RM11 and RM12.6 about 5 times greater than those observed downstream. This difference is large enough and sustained enough to indicate the existence of a significant upriver source of dieldrin during this period. While dieldrin concentrations decline from their 1960s maxima, this trend does not continue after 1985, and concentration begin to increase in the upper portions of all five cores, increasing about five-fold from 1985 to 2005. This increasing trend is continued by the 2007 Be-7 bearing samples, as shown in the third panel of Figure 3-11b. Dieldrin is the only contaminant with a consistent increase in concentration across all five cores in the post-1980 period. As discussed in Data Evaluation Report No. 2, the 2007 sampling results for the Third River (at RM11) and the Saddle River (at RM15.4) both show elevated concentrations of dieldrin in suspended solids and Be-7-bearing sediments. Dieldrin concentrations in Upper Passaic River Be-7 bearing sediments are comparable to those observed in Lower Passaic River Be-7 bearing sediments. The dated sediment core results taken together with the Be-7 bearing sediment results, indicate that the Upper Passaic River, the Saddle River and the Third River are likely substantive external sources of dieldrin to the Lower Passaic River. Of these, it is likely that the Upper Passaic River is the most important source, simply because of the size of the flow from this tributary. This indication is quantitatively evaluated in Appendix C.

The observations that dated sediment core concentrations of dieldrin have trended roughly parallel since 1985 despite the presence of ongoing sources is further indication of the extent and rapidity of mixing within the river. The river has further reduced the variability from 1995, when the variation among cores was an order of magnitude

variation to the most recent samples, which vary about a factor of three. This decline in variability has occurred even as the overall mean concentration has roughly doubled since 1995.

Trans (or gamma) Chlordane concentrations follow a trend that falls between the behaviors of DDE and Total PAHs (see Figure 3-11c). Trans Chlordane has a broad maximum between 1960 and 1975 with approximately a factor of three variations across all five cores, followed by a slow rate of decline such that changes from 1985 to the present are barely detectable. Variation among cores is reduced during the post 1975 period, with a typical range of a factor of two and often less. Like dieldrin, the concentrations in the Upper Passaic cores are comparable to those of the Lower Passaic River (see Data Evaluation Report No. 2).

Figure 3-12 presents a comparison of dieldrin for the 1995 TSI and 2005 high resolution cores. The dieldrin profiles for 1995 have notably poor resolution (fewer data points with depth than other contaminants, particularly in top few feet) and so provide little information for the most recent deposition. Additionally, since the most recent rise takes place since 1985, the TSI cores were collected too close to the change in slope to exhibit the increase given their resolution. Nonetheless, the 1995 cores do provide support for several features seen in the 2005 cores. The surface concentrations for all the cores from these two datasets are comparable, in the range of 5 to 20 µg/kg. The range in peak concentrations in the 1995 cores (50 to 250 µg/kg) is essentially the same as the range observed in the 2005 cores (40 to 240 µg/kg). Finally, the maximum in the TSI cores occur around the Cs-137 maximum, consistent with the 1960s maxima seen in the 2005 cores.

In summary, the variation of these pesticides over time, although clearly not the same as that for the other organic compounds, still identify the 1960s as the period of maximum release. Unlike the other chlorinated organic compounds 2,3,7,8,-TCDD and Total PCBs, the trends for the pesticides do not decline appreciably over time. The pesticide temporal trends are closer to that of the PAHs. One pesticide, dieldrin, clearly shows an increasing

trend with time, indicating an increase in external loads during the post-1985 period. The pesticide results also support the supposition of extensive tidal mixing throughout the Lower Passaic River. The historical sources of these pesticides, especially dieldrin and Chlordane, are unlikely to be the same as those for 2,3,7,8-TCDD or Total PCBs or PAHs and yet difference among the core profiles for post-1980 deposition remain minor in comparison to their historical maxima. This observation is further evidence for the importance of tidal mixing in the control of depositing solids throughout the Lower Passaic River.

3.2.5 Metals Profiles

For the 2005 high resolution cores, metals analyses were performed on every core segment in the five dated sediment cores, typically 40 samples per core. In order to provide similar temporal resolution to the organic analytes (at nominally 20 samples per core), reported metal concentrations were averaged in pairs to create the same sediment intervals as the organic analyses. Dated sediment core profiles for cadmium, chromium, copper, lead, and mercury are presented in (Figures 3-13a to 3-13e). In general, metals concentrations varied approximately one order of magnitude or less over time with maximum concentrations occurring in the 1950s and 1960s, depending on metal and location. Note that the concentration axis is linear on Figures 3-13a to 3-13e, unlike the concentration axes for the organic compounds. For all the metals examined except for lead, the maximum concentration for the two upper river cores (RM11 and RM12.6) is higher than those in the lower portion of the river (RM1.4 to RM7.8). For lead, the highest peak concentration was found at RM7.8 followed by the cores at RM11 and RM12.6. Additionally, the maximum concentration consistently occurred earlier downstream relative to upstream, with maximum concentrations occurring in the mid-1950s at RM1.4 and RM2.2 followed by RM7.8 and RM11 and ending at RM12.6 in the mid-1960s. As described previously, all of the dated sediment cores with 1954 and 1963 Cs-137 horizons show a decline in deposition rate after 1963.

While this observation is of some interest relating to historical loads, of far greater importance is the convergence of the metals concentrations across all five cores during

the post-1980 period. This is the same convergence observed for all of the organic compound classes, and again is considered indicative the effectiveness of tidal mixing and the absence of major external sources. Also similar is the very gradual decline in concentrations since 1980 for all five metals examined. This trend also parallels the trend observed for most organics and suggests a similar causative mechanism for contamination observed in depositing solids for all the compounds and metals examined here (*i.e.*, resuspension of contaminated Lower Passaic River sediments).

Like all of the organic interpretations presented here, the metals observations from the 2005 USEPA cores are supported by the 1995 TSI cores. Figure 3-14 shows a comparison between the 1995 TSI and 2005 high resolution cores for mercury. Similar to the observation on the other contaminants, the mercury surface concentration of the 1995 TSI cores is comparable to that of the 2005 high resolution cores, approximately 1.5 to 3.5 milligrams per kilograms of sediment (mg/kg) for the 1995 cores *vs.* about 1 to 2 for the 2007 Be-7-bearing sediments. The 1995 TSI cores are poorly resolved and are subject to somewhat greater analytical uncertainty than the 2005 USEPA cores (see the sample duplicate pair at RM6.3, depth of 9.5 ft). These results are too poorly resolved to confirm the trends in the mercury maximum with river mile and time seen in the USEPA cores.

3.2.6 PCB Profiles

In this and each of the remaining subsections under Section 3.2, the data presentations are provided in a parallel fashion to that shown for 2,3,7,8-TCDD. Downcore profiles for Total PCB are presented in Figure 3-7a for the 2005 high resolution cores. The left hand panel of Figure 3-7a shows the downcore profile of Total PCBs for the best dated core (RM11). All five cores are shown in the middle panel, and an expanded view of the top portion of the cores, along with the 2007 results are shown in the right hand panel. Similar to 2,3,7,8-TCDD, Total PCB profiles show peak concentrations in the late 1950s and early 1960s. The peak concentrations range from about 10,000 to 30,000 µg/kg. Also similar to 2,3,7,8-TCDD, the Total PCB concentration declines slowly in all cores from 1980 to the present. In any given time period within the dated cores, the variation among the cores is less than that observed for 2,3,7,8-TCDD, *i.e.*, approximately a factor of two.

The most recent Be-7 bearing samples (2007) exhibit somewhat greater variability. The Total PCB concentrations post-1980 have declined by about a factor of three but there has been almost no change between 1995 and 2007 (see the right hand panel of Figure 3-15a). Like 2,3,7,8-TCDD, there is a similar spatial pattern of the Total PCB, with lower concentrations at the upstream-most and downstream-most high resolution core locations after about 1990. However, the difference between the extremes and the middle river mile locations is less pronounced than that observed for 2,3,7,8-TCDD. The minimal scatter in the Total PCB concentrations among the profiles over different year suggests that the solids delivered by the Upper Passaic River and Newark Bay are fairly comparable in PCB concentration to the resuspended solids of the Lower Passaic River, resulting in smaller gradients across the entire Lower Passaic River. As is shown in Data Evaluation Report No. 4, the Be-7-bearing sediments show concentration gradients outside the RM2 to RM12 interval similar in direction to those suggested by the 2005 high resolution cores, but the gradients are only about a factor of two, not the orders of magnitude observed for 2,3,7,8-TCDD. Like 2,3,7,8-TCDD, the observations for Total PCBs support the conclusions about tidal mixing and the absence of major point source discharges in the Lower Passaic River.

Four PCB congeners are presented to examine the individual congeners. Two low molecular weight congeners (Ballschmiter and Zell [BZ] 52 and BZ61) and two high molecular weight PCBs (BZ110 and BZ180) were plotted in Figures 3-7b through 3-7e.[9] The individual PCB congeners followed similar trends to the Total PCB profile, indicating that the mixture of PCBs has remained fairly constant over time. From this it can be inferred that the congener mixtures in the sources of PCBs to the river have remained fairly consistent through time as well. Taken together with the concentration differences noted among the cores and the distribution of PCBs in Be-7-bearing sediments, these results suggest that the sediments of the main stem of the Lower Passaic River are more contaminated with PCBs relative to external sources over at least the last

[10] This analysis compared the sum of detected PCB congeners with the sum of detected Aroclors for 10 low resolution core samples collected in 2006 from various locations in the Lower Passaic River. This analysis indicated the likelihood of a relatively small difference between the two methods for Lower Passaic River PCBs. The Aroclor method was on the order of 25 percent lower relative to the sum of PCB congeners. This difference was significant at about a 93 percent level of confidence. The summary statistics for this analysis are presented in Attachment B.

10 to 15 years, with solids containing lower PCB concentrations contributed by the Upper Passaic River and Newark Bay. Like the observations for 2,3,7,8-TCDD, the observations of PCBs in the tops of the 2005 cores indicate the absence of concentration gradients between RM2 and RM12, supporting the inference of rapid tidal mixing (see Data Evaluation Report No. 4).

A comparison between the five 1995 TSI cores identified previously and the 2005 high resolution cores is shown in Figure 3-8. The comparison was made for Total PCB only since the 1995 TSI cores were analyzed for PCB Aroclors and only a limited number of PCB congeners. Although the sum of Aroclors from the 1995 cores and the sum of PCB congeners from the 2005 cores are not exactly the same measurement, the sum of Aroclors can still be examined as a surrogate for the sum of PCB congeners. This premise was borne out by analysis of a subset of USEPA's low resolution sediment cores wherein samples were analyzed for both PCB congeners and Aroclors.[10] A similar sum cannot be constructed from the 1995 congener data since too few congeners were reported to represent a true sum of all PCB congeners present. As was the case for the 2,3,7,8-TCDD comparison, the 1995 cores have relatively poor temporal resolution for PCBs but still allow for some useful comparisons.

Consistent with the 2005 cores, the 1995 cores also show PCB maxima occurring in the early 1960s. The magnitude of the peak is between 3,500 and 10,000 µg/kg, lower than the observations for the 2005 cores (10,000 to 30,000 µg/kg) but the variation in the values are similar (about a factor of three from minimum to maximum). The difference in the absolute magnitude of the core maximum can only partially be explained by differences in the analytical procedures (see footnote 9). More importantly, however, just like the 2005 high resolution cores, all 1995 TSI cores show a decline in concentration from the peak concentration to the top of the cores. The surface concentration of the 1995 cores is comparable to that of the 2005 high resolution cores, approximately 1,000 to

[10] This analysis compared the sum of detected PCB congeners with the sum of detected Aroclors for 10 low resolution core samples collected in 2006 from various locations in the Lower Passaic River. This analysis indicated the likelihood of a relatively small difference between the two methods for Lower Passaic River PCBs. The Aroclor method was on the order of 25 percent lower relative to the sum of PCB congeners. This difference was significant at about a 93 percent level of confidence. The summary statistics for this analysis are presented in Attachment B.

2,000 µg/kg. Just as for 2,3,7,8-TCDD, the observations from the 1995 TSI cores directly support the observations from the more detailed 2005 cores.

3.3 Summary of the Contaminant History as Recorded in the Sediments and its Implications

The analysis of contaminant histories for the five compound classes examined above provides the following significant observations.

- Dated sediment cores provide a means to compare temporal variations in contamination over the entire length of the Lower Passaic River. The procedure to establish core chronologies is well established in the literature. Dated sediment cores were obtained by both USEPA and TSI (under USEPA oversight).
- The cores provided a means to examine a broad range of contaminants and their histories, including 2,3,7,8-TCDD, PCBs, PAHs, pesticides, and heavy metals.
- The results obtained from the USEPA 2005 high resolution cores are well supported by the 1995 TSI cores. Although the 1995 TSI cores lack temporal resolution, they still confirm the occurrence and magnitude of historical contaminant concentrations and the gradual decline in sediment concentrations since the peak periods.
- The results obtained from the USEPA 2005 high resolution cores are well supported by the 2007 Be-7-bearing sediment survey, which served to confirm the similarity of concentrations across from RM2 to RM12 in recently-deposited sediment indicated by the 2005 dated sediment cores. The 2007 results also confirmed the anticipated concentration trend for most contaminants in recently-deposited sediments predicted from the 2005 core profiles.
- The core profiles showed that all of the contaminants examined converge to a relatively narrow range of concentrations after about 1980. Typical intra-annual concentrations for a given analyte varied about a factor of two or less across dated sediment cores separated by as much as 11 miles, spanning about two-thirds of the entire length of the Lower Passaic River and a 25-year time span. This high level of agreement should be contrasted with the range of historical concentration

measurements of these contaminants, which often vary by orders of magnitude over short distances.

  - The observed narrow range in concentration across many contaminant types and across nearly two-thirds of the river is considered direct evidence of the extent and intensity of tidal mixing of solids prior to permanent deposition, and the absence of major external sources comprised of highly concentrated discharges (*i.e.*, no point sources).
  - This dynamic mixing condition has existed since at least since 1980, given the narrow range of concentrations in depositing sediments (*i.e.*, the narrow range in the dated sediment cores) that have existed since that time. Infilling of the channel by depositing sediments may be a factor, serving to increase water velocities that would then cause more thorough mixing of suspended solids in more recent times.

- The ratio of 2,3,7,8-TCDD to Total TCDD showed the sediment burden of 2,3,7,8-TCDD to be almost exclusively industrial in nature since the early 1950s. The core analysis combined with other USEPA sampling work showed that this signature ratio value does not occur in any of the external sources to the Lower Passaic River. See Data Evaluation Report No. 2 and in Data Evaluation Report No. 4.
- Most contaminant concentrations declined over time, but only slowly, with "half times" for the decline in sediment concentration on the order of 30 years for post-1980 deposition.
  - The parallel decline among many different compounds with many different sources over time implies that concentrations of these compounds in recently-deposited sediments are no longer governed by multiple sources but rather by a single causative process that governs organic and inorganic substances alike.
  - Based on a number of lines of evidence (as discussed throughout these data evaluation reports), including existing sediment contaminant concentrations, solids transport, and variations among bathymetric survey elevations, the single causative process sustaining these concentrations at

the river's surface and in the depositing sediments captured by the high resolution cores is the resuspension of contaminated sediments of the Lower Passaic River.

- The strongest geochemical evidence for both resuspension and the intensity and extent of tidal mixing of solids is provided by 2,3,7,8-TCDD, which has the largest absolute differences between Lower Passaic River sediments and external solids sources and yet still follows the trends seen in the other, less varied contaminants. In particular, the dated sediment cores show close agreement in concentration from RM1.4 to RM12.6 for 2,3,7,8-TCDD since 1980 (excluding the circa 2000 event) paralleling the more detailed trend in 2,3,7,8-TCDD concentrations documented by the Be-7 bearing sediments collected in 2007 (see Data Evaluation Report No. 4).
- A few contaminants did not decline at all with time although they still exhibited a narrow range of concentration. These contaminants indicate the presence of important external sources but also show them to be sufficiently low in concentration that tidal mixing is able to distribute these loads across the Lower Passaic River, resulting in the characteristic lack of concentration gradients from RM2 to RM12. As will be shown in Appendix C, resuspension of contaminated Lower Passaic River sediments still comprises major sources for these contaminants but their concentrations in external sources largely prevents any notable decline in their concentrations with time.
    - PAHs contamination showed no decline with time since about 1970 and appears to be controlled by external loads originating in the Upper Passaic River.
    - Dieldrin concentrations have been rising since reaching a minimum in the mid-1980s. Much of the dieldrin likely originates with tributaries to the Lower Passaic River, including the Upper Passaic River.
    - These observations are further discussed in Data Evaluation Report No. 2 and in Data Evaluation Report No. 4.
- Although a relatively narrow range of concentrations was observed among the dated sediment cores, the core locations at the upstream and downstream-most

locations were typically lower than those from RM2.2 to RM11 for 2,3,7,8-TCDD and Total PCBs.

- Lower concentrations at RM1.4 and RM12.6 for these compounds are likely due to the introduction of relatively clean solids from the main external sources of solids.
- Despite the substantive differences between the concentrations on these external solids and those found within the river, extensive tidal mixing serves to eliminate much of the concentration gradient across the central 10 miles of the Lower Passaic River.

4 ACRONYMS

2,3,7,8-TCDD	2,3,7,8-Tetrachlorodibenzo-p-dioxin (also referred to as “dioxin”)
Be-7	Beryllium-7
BZ	Ballschmiter and Zell
C-14	Carbon-14
CLP	Contract Laboratory Program
cm	centimeters
cm/yr	centimeters per year
COPC	Contaminants of Potential Concern
COPEC	Contaminants of Potential Ecological Concern
CPG	Cooperating Parties Group
Cs-137	Cesium-137
CSO	Combined Sewer Overflow
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
dioxins	Polychlorinated Dibenzodioxins/furans
DQO	Data Quality Objective
FFS	Focused Feasibility Study of the Lower Eight Miles of the Lower Passaic River
g	gram
HMW	High Molecular Weight
L-DEO	Lamont-Doherty Earth Observatory
LMW	Low Molecular Weight
LPRSA	Lower Passaic River Study Area
mg/kg	milligrams per kilograms of sediment
ng/kg	nanograms per kilograms of sediment
PAH	Polycyclic Aromatic Hydrocarbon
Pb	Lead
PCB	Polychlorinated Biphenyl

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pCi/g	picocuries per gram of sediment
PTBT	Partial Test Ban Treaty
QAPP	Quality Assurance Project Plan
RI	Remedial Investigation
RI/FS	Remedial Investigation and Feasibility Study
RM	River Mile
RPI	Rensselaer Polytechnic Institute
SWO	Stormwater Outfall
$t_{1/2}$	half-life
TAL	Target Analyte List
TOC	Total Organic Carbon
Total TCDD	Total Tetrachlorodibenzo-p-dioxin
TCDD	Tetrachlorodibenzo-p-dioxin
TPH	Total Petroleum Hydrocarbons
TSI	Tierra Solutions, Inc.
µg/kg	micrograms per kilograms of sediment
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency

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TABLES

Table 3-1: Locations of 1995 TSI Cores with Complete Cesium-137 Profiles

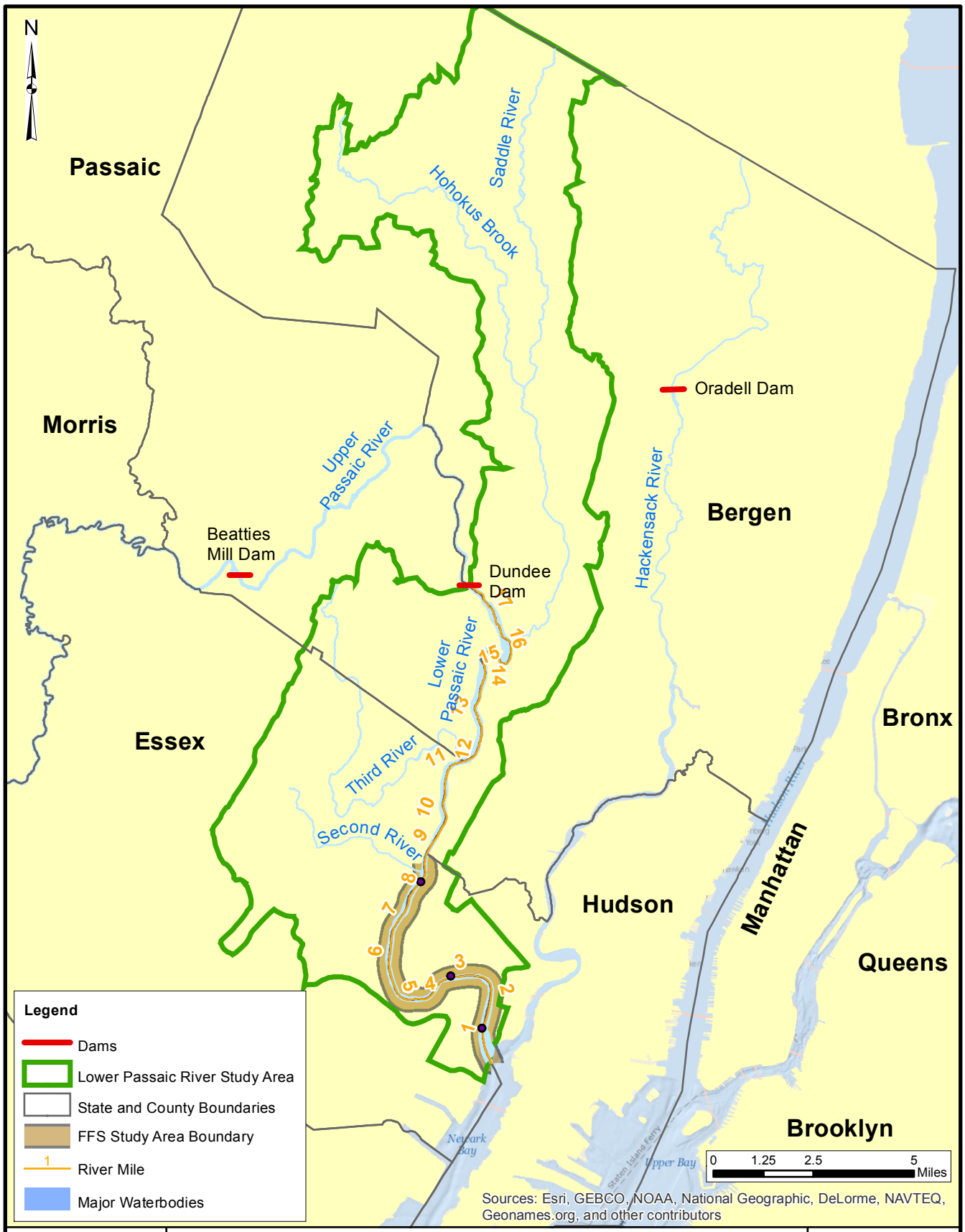
Tierra Solutions, Inc. Location	X-Coordinate	Y-Coordinate	River Mile	Depth of Sediment Sampled (feet)[a]
TSI 209	598198	691320	1.46	5.5
TSI 222[b]	595563	695459	2.65	13.6
TSI 228[b]	593188	695244	3.10	11
TSI 230	593149	695455	3.10	7.2
TSI 286	593249	695021	3.10	5.6
TSI 232	592028	694972	3.33	6
TSI 235	591151	694213	3.55	7.2
TSI 241[b]	589595	692519	4.01	11.9
TSI 248[b]	587218	692459	4.47	14.8
TSI 251	586182	693013	4.70	8.5
TSI 253	585542	693974	4.92	5.5
TSI 272[b]	585243	701014	6.27	10.5
TSI 296	585527	701638	6.40	5.6
TSI 275	585643	702116	6.49	7

Notes:

a: Depth represents bottom of last core segment sampled for either radiological or analytical samples. This depth does not necessarily represent the total coring depth since segmentation of the core extended only to the 1940 time horizon [Field Sampling Plan (Tierra Solutions, Inc., 1995a)].

b: These cores were selected for comparison with 2005 EPA cores.

FIGURES



FFS Study Area Location Map

Lower Eight Miles of the Lower Passaic River

Figure 1-1

2014

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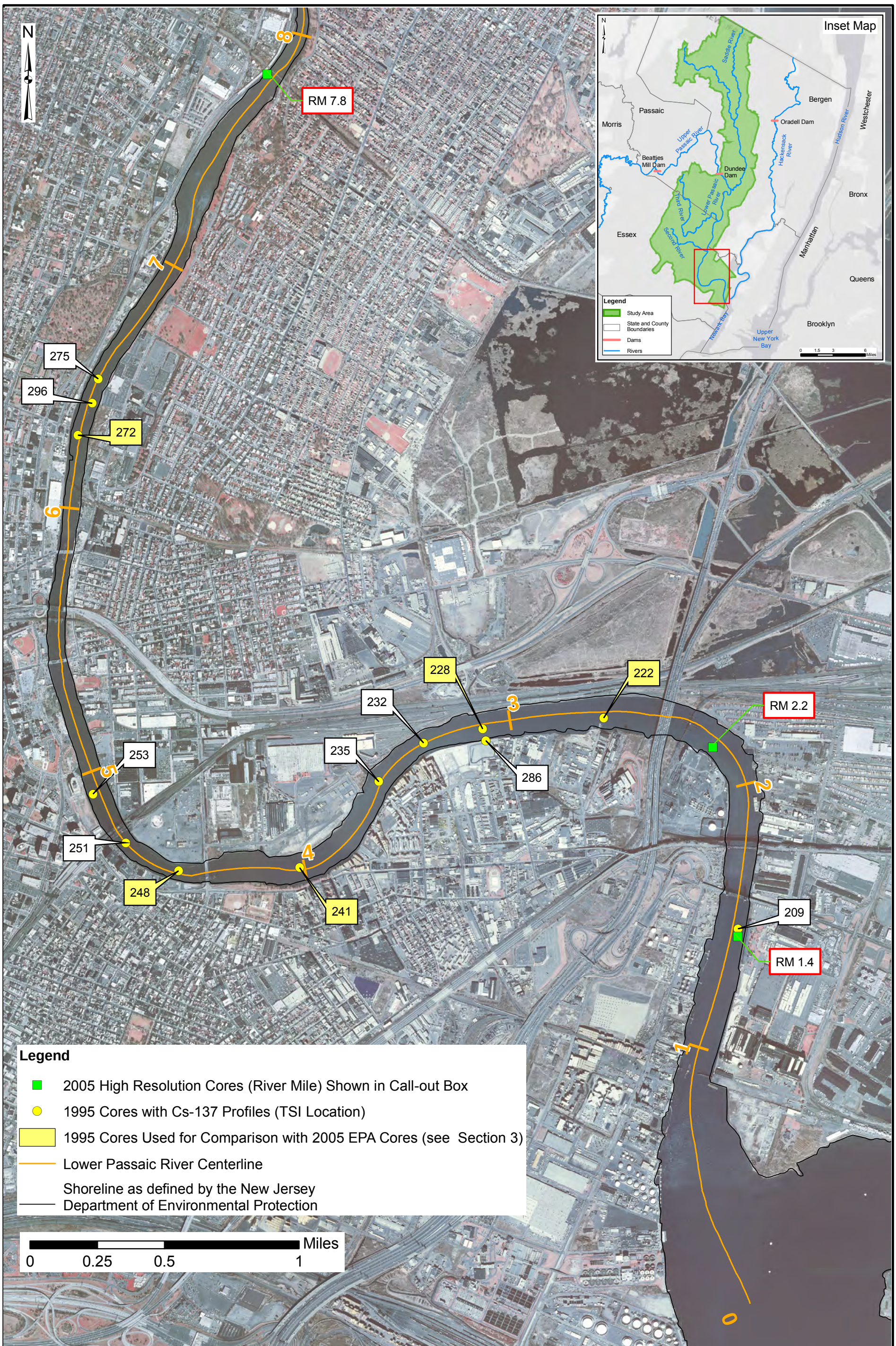

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Locations of Passaic River Samples Used In the Mass Balance Model

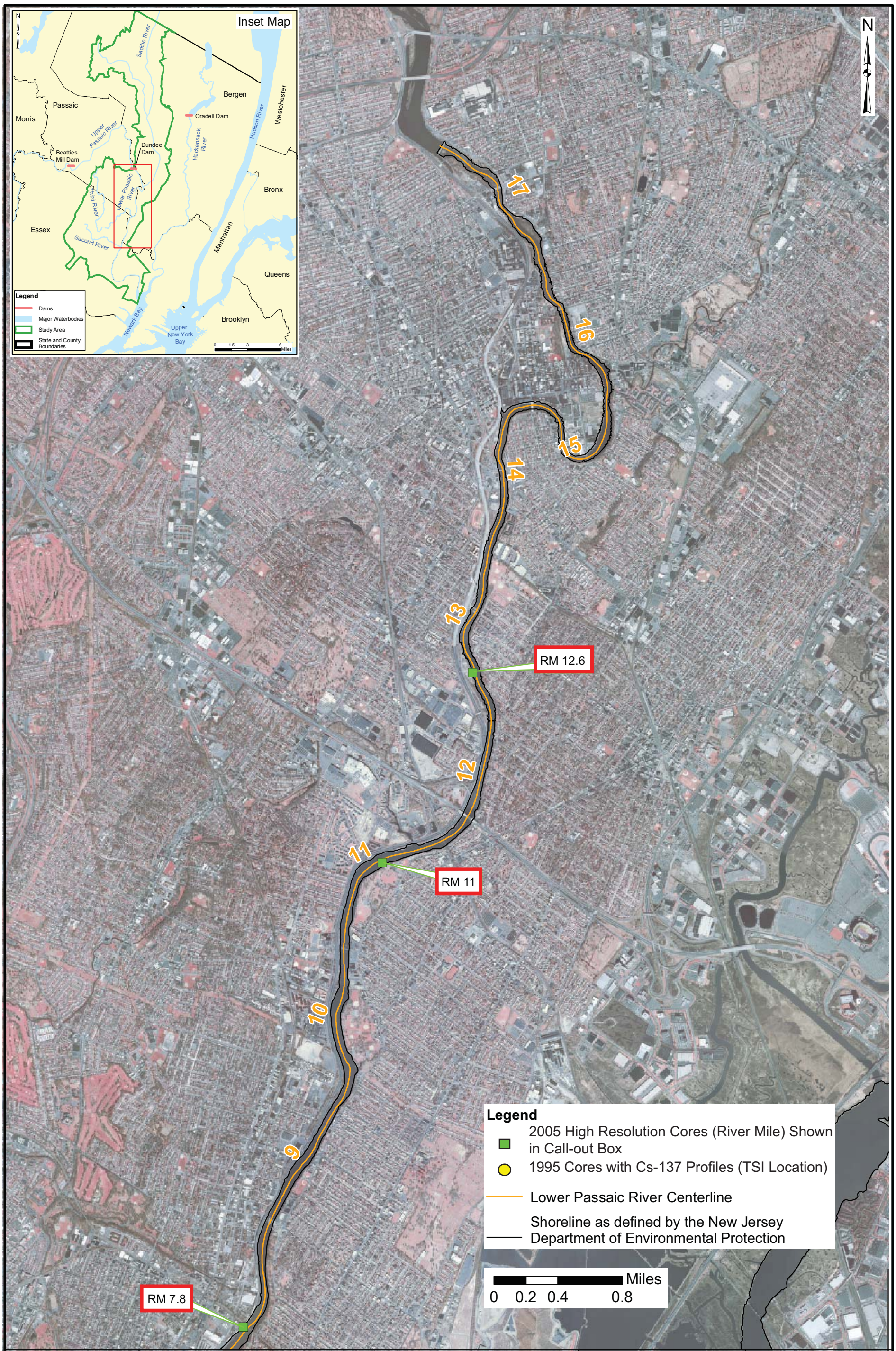
Lower Eight Miles of the Lower Passaic River

Data Source: 2002 Aerial photographs from the New Jersey State data clearing house (http://njgin.state.nj.us).

Figure 1-2a

2014

R2-0026731



Locations of Lower Passaic River Sediment Cores Used to Examine Contaminant History

Lower Eight Miles of the Lower Passaic River

Data Source: 2002 Aerial photographs from the New Jersey State data clearing house (http://njgin.state.nj.us).

Figure 1-2b

2014

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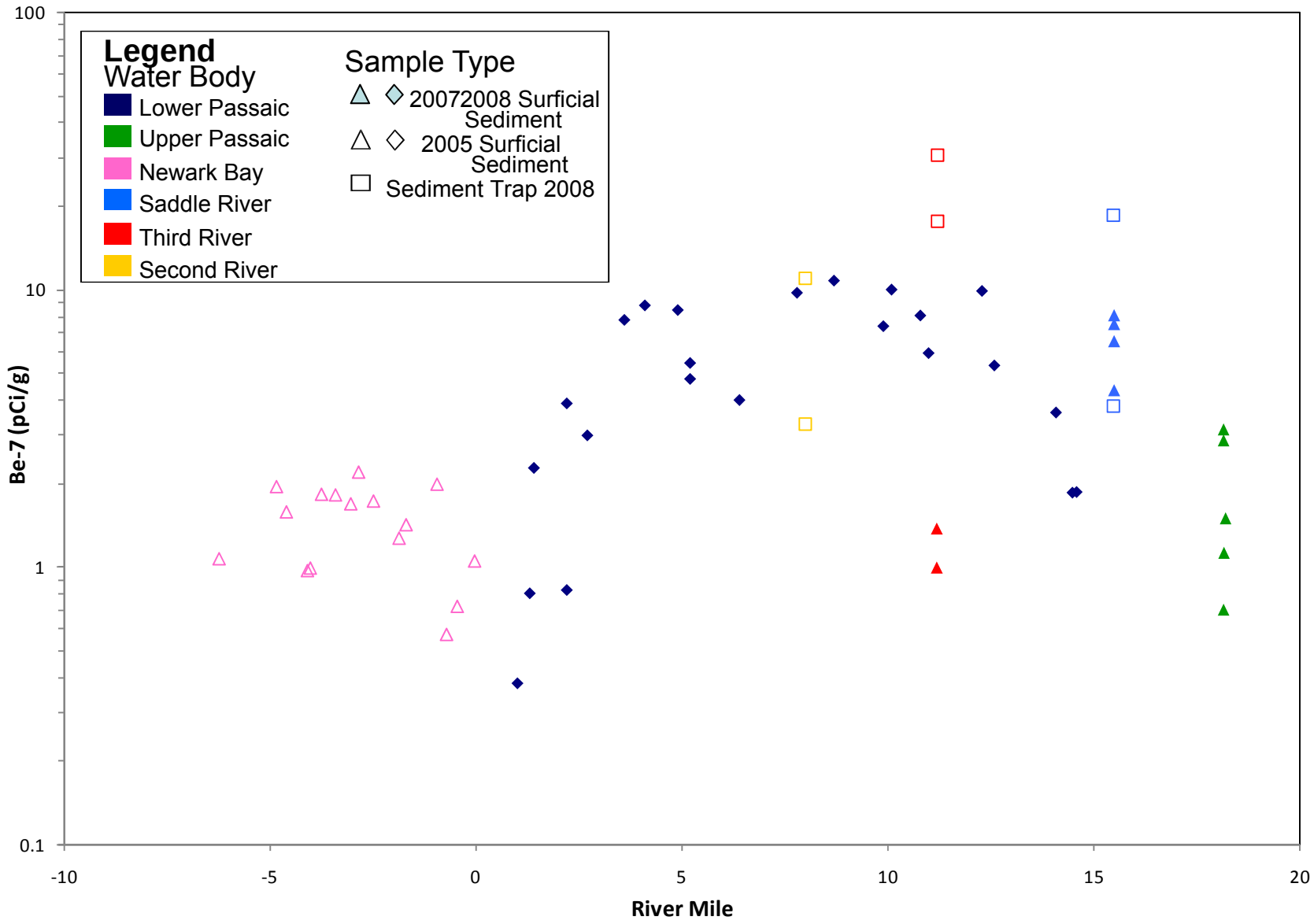
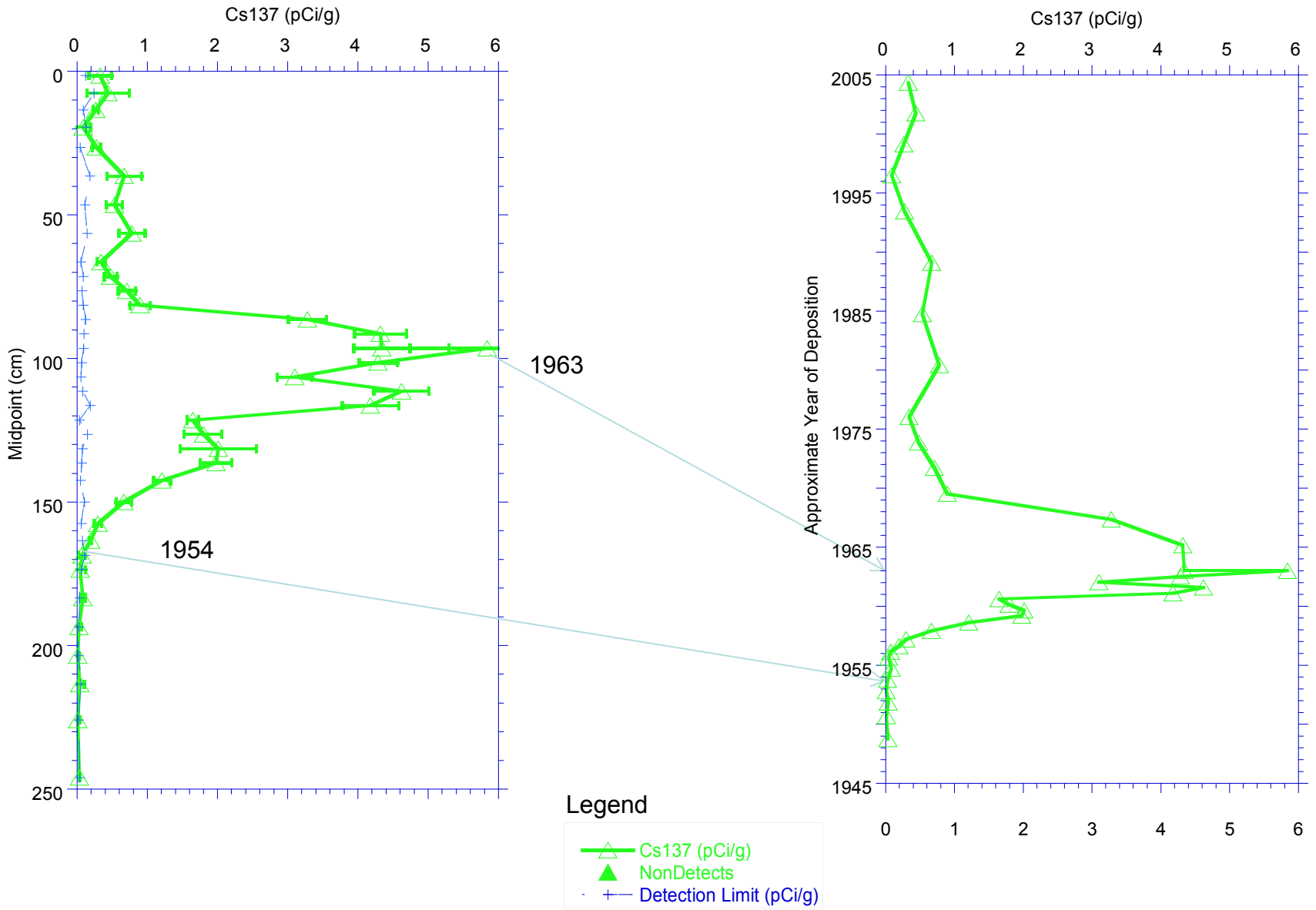


	Beryllium-7 Activity vs. River Mile *Lower Eight Miles of the Lower Passaic River*	Figure 2-1 2014

R2-0026733



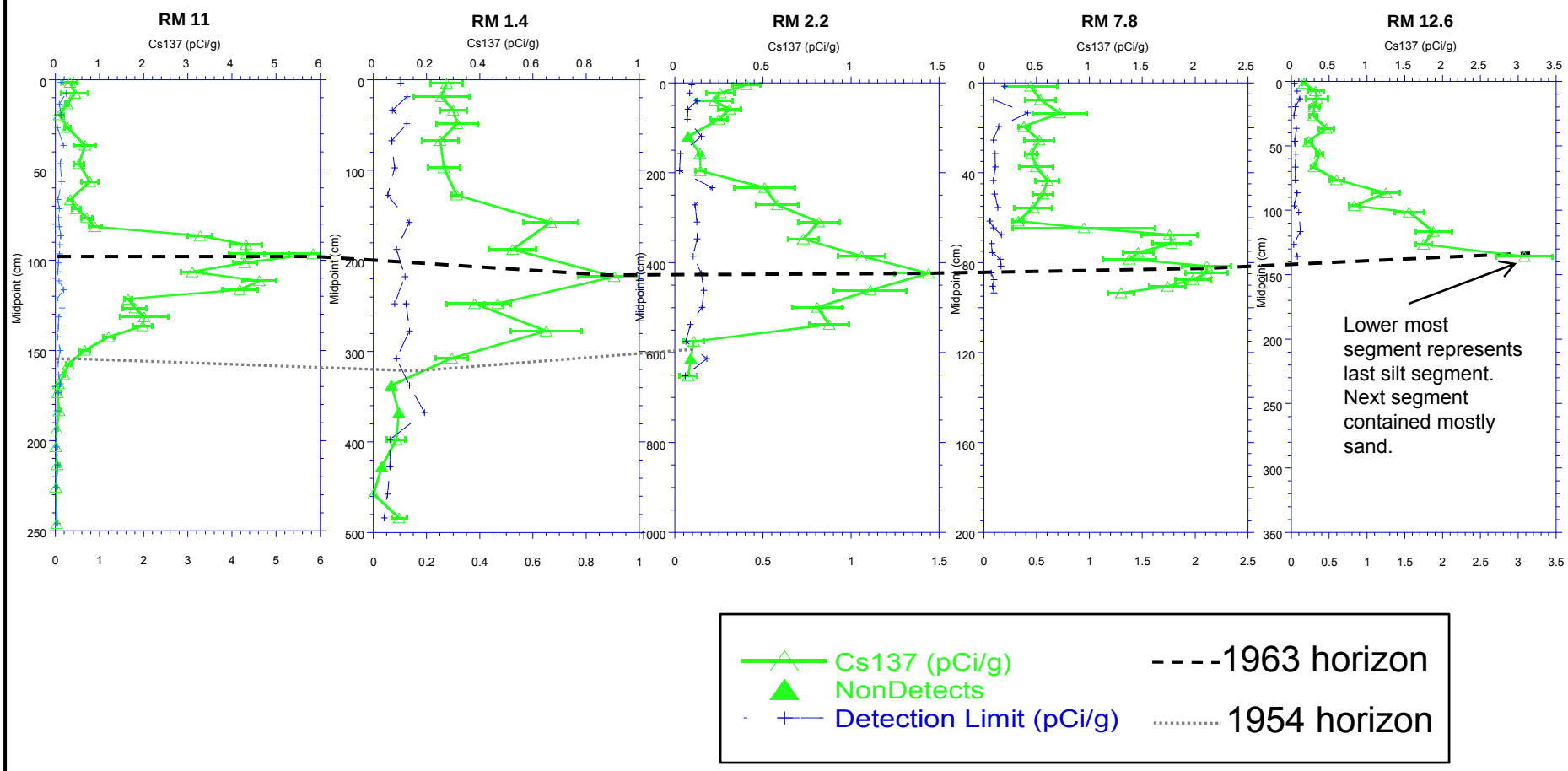
Assignment of the Approximate Year of Deposition based on the Cs-137 Profile for the Core at RM11

Lower Eight Miles of the Lower Passaic River

Figure 3-1

2014

R2-0026734



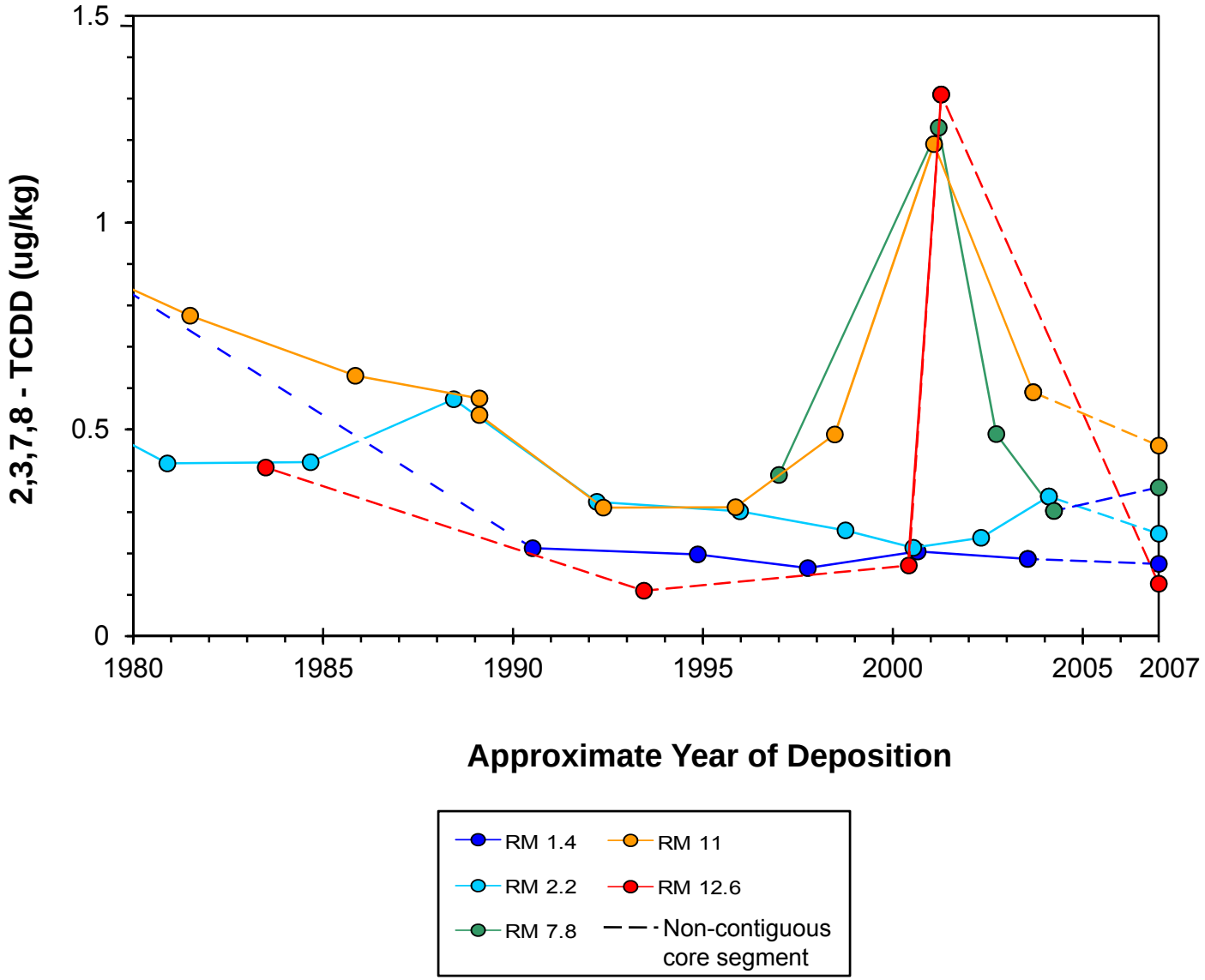
Cs-137 Downcore Profiles for 2005 High Resolution Cores

Lower Eight Miles of the Lower Passaic River

Figure 3-2

2014

R2-0026735



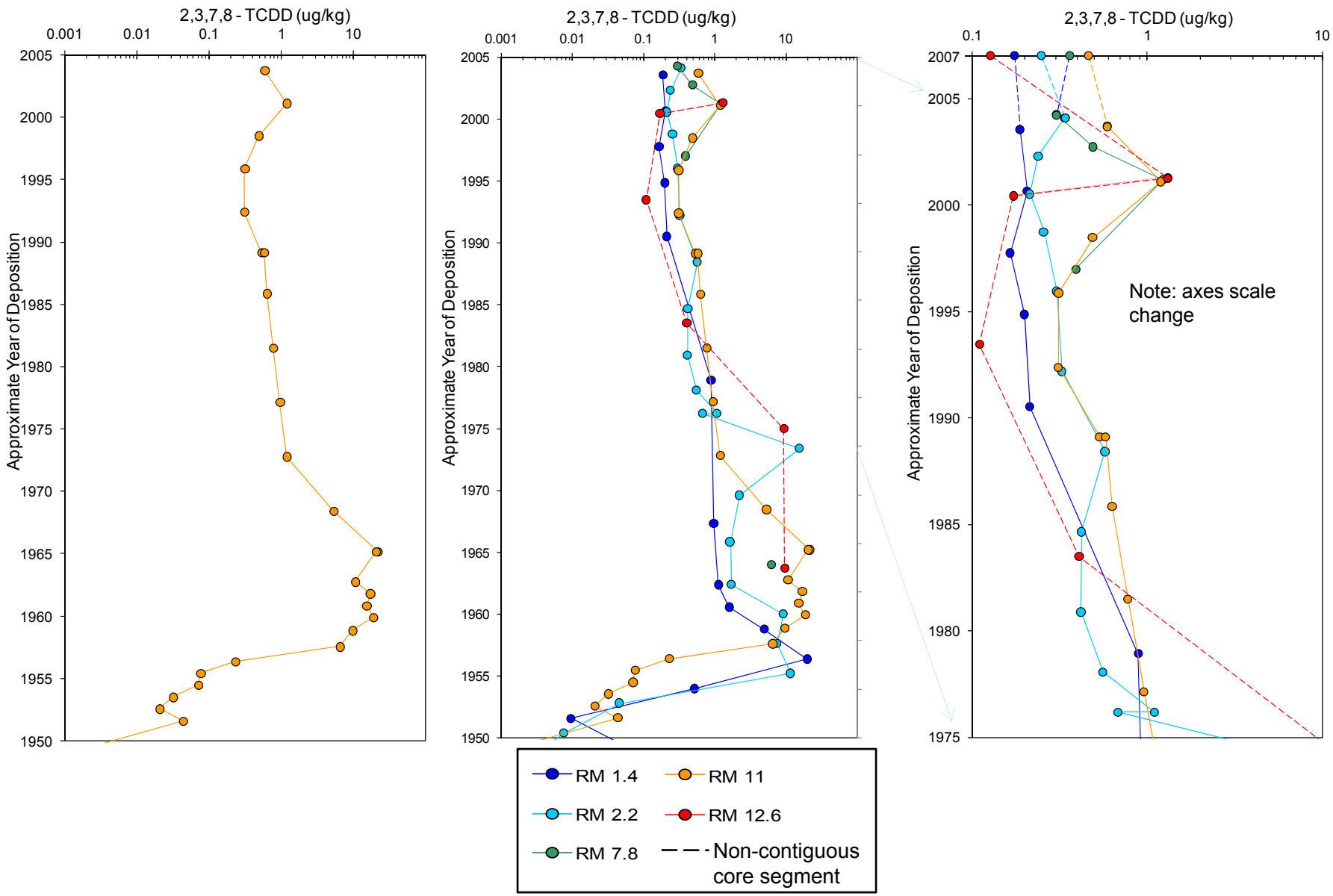
Dated Sediment Core Profiles for 2,3,7,8-TCDD:
Post 1980 Deposition - Linear Scale

Lower Eight Miles of the Lower Passaic River

Figure 3-3

2014

R2-0026736



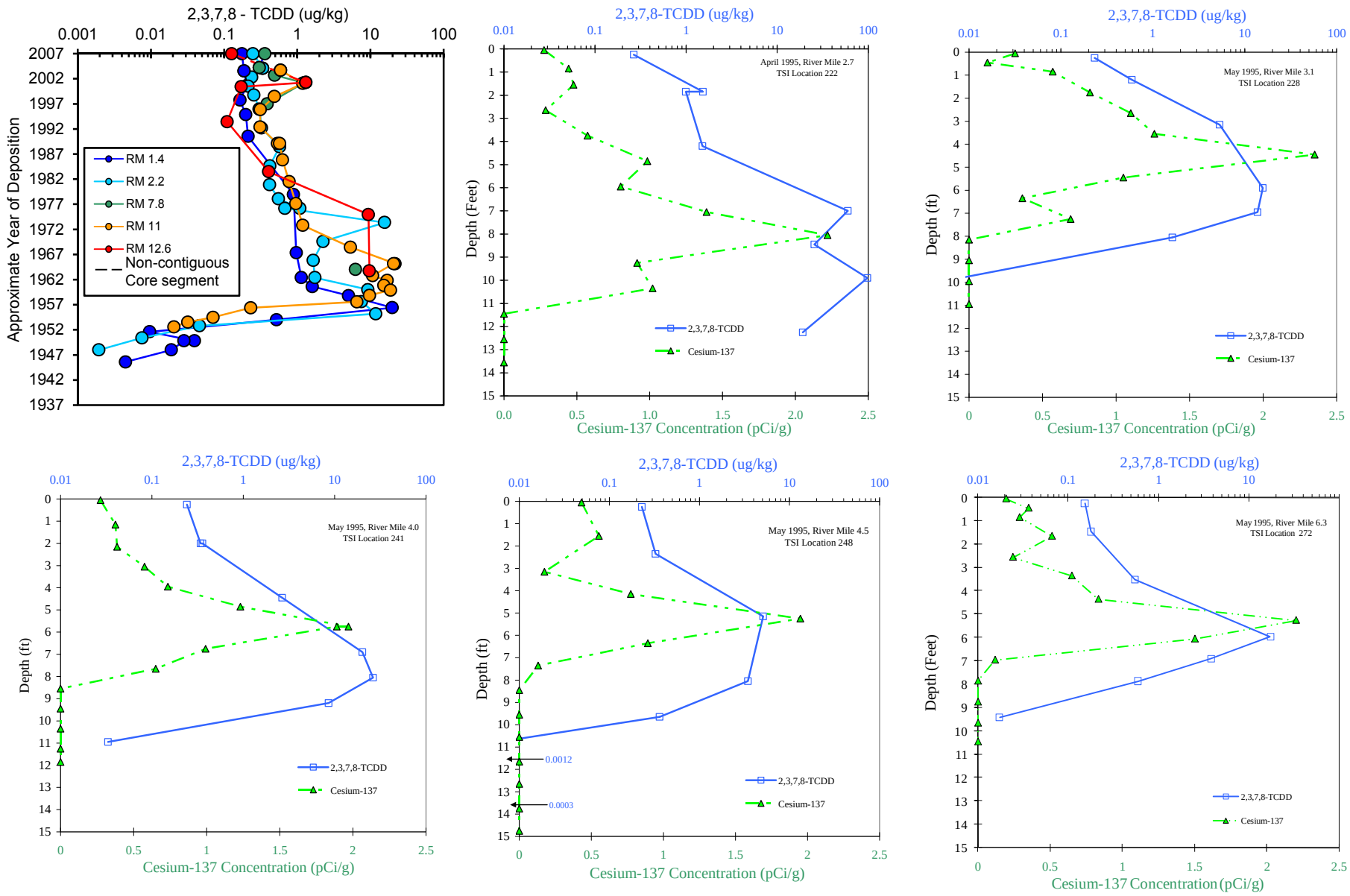
Dated Sediment Core Profiles for 2,3,7,8-TCDD:
2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3-4

2014

R2-0026737



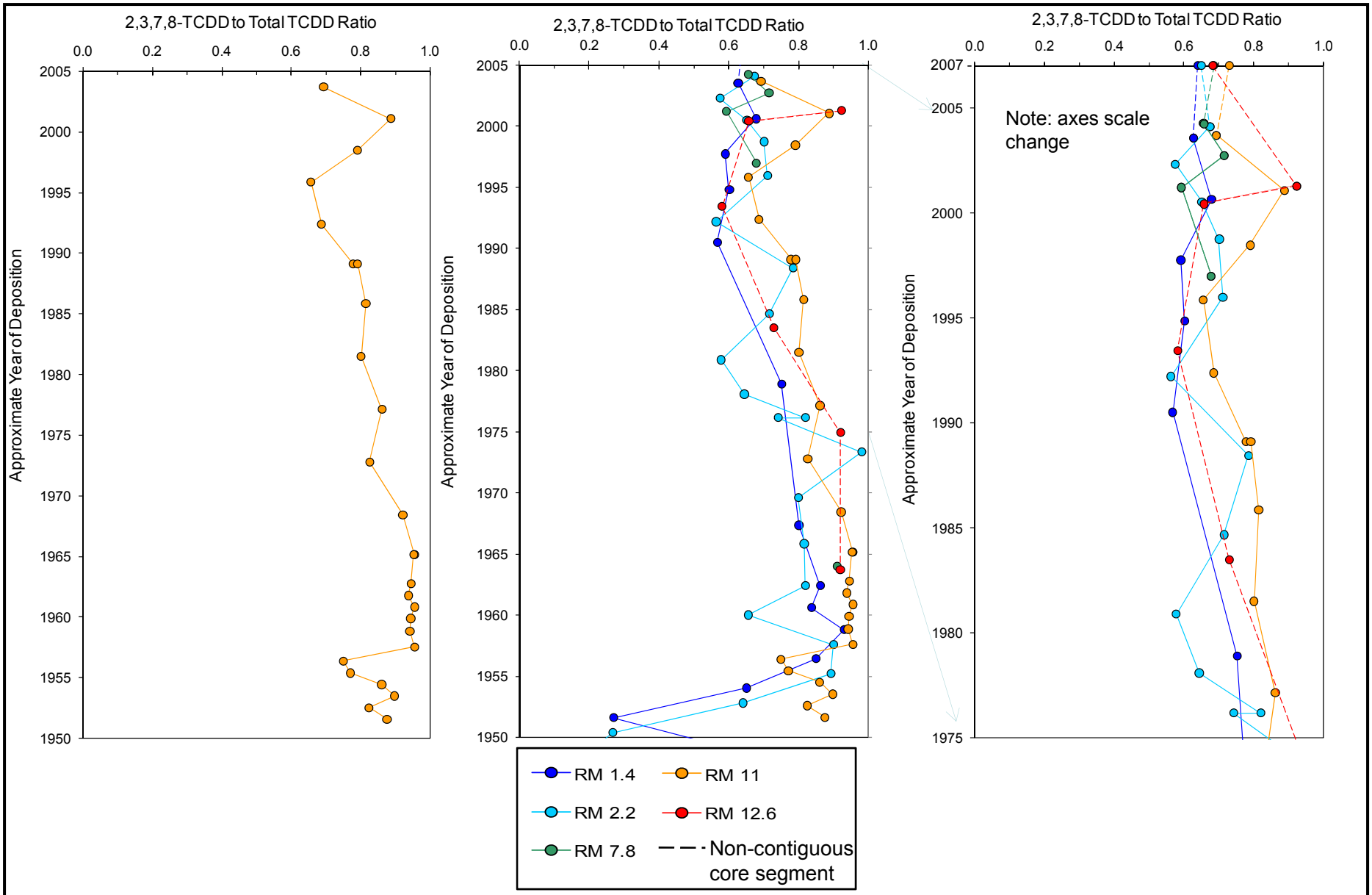
Comparison of EPA 2005 and TSI 1995 Downcore Profiles: 2,3,7,8-TCDD

Lower Eight Miles of the Lower Passaic River

Figure 3-5

2014

R2-0026738



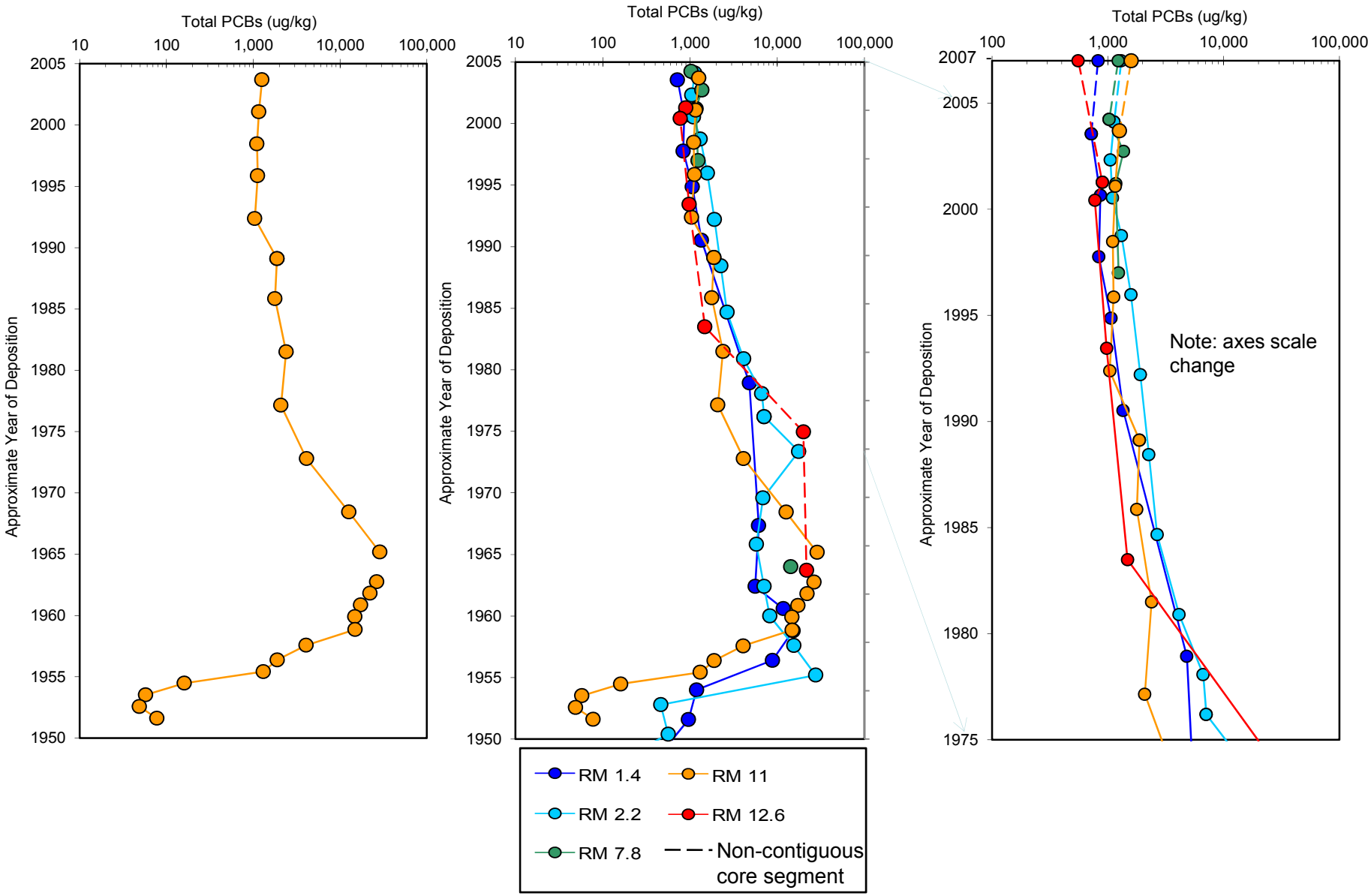
Dated Sediment Core Profile for 2,3,7,8-TCDD to Total TCDD Ratio: 2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3-6

2014

R2-0026739



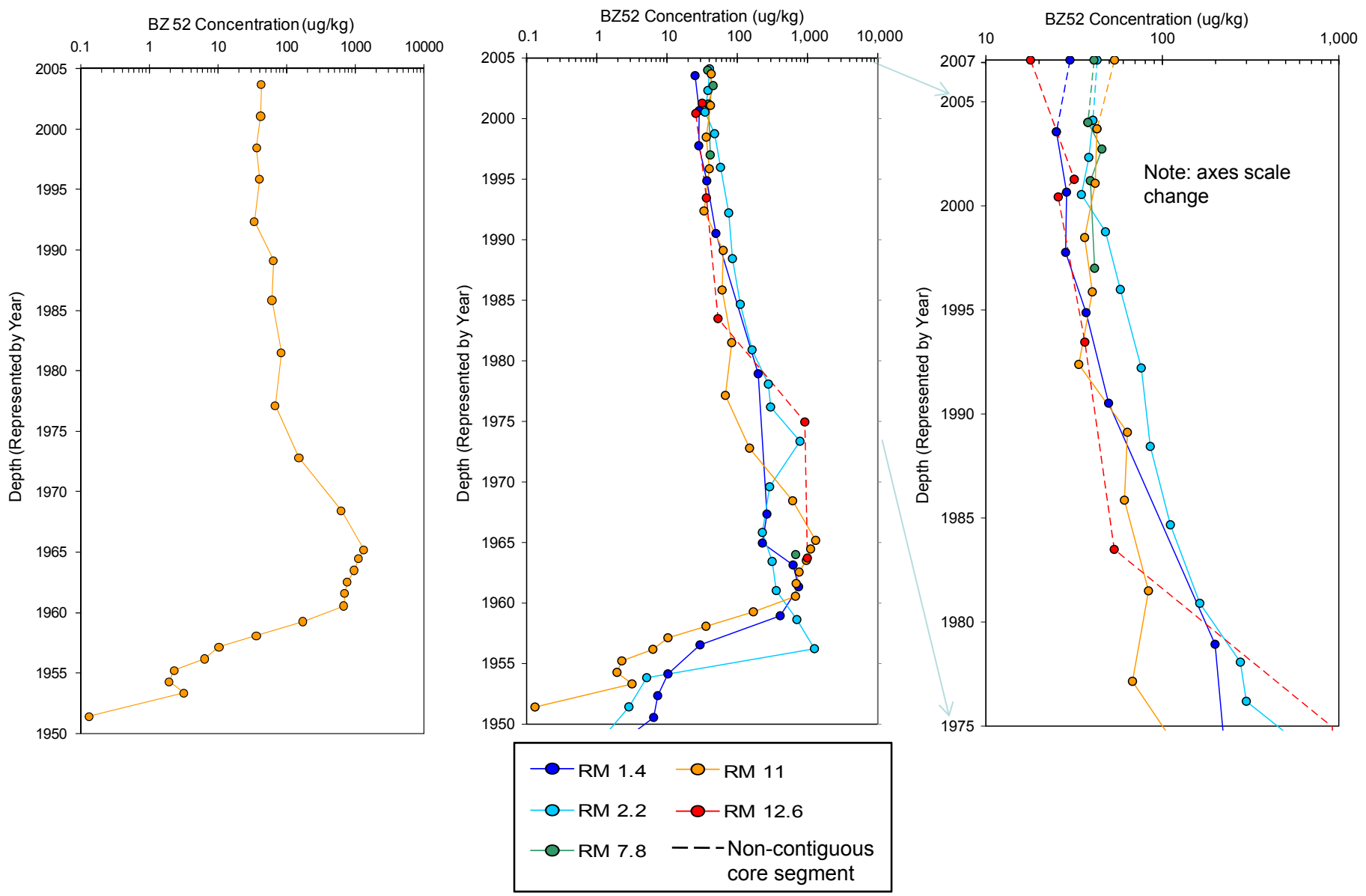
Dated Sediment Core Profile for Total PCBs:
2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3-7a

2014

R2-0026740



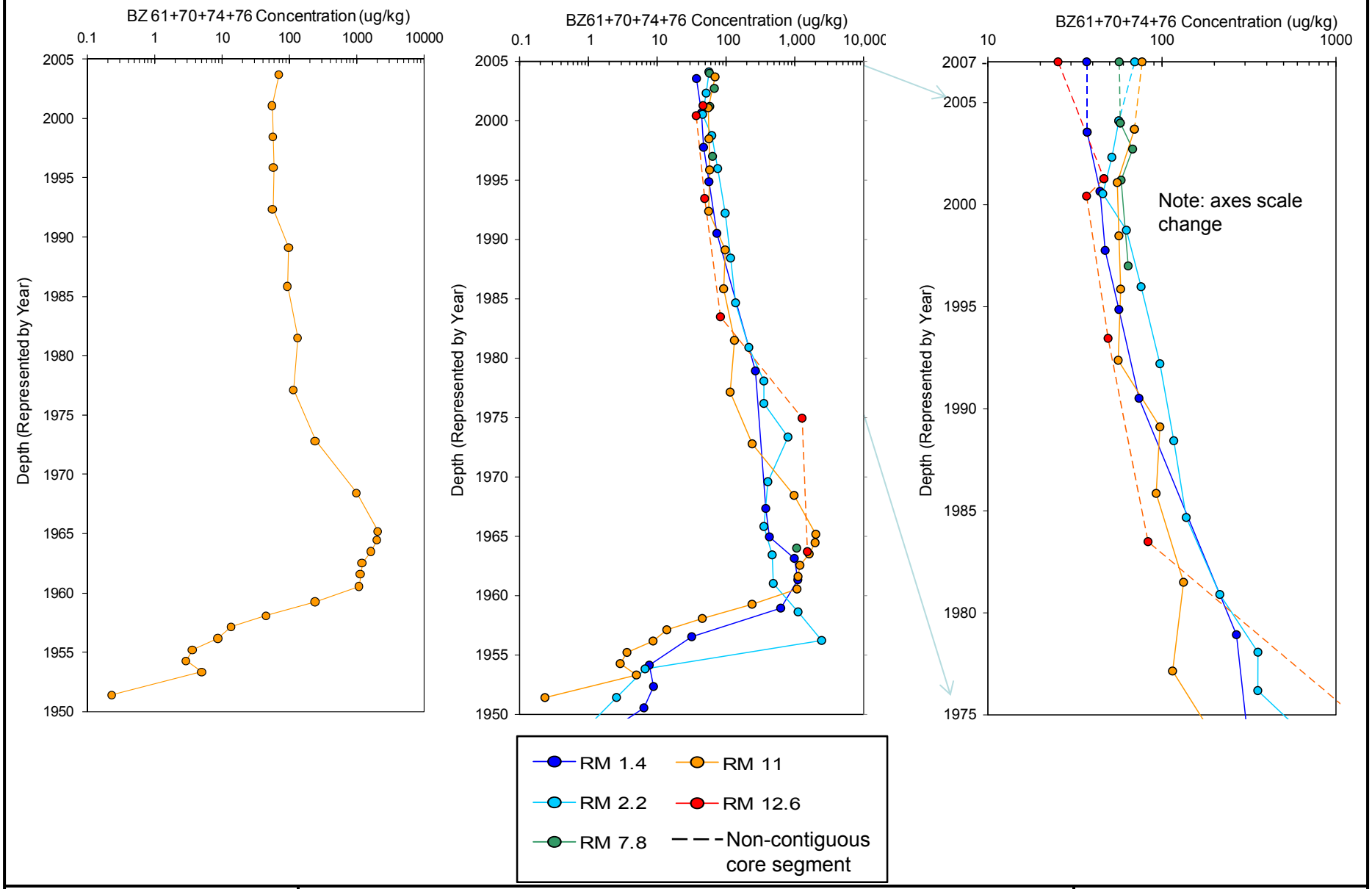
Dated Sediment Core Profile for BZ52:
2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3-7b

2014

R2-0026741



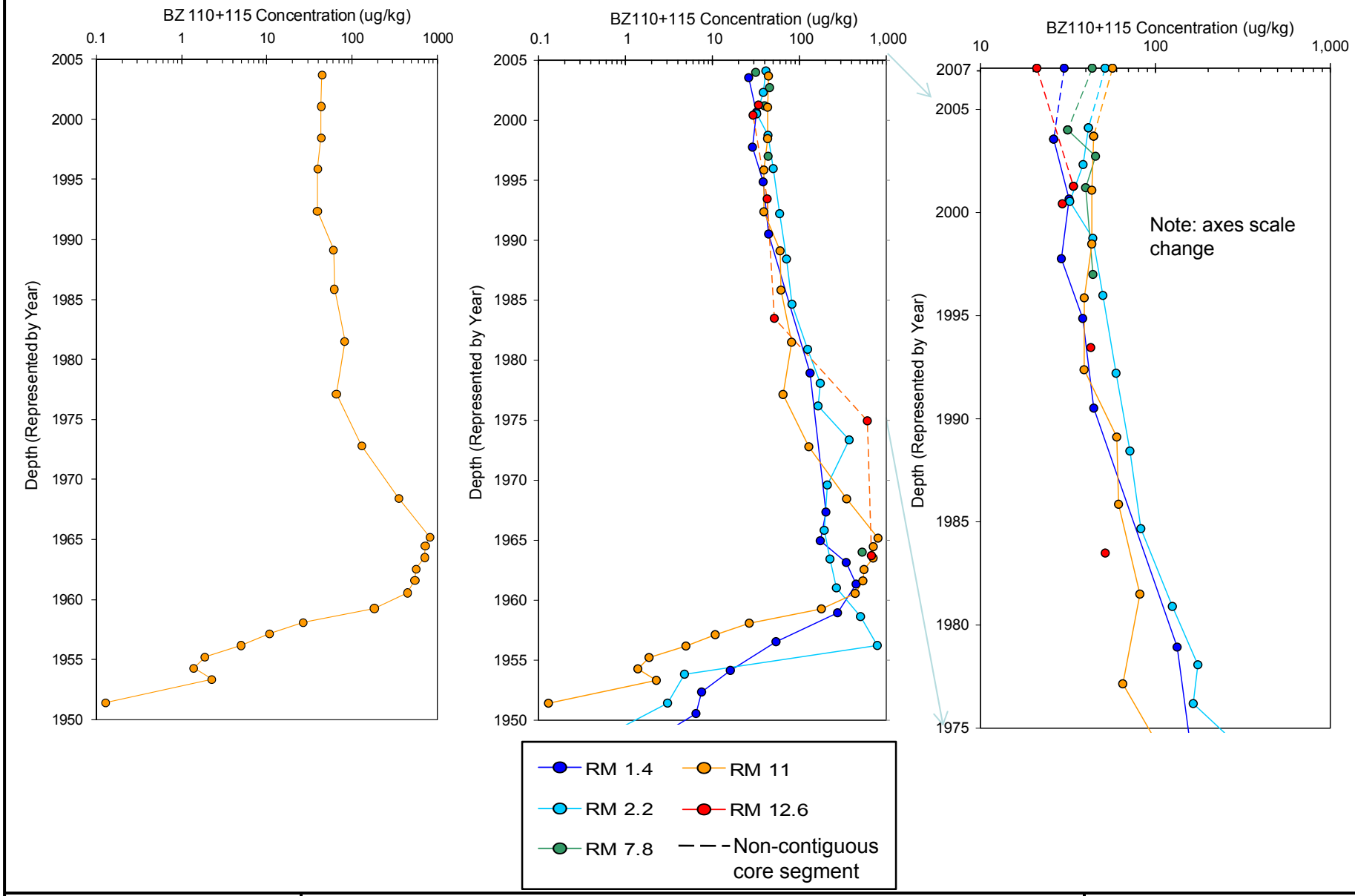
Dated Sediment Core Profile for BZ61+70+74+76:
2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3-7c

2014

R2-0026742



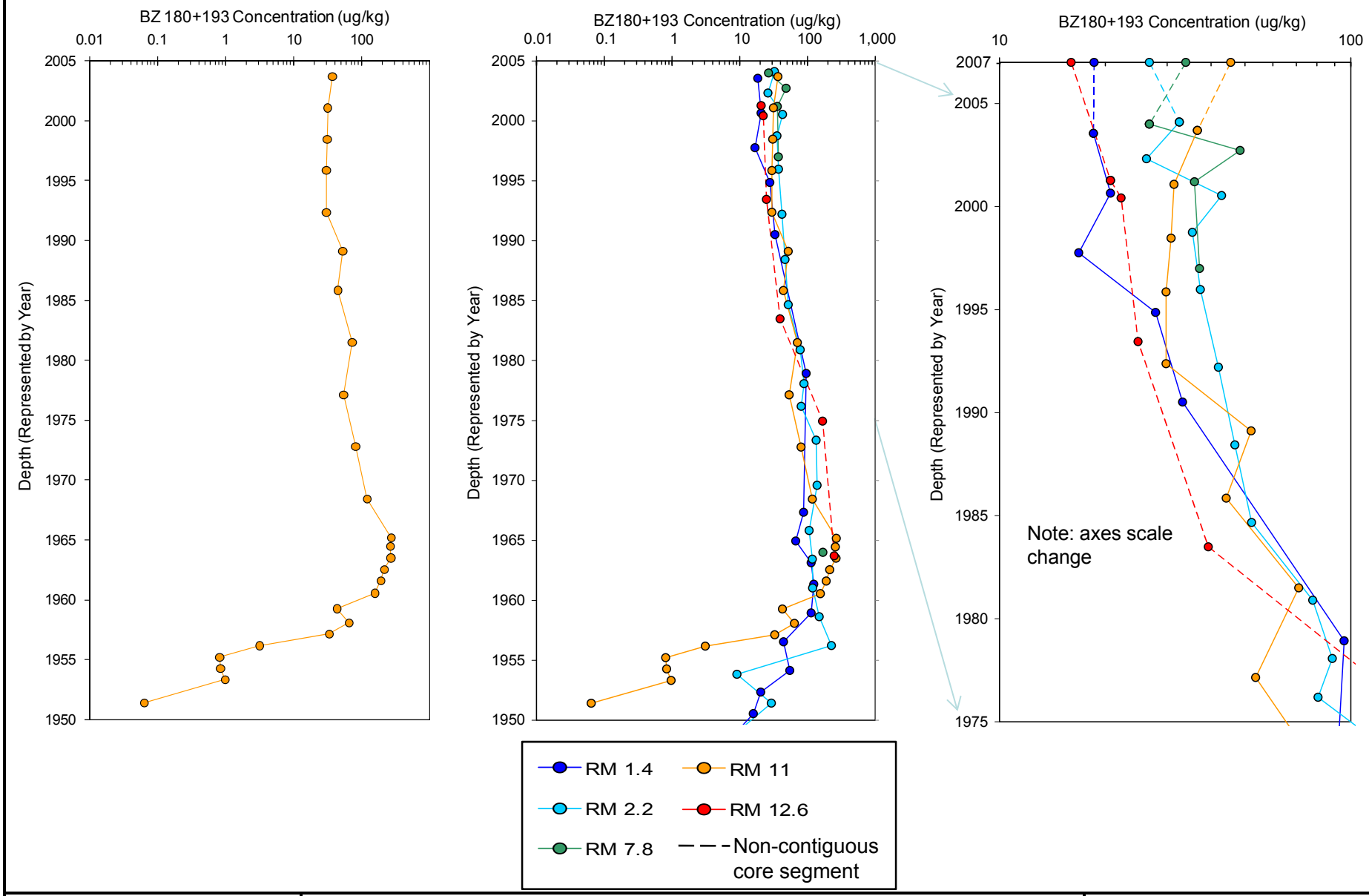
Dated Sediment Core Profile for BZ110+115:
2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3-7d

2014

R2-0026743



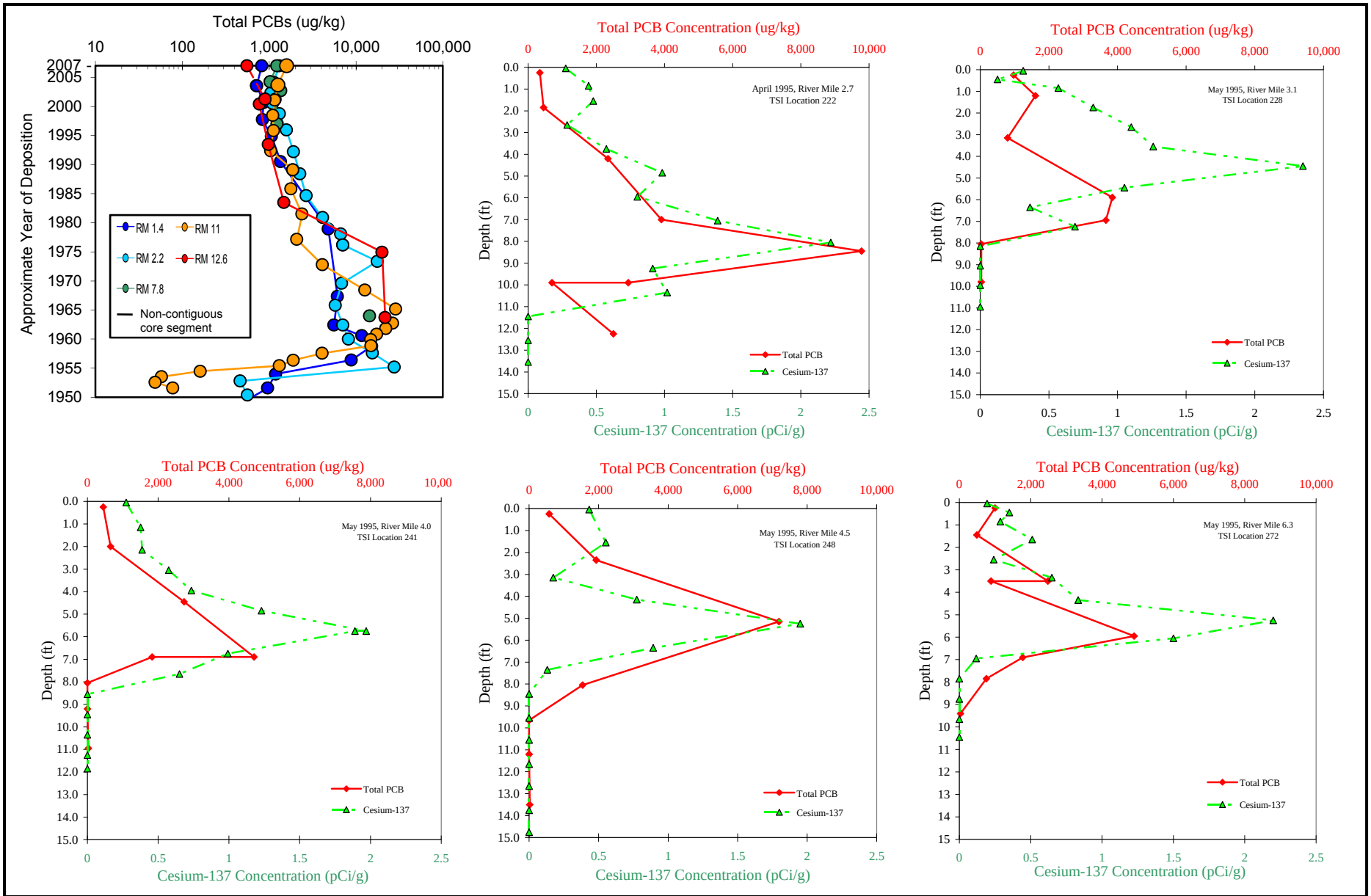
Dated Sediment Core Profile for BZ180+193:
2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3-7e

2014

R2-0026744



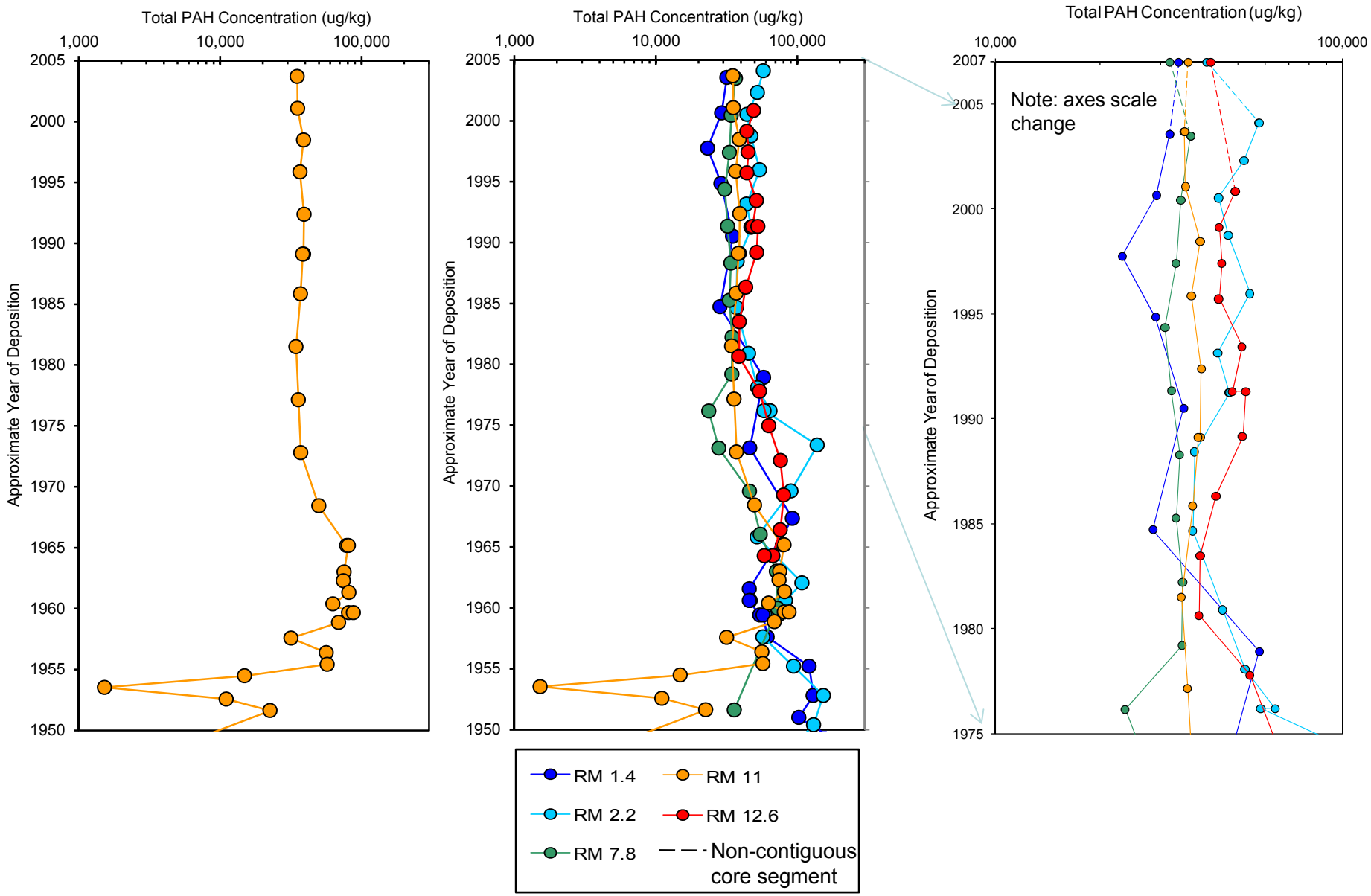
Comparison of EPA 2005 and TSI 1995 Downcore Profiles: Total PCBs

Lower Eight Miles of the Lower Passaic River

Figure 3-8

2014

R2-0026745



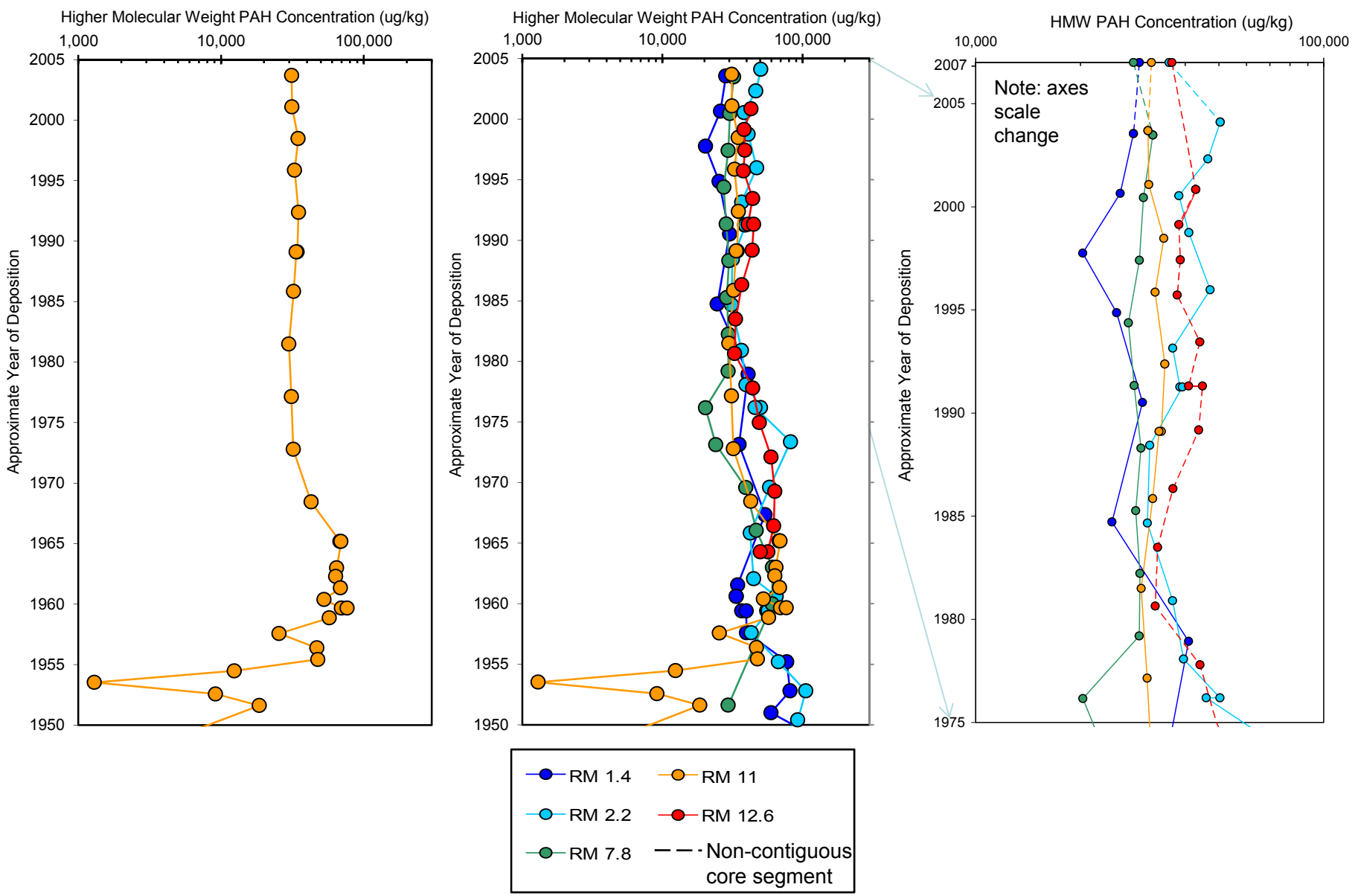
Dated Sediment Core Profile for Total PAHs:
2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3-9a

2014

R2-0026746



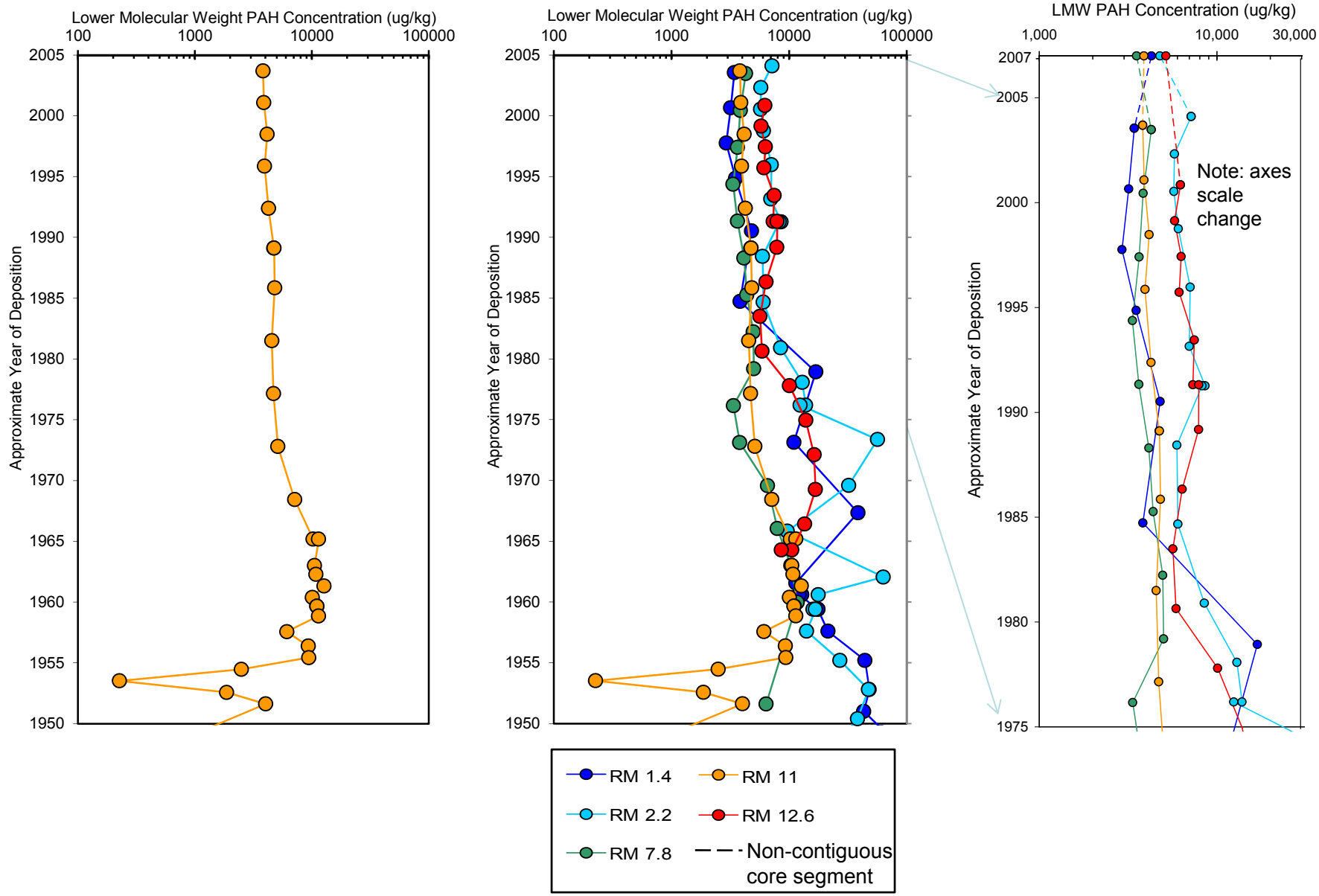
Dated Sediment Core Profile for High Molecular Weight PAHs: 2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3-9b

2014

R2-0026747



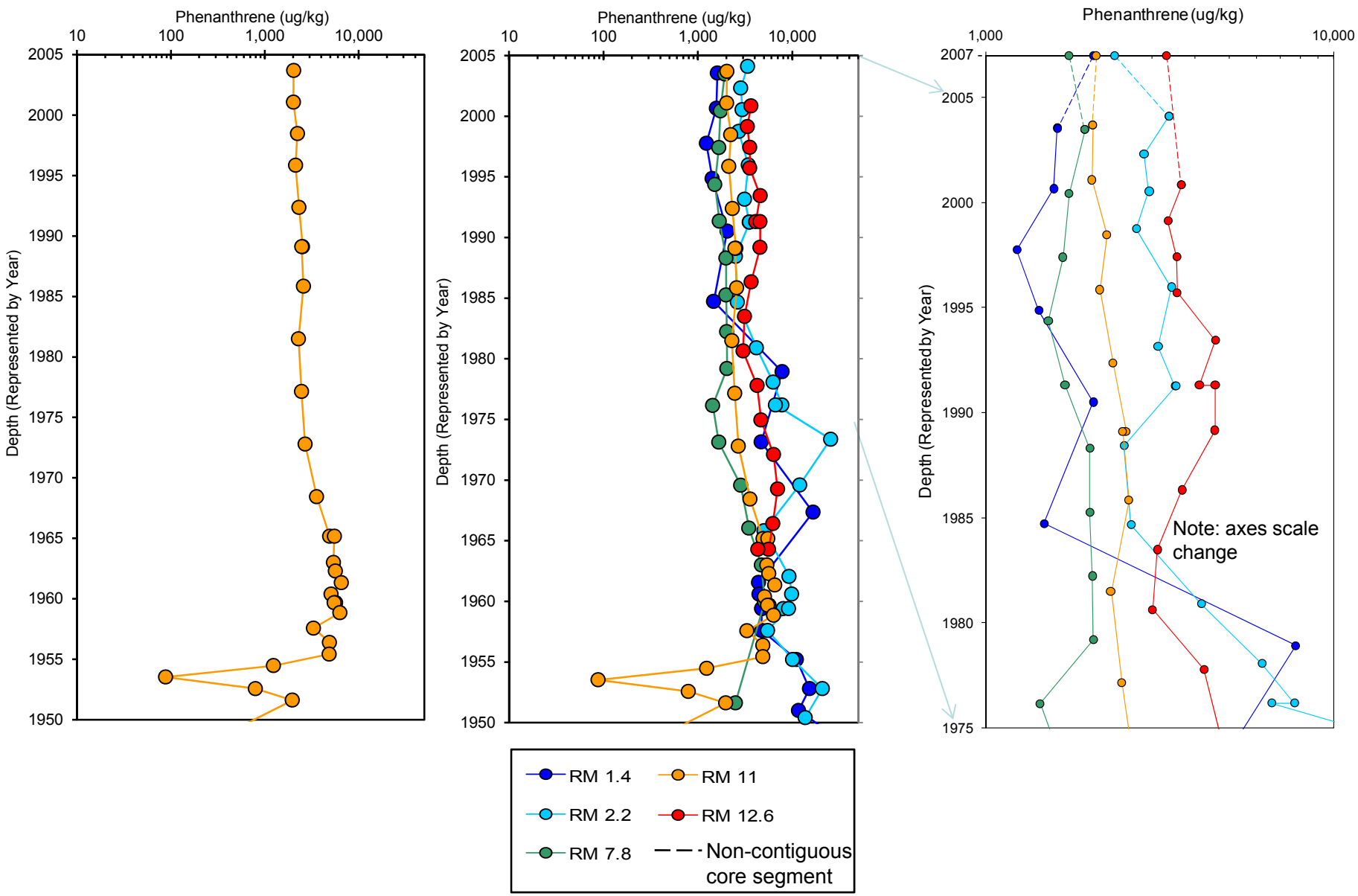
Dated Sediment Core Profile for Low Molecular Weight PAHs: 2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3-9c

2014

R2-0026748



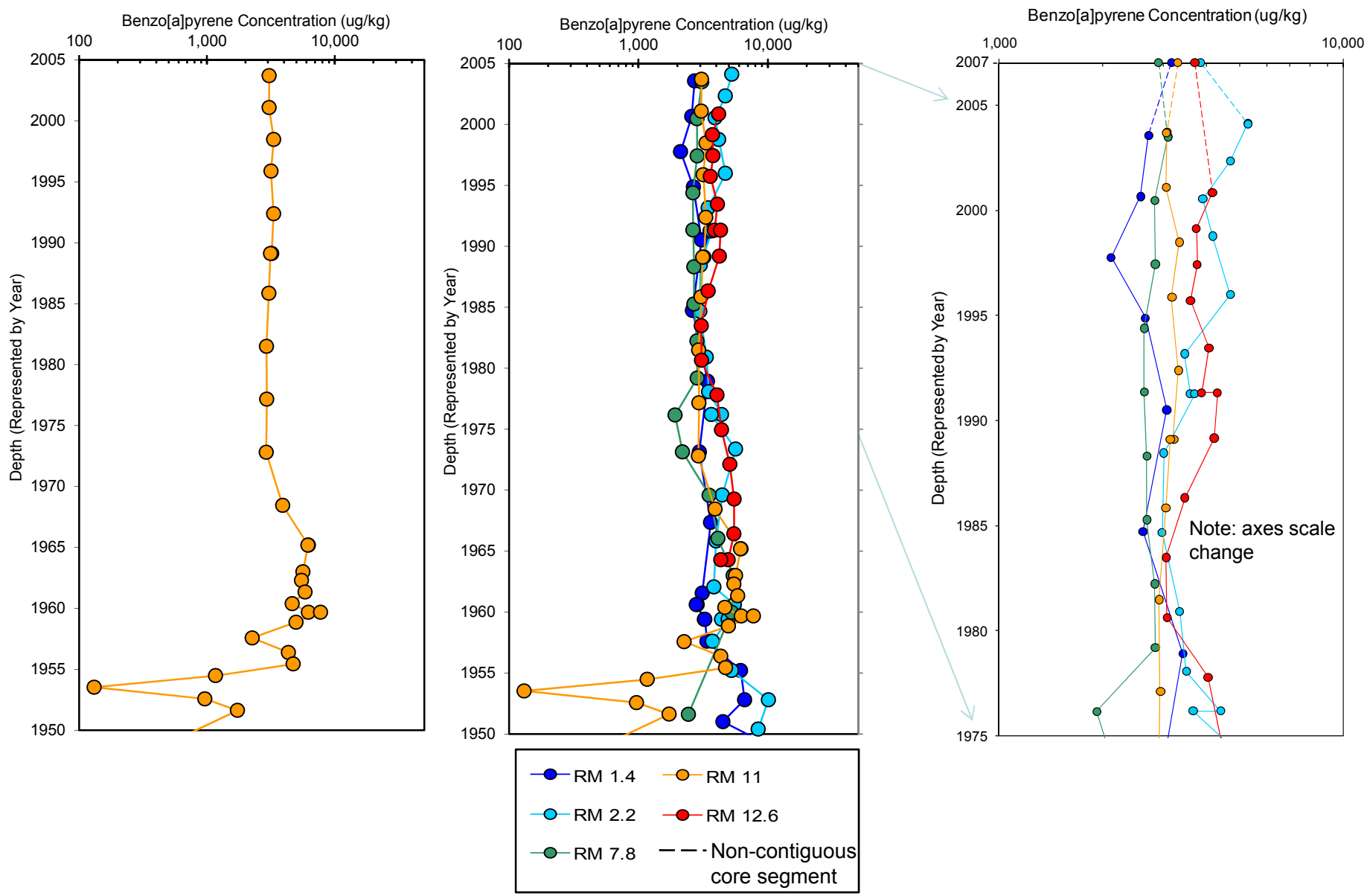
Dated Sediment Core Profile for Phenanthrene:
2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3-9d

2014

R2-0026749



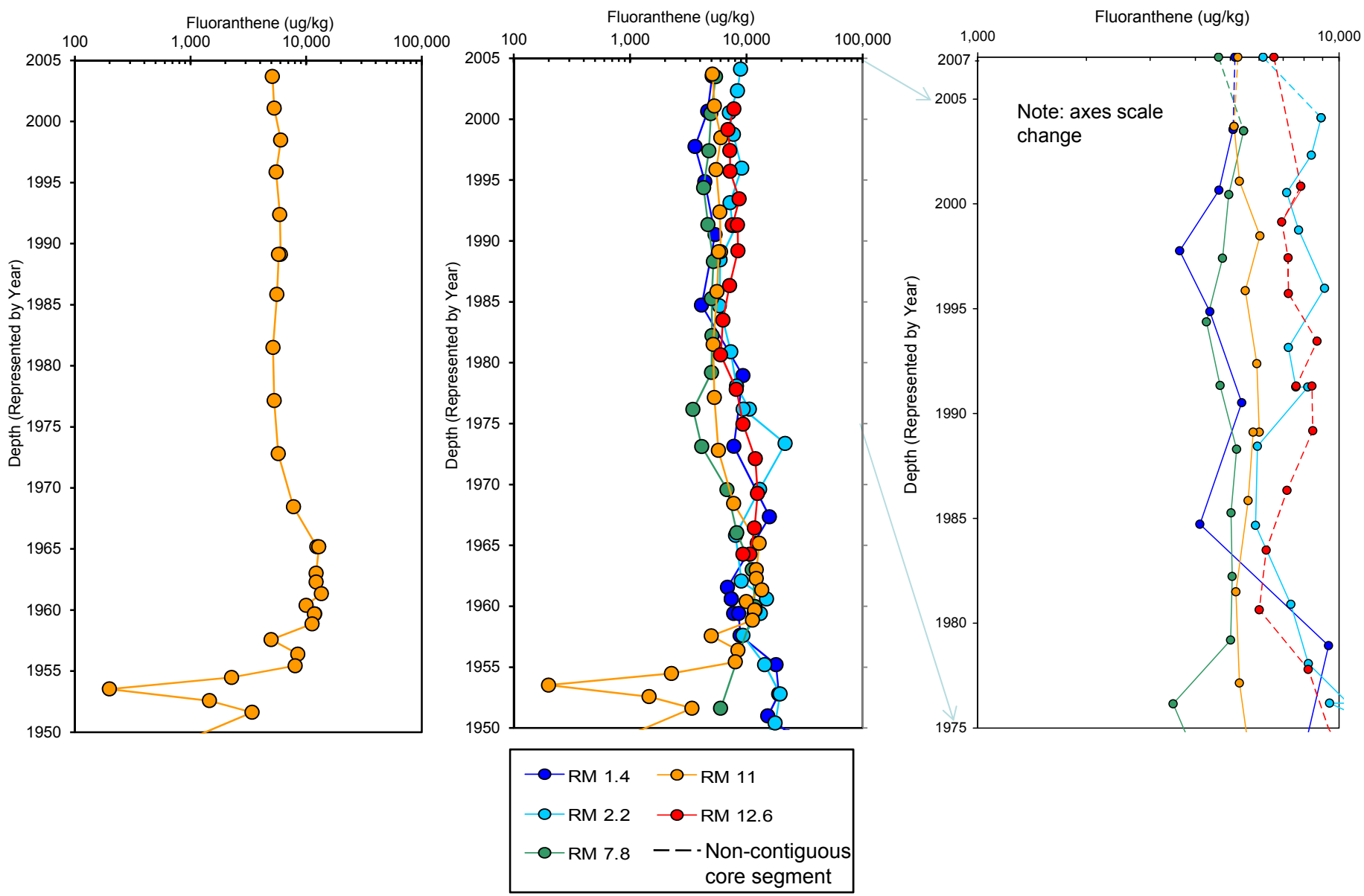
Dated Sediment Core Profile for Benzo[a]pyrene:
2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3-9e

2014

R2-0026750



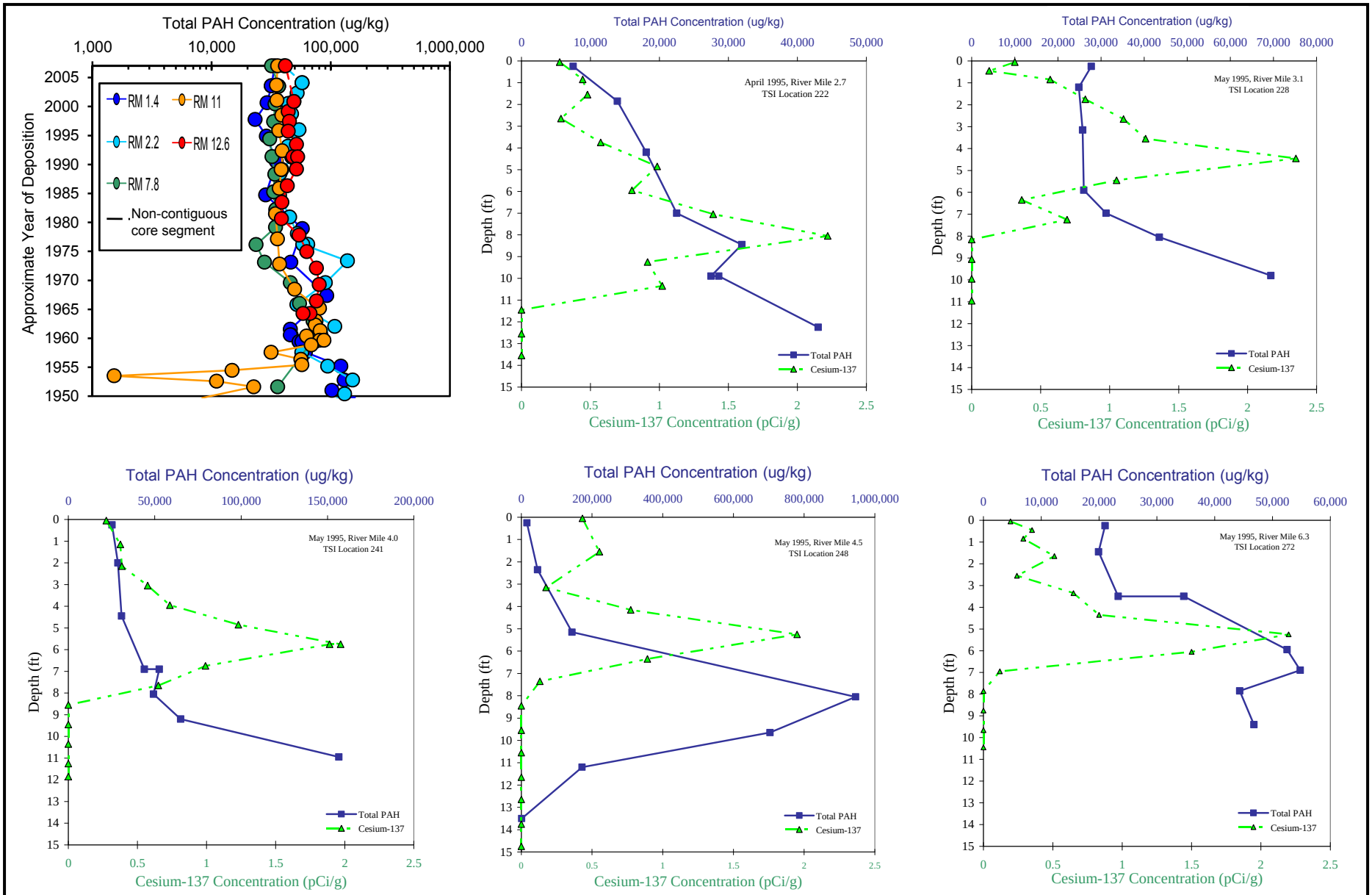
Dated Sediment Core Profile for Fluoranthene:
2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3-9f

2014

R2-0026751



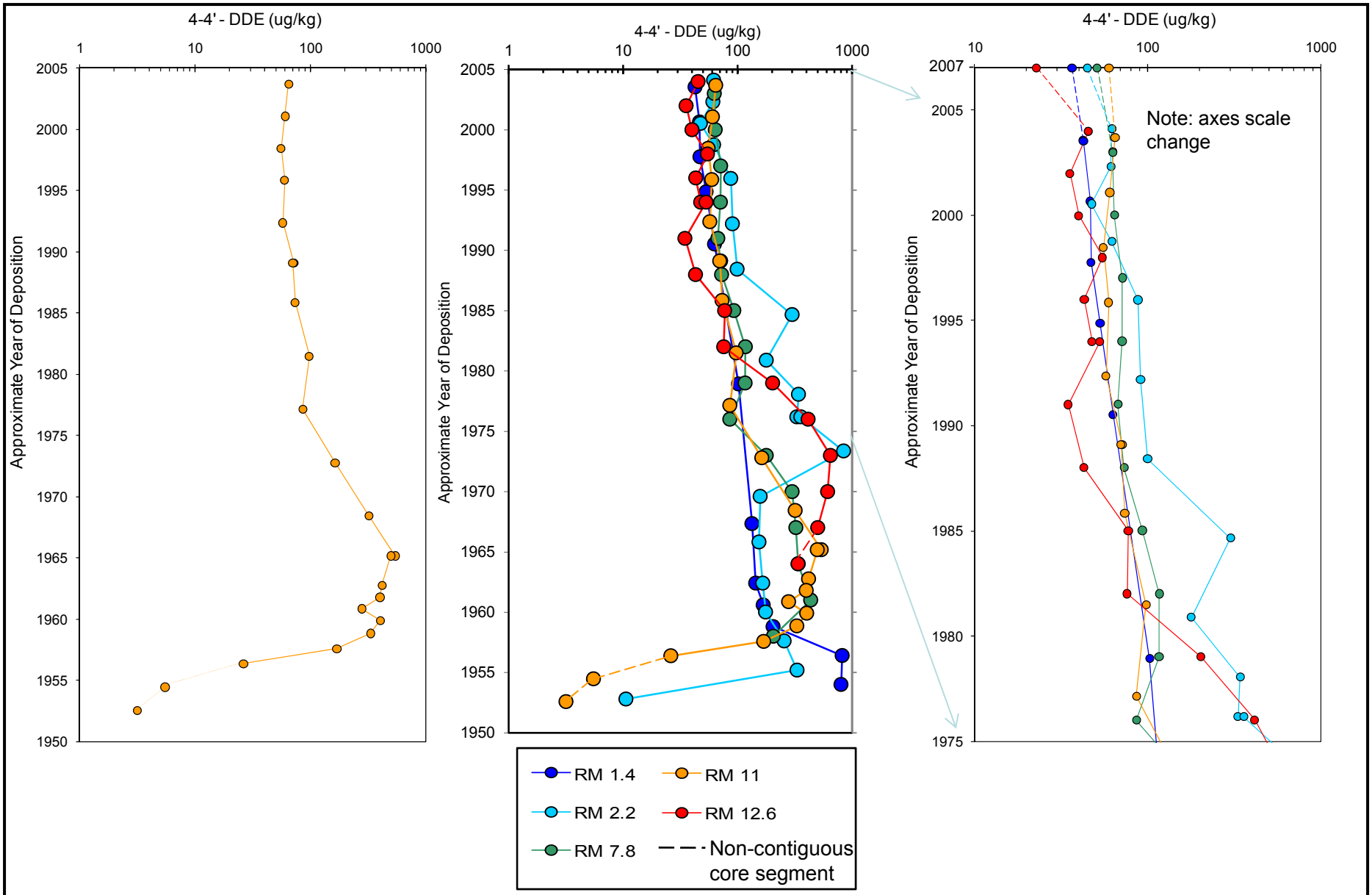
Comparison of EPA 2005 and TSI 1995 Downcore Profiles: Total PAHs

Lower Eight Miles of the Lower Passaic River

Figure 3-10

2014

R2-0026752



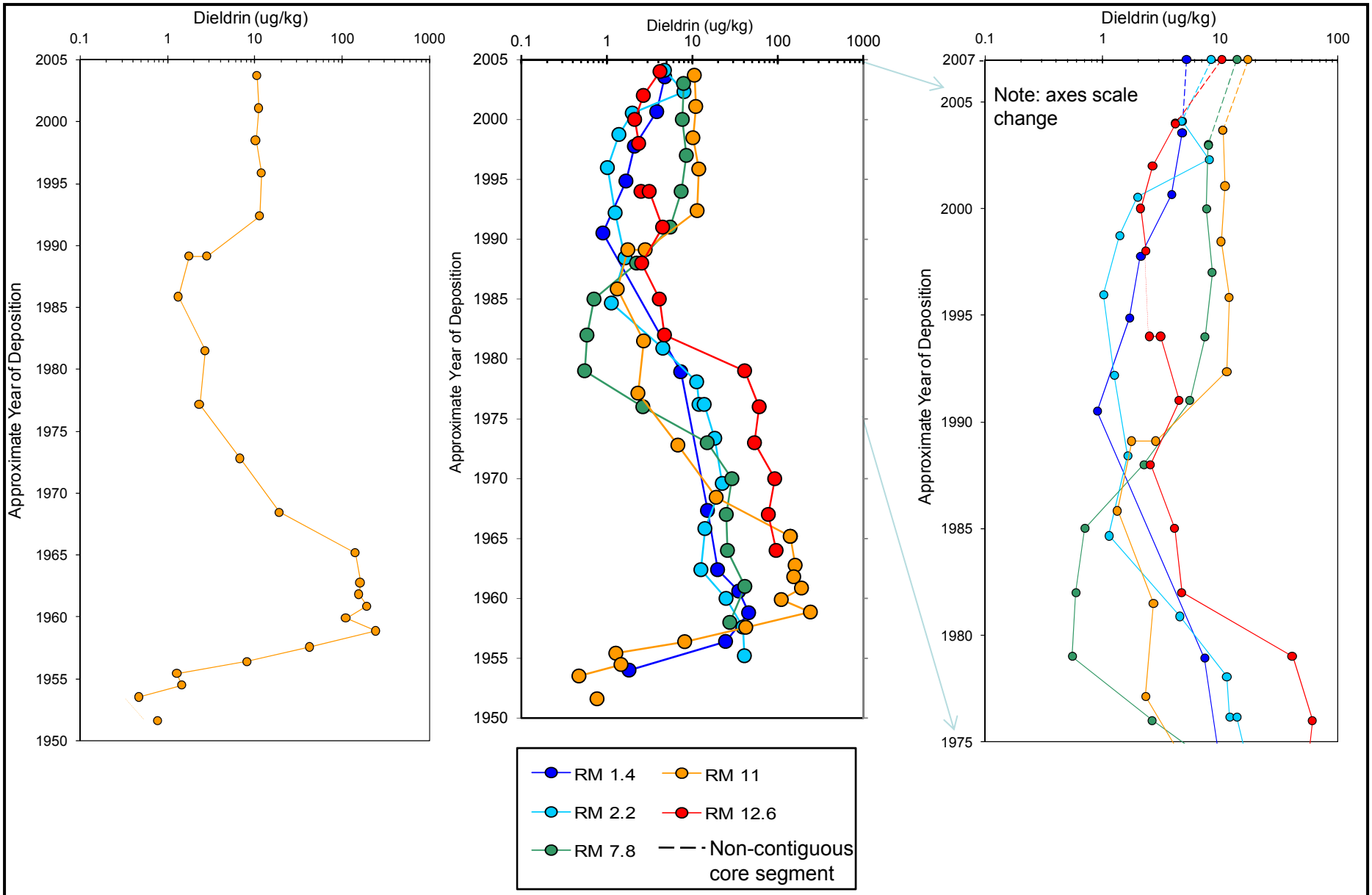
Dated Sediment Core Profile for 4,4'-DDE:
2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3-11a

2014

R2-0026753

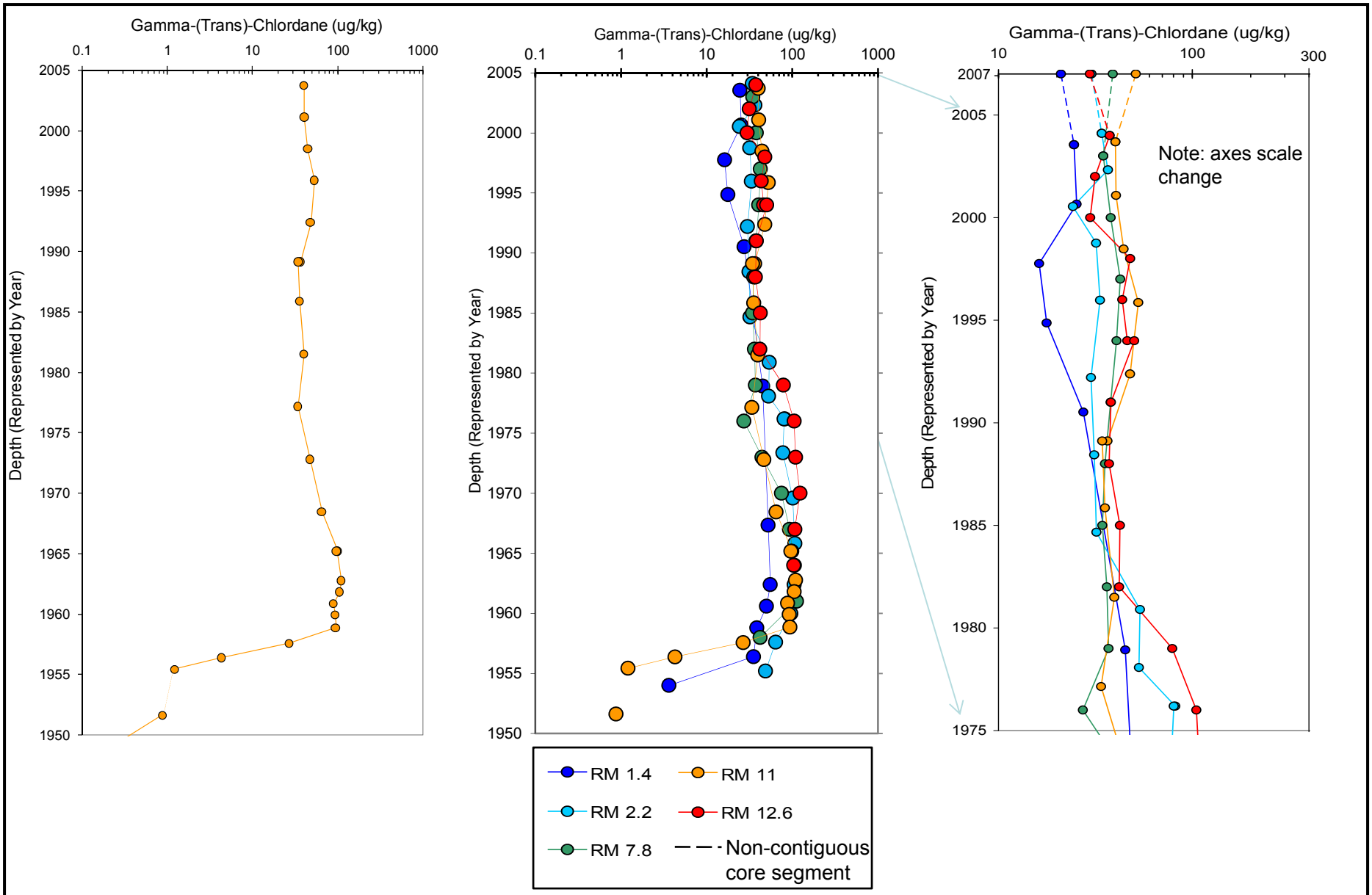


Dated Sediment Core Profile for Dieldrin:
2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3-11b

2014



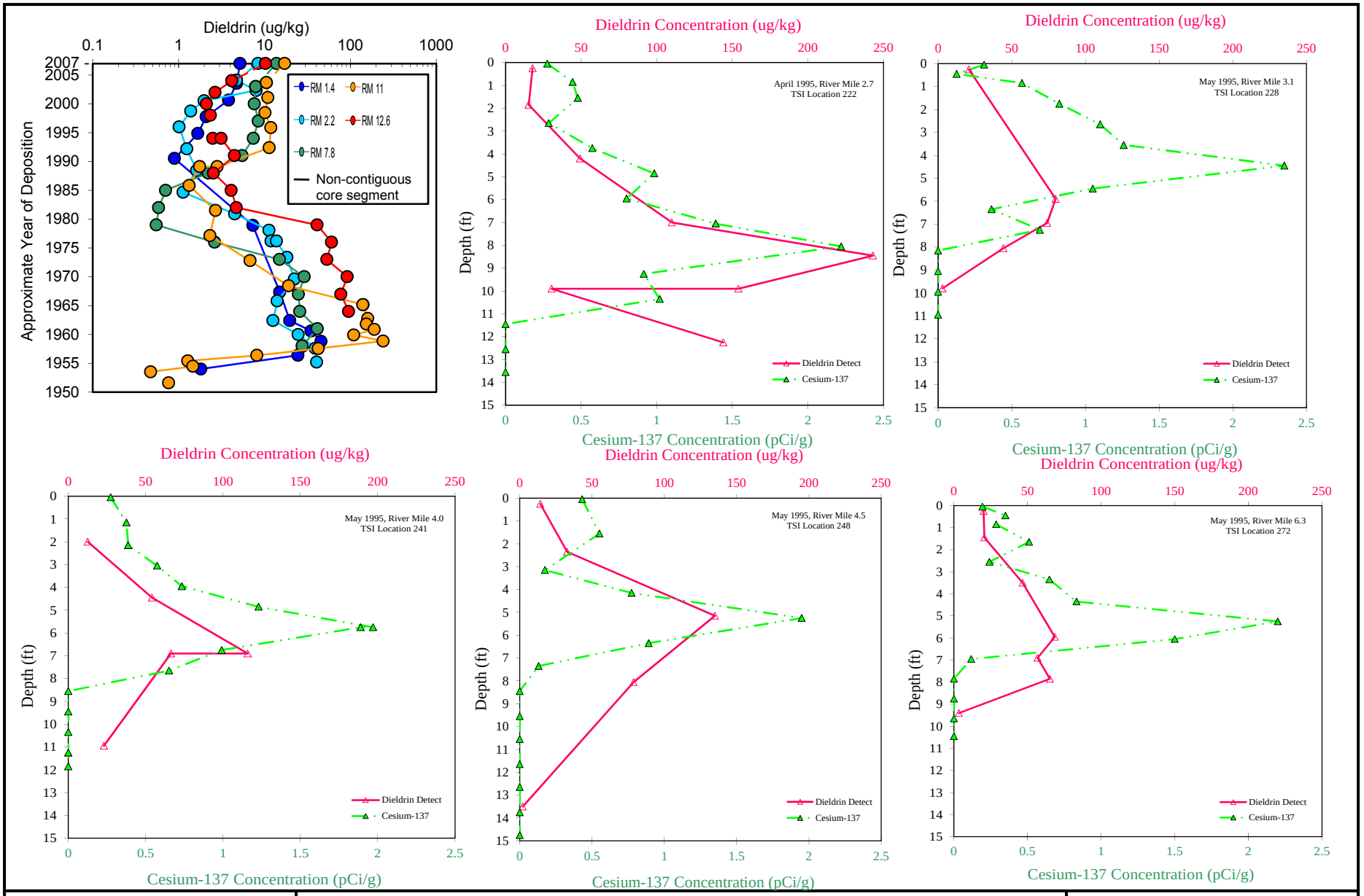
Dated Sediment Core Profile for Chlordane (gamma, trans): 2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3-11c

2014

R2-0026755



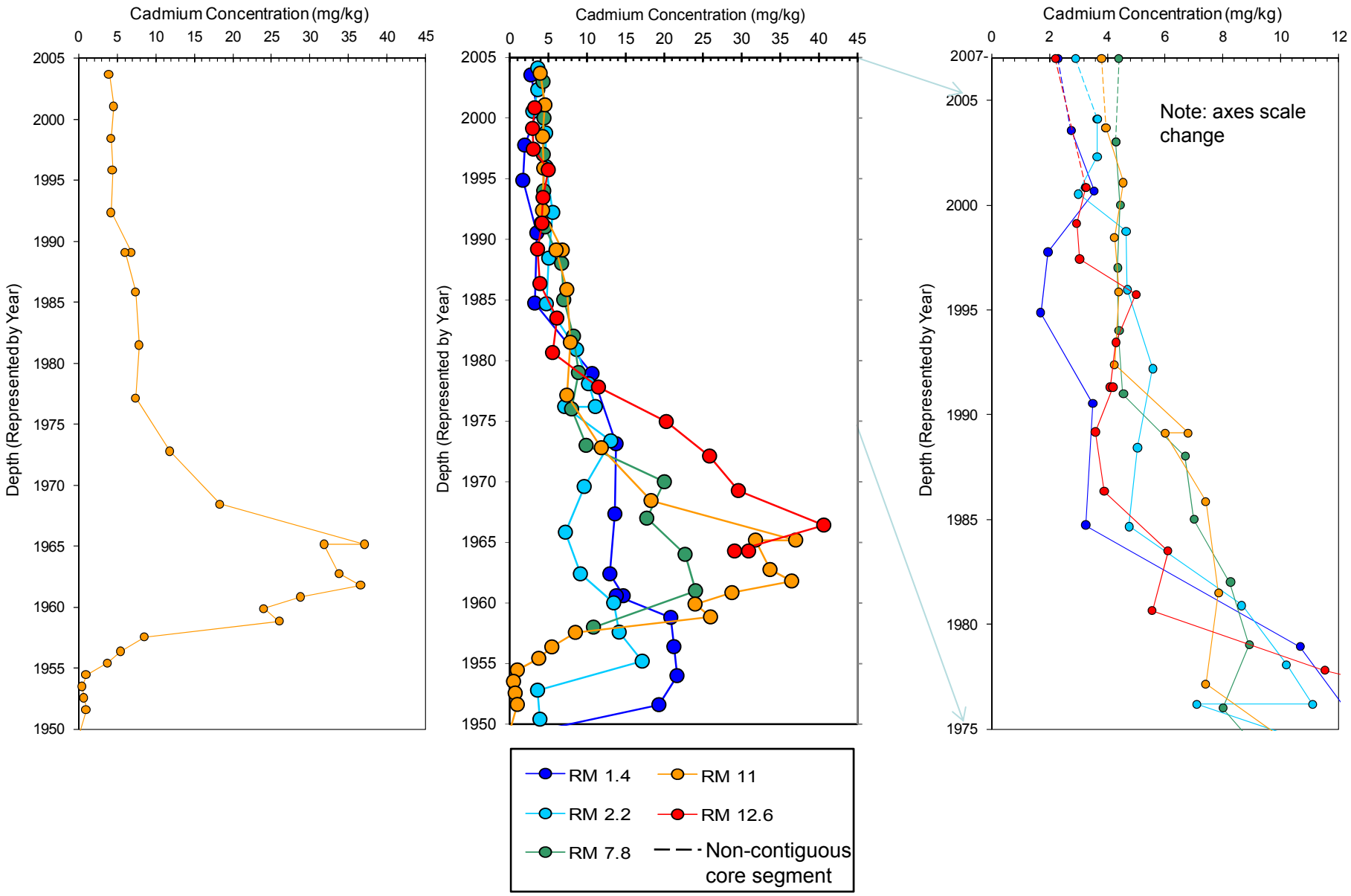
Comparison of EPA 2005 and TSI 1995 Downcore Profiles: Dieldrin

Lower Eight Miles of the Lower Passaic River

Figure 3-12

2014

R2-0026756



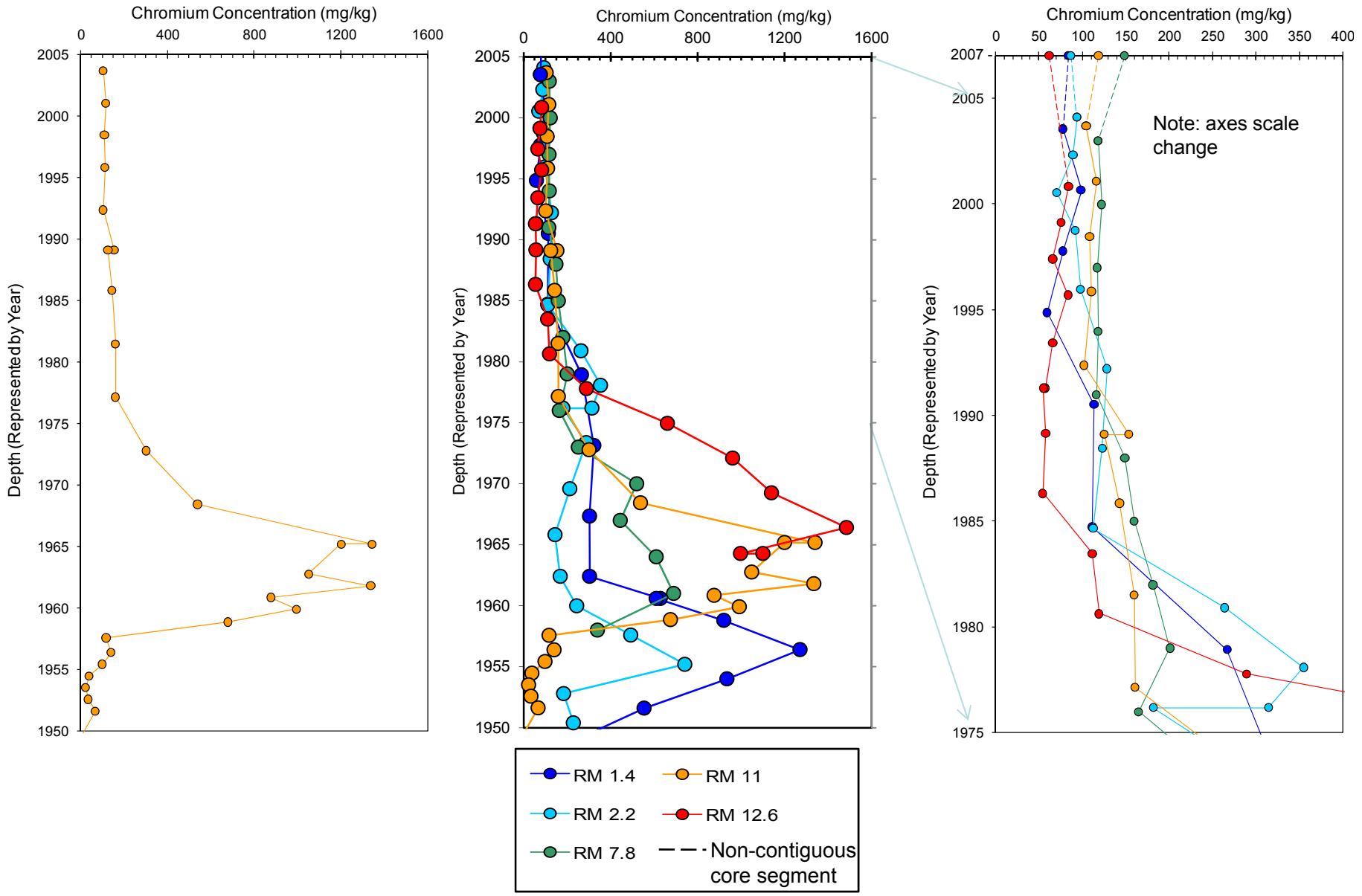
Dated Sediment Core Profile for Cadmium:
2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3-13a

2014

R2-0026757



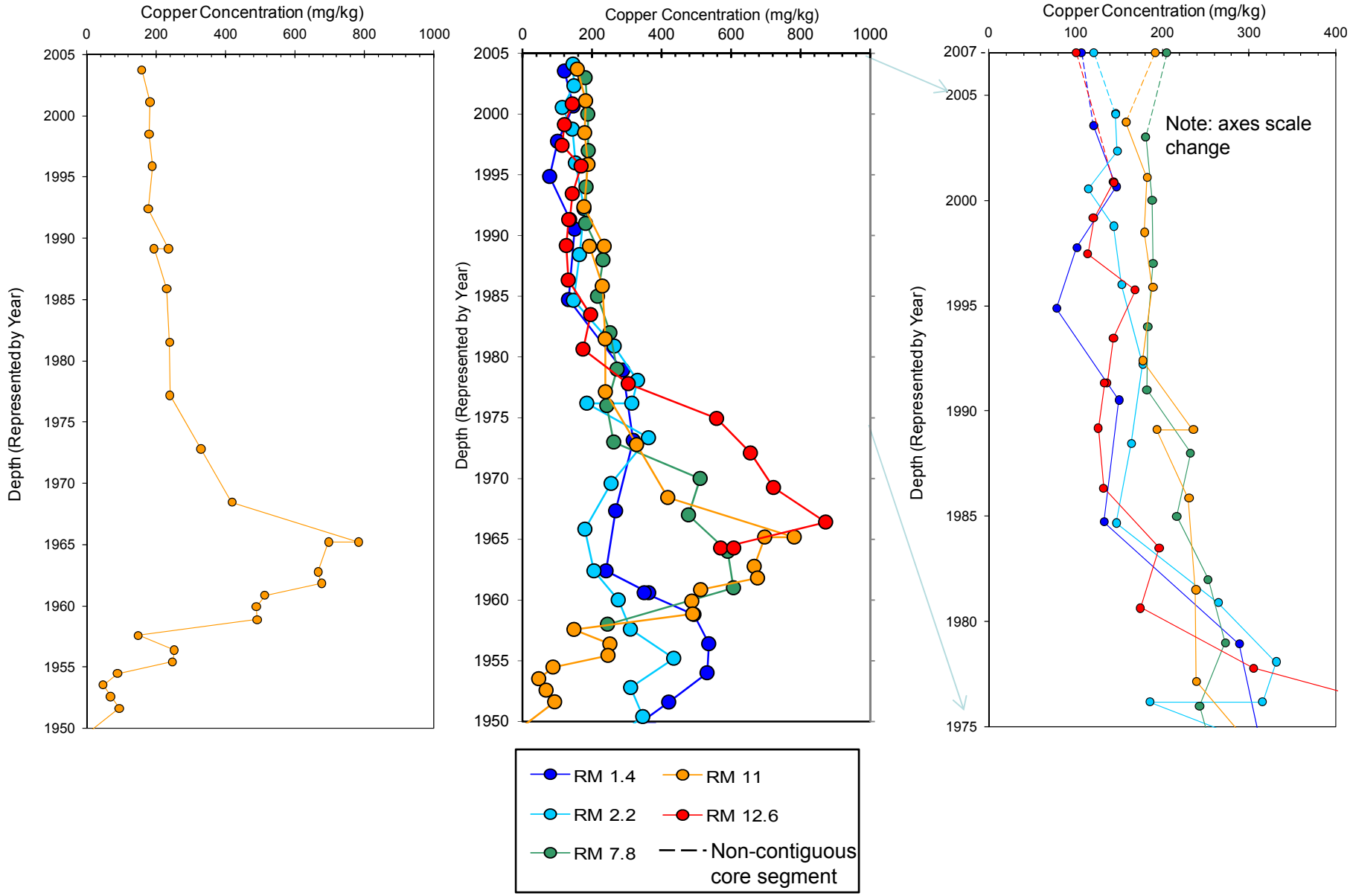
Dated Sediment Core Profile for Chromium:
2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3-13b

2014

R2-0026758



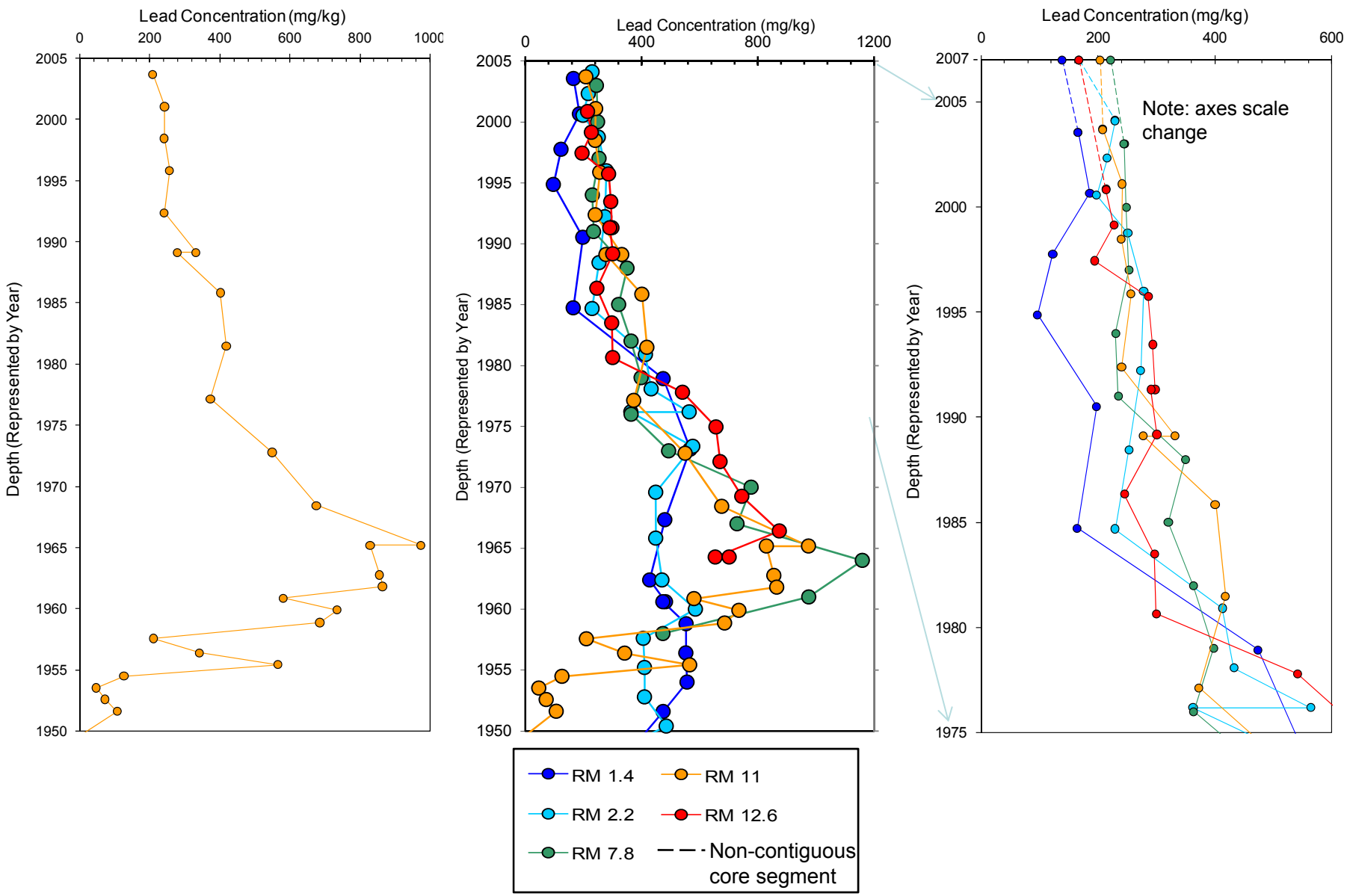
Dated Sediment Core Profile for Copper:
2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3-13c

2014

R2-0026759



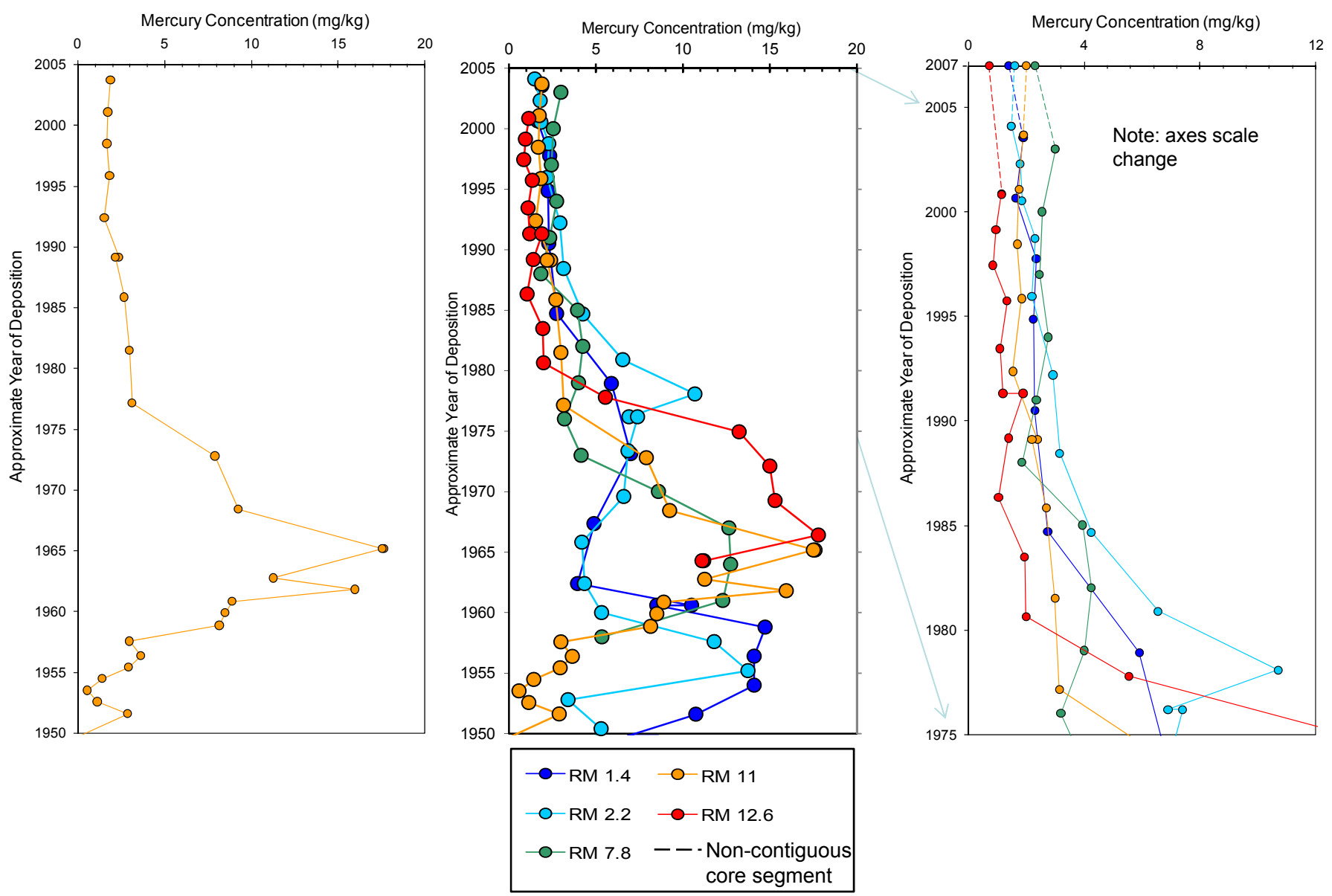
Dated Sediment Core Profile for Lead:
2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3-13d

2014

R2-0026760



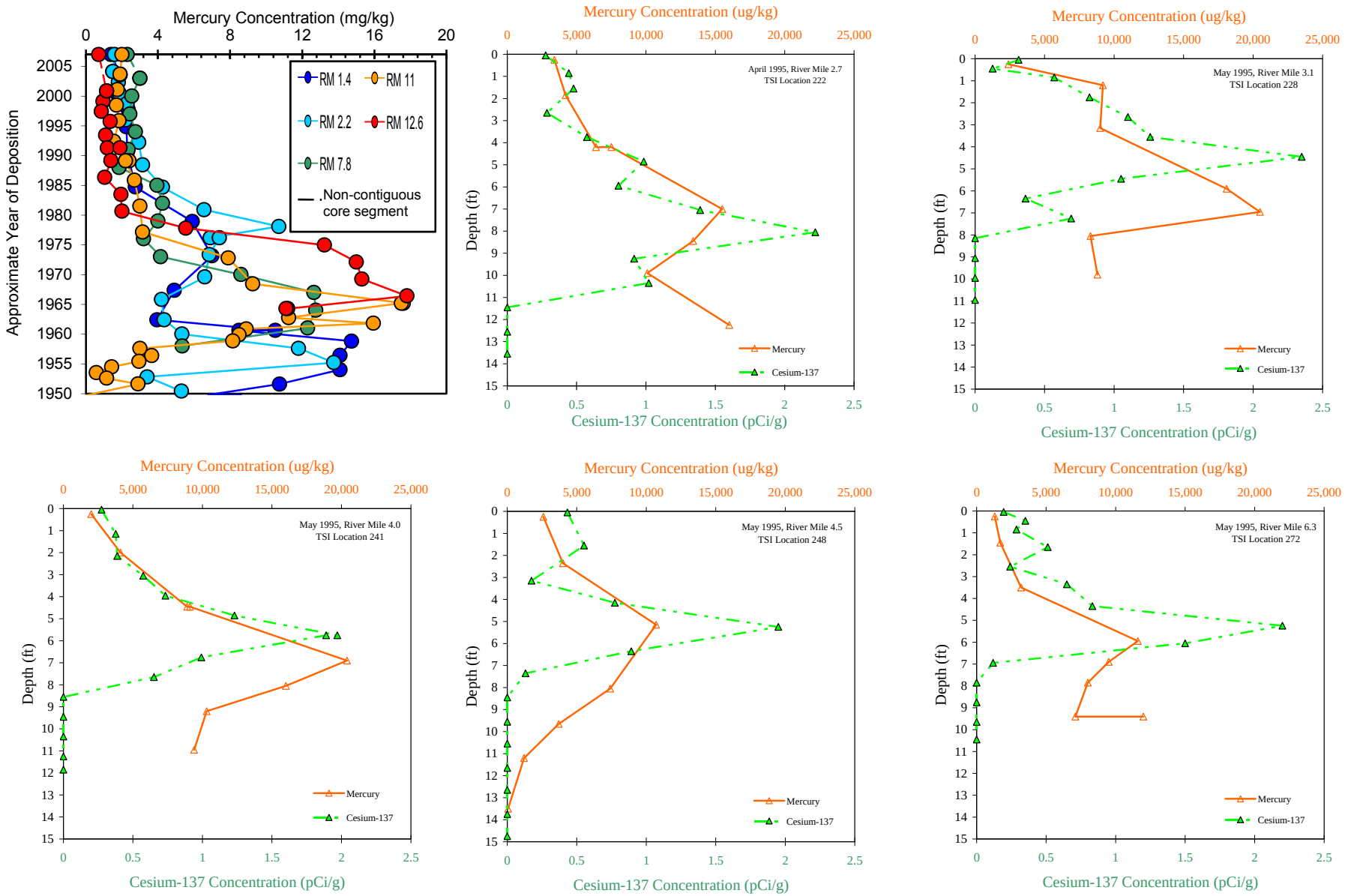
Dated Sediment Core Profile for Mercury:
2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3-13e

2014

R2-0026761



Comparison of EPA 2005 and TSI 1995 Downcore Profiles: Mercury

Lower Eight Miles of the Lower Passaic River

Figure 3-14

2014

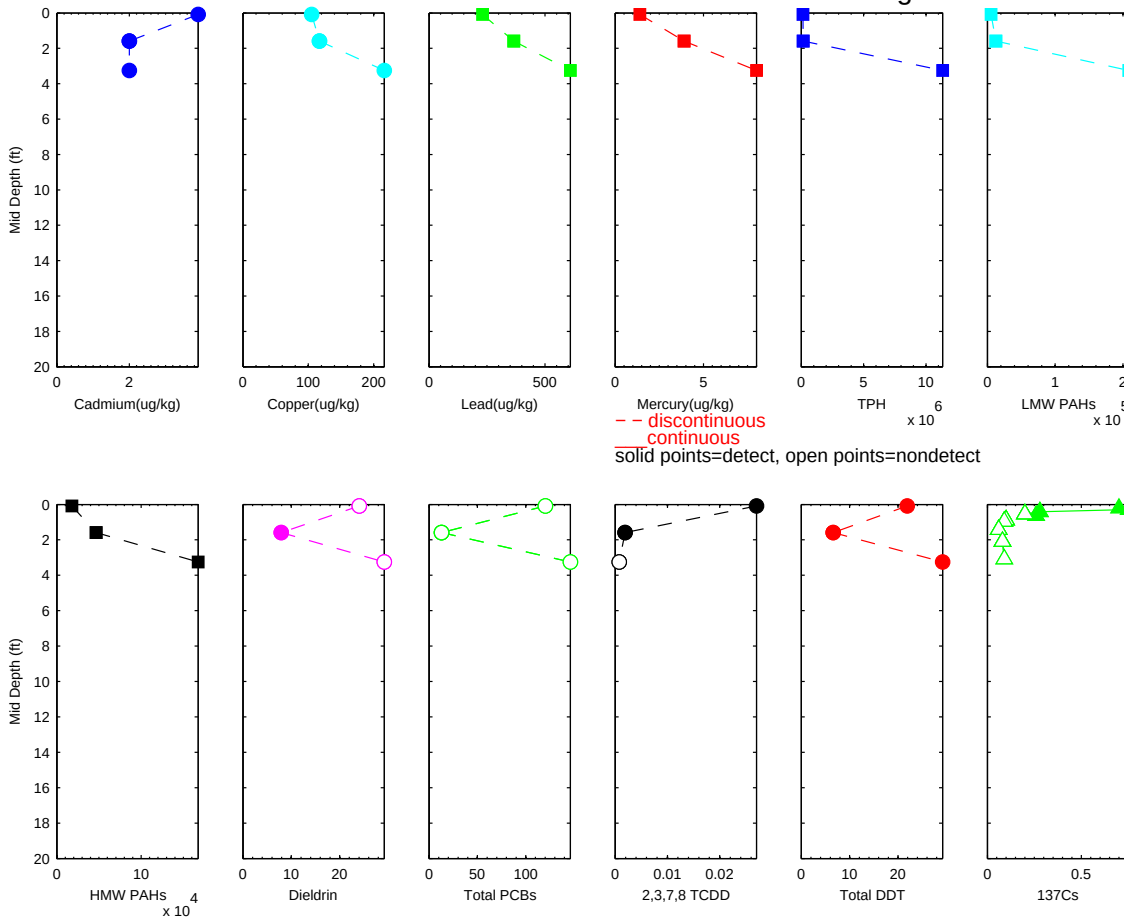
R2-0026762

ATTACHMENTS

Attachment A

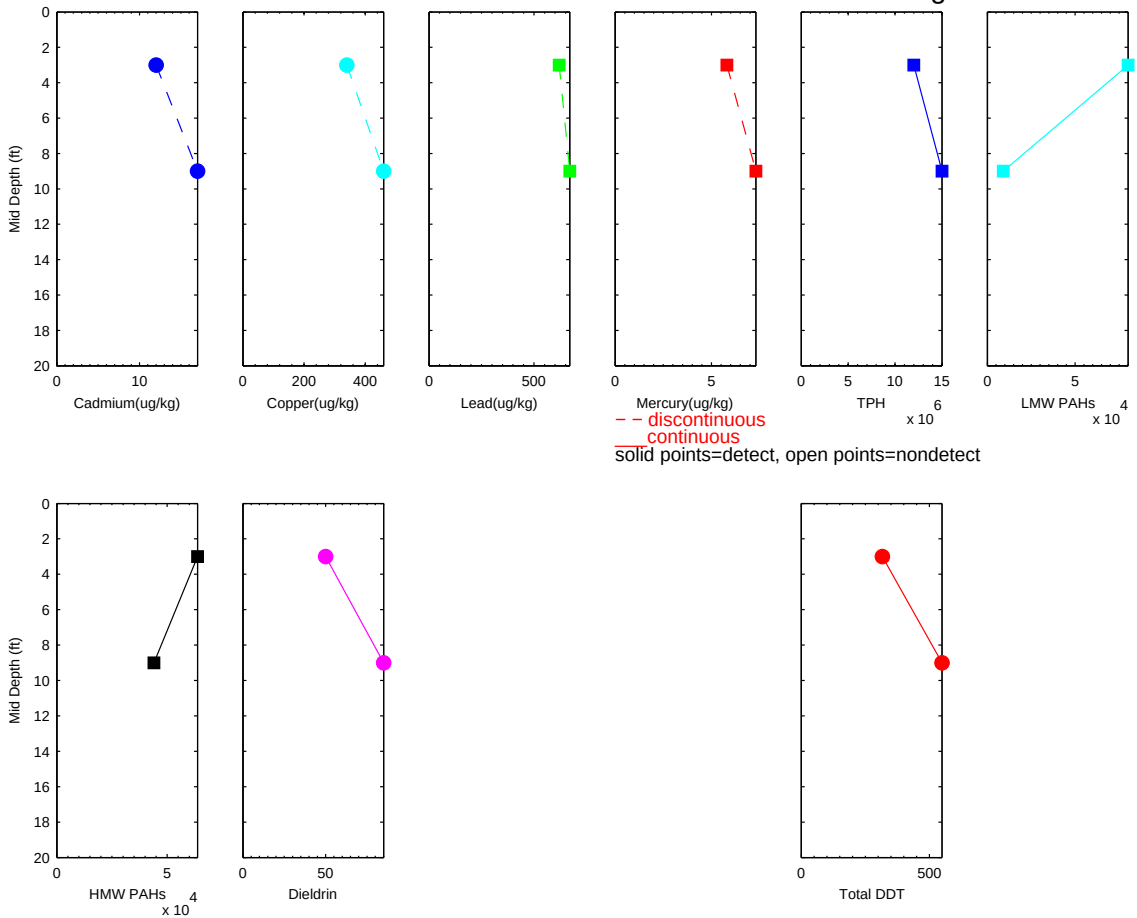
Downcore Profiles of Historical Cores (1991 to 1995)

Sample ID: 01A River Mile 17.43 PASSAIC 1991 Core Sediment Investigation



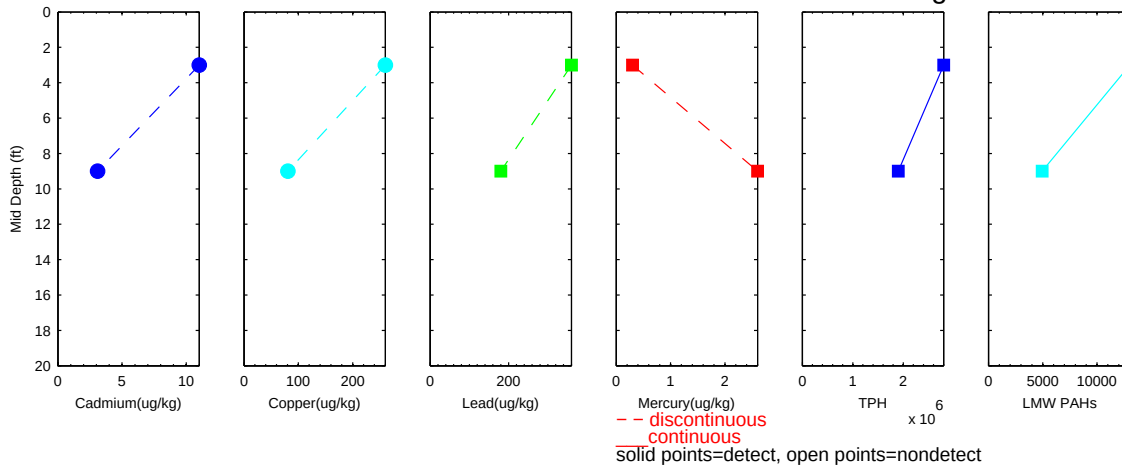
R2-0026765

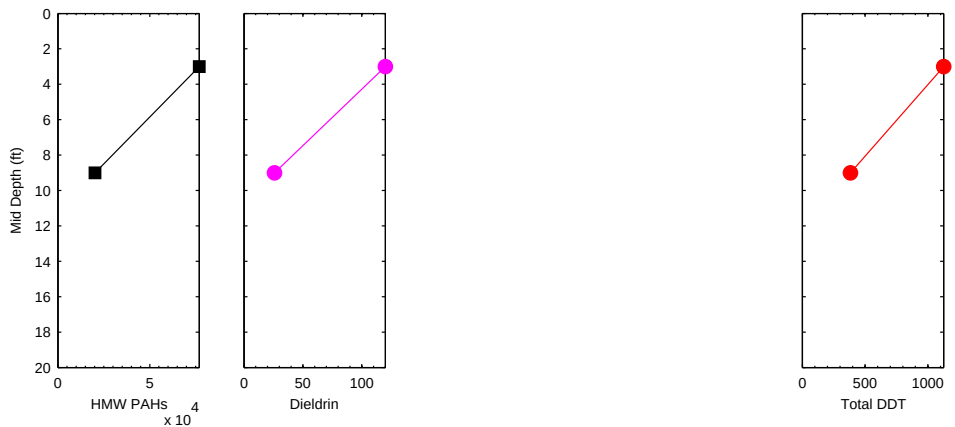
Sample ID: WTH−6 River Mile 4.98 PASSAIC 1995 USACE Minish Park Investigation



R2-0026766

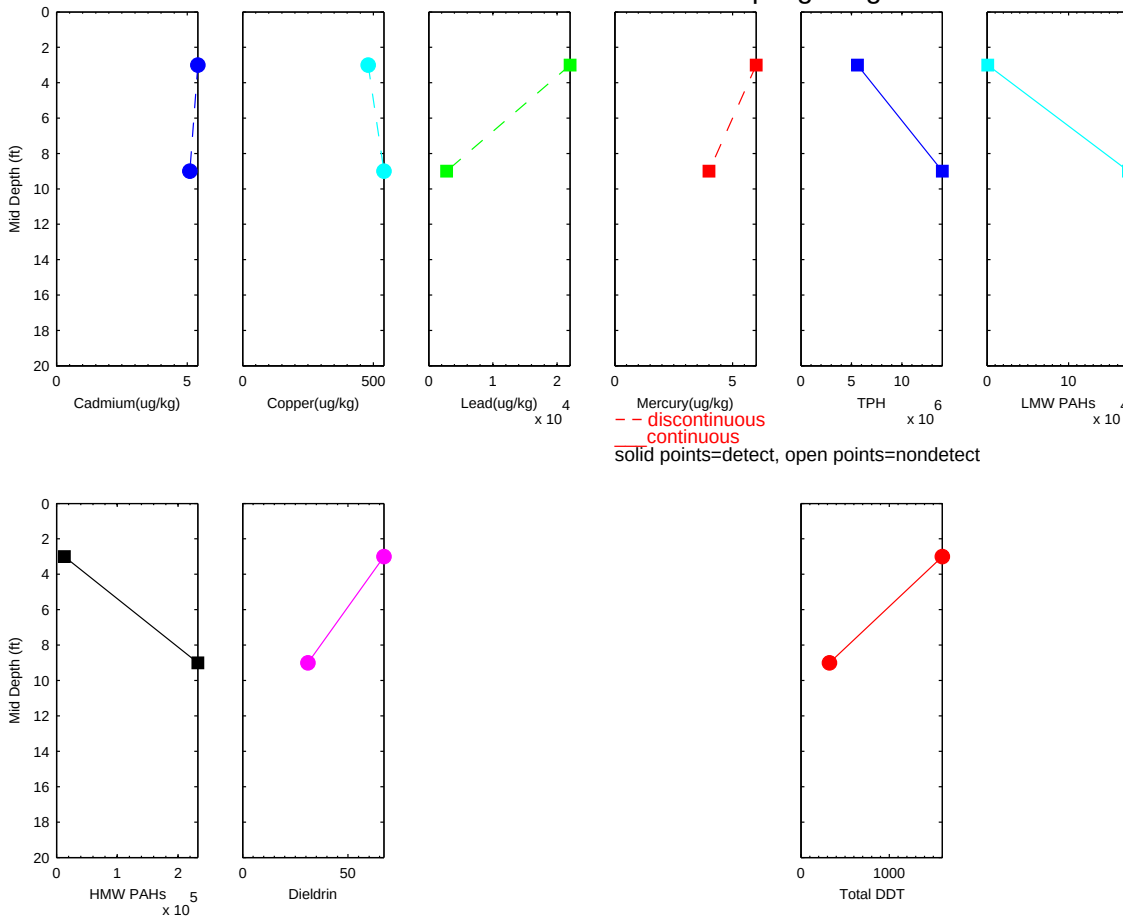
Sample ID: WTH−5 River Mile 4.74 PASSAIC 1995 USACE Minish Park Investigation





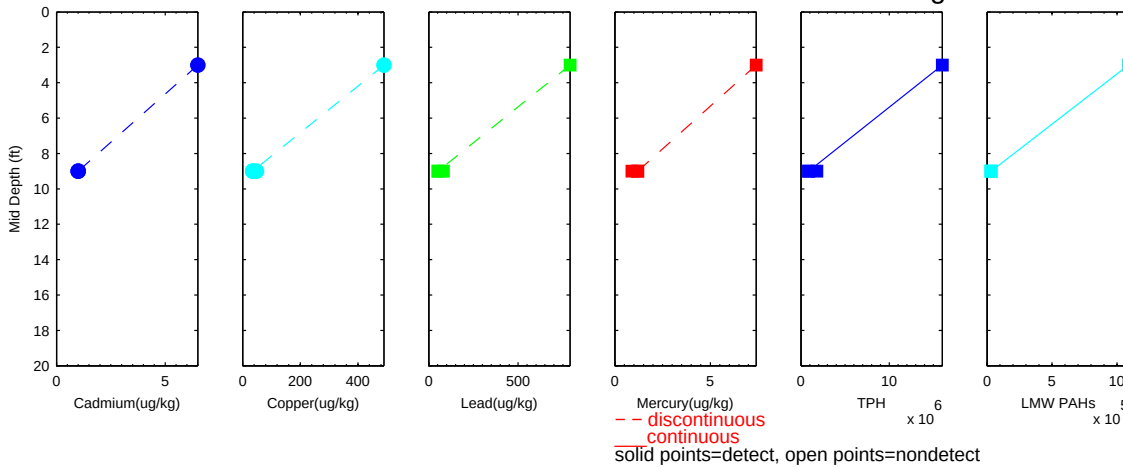
R2-0026767

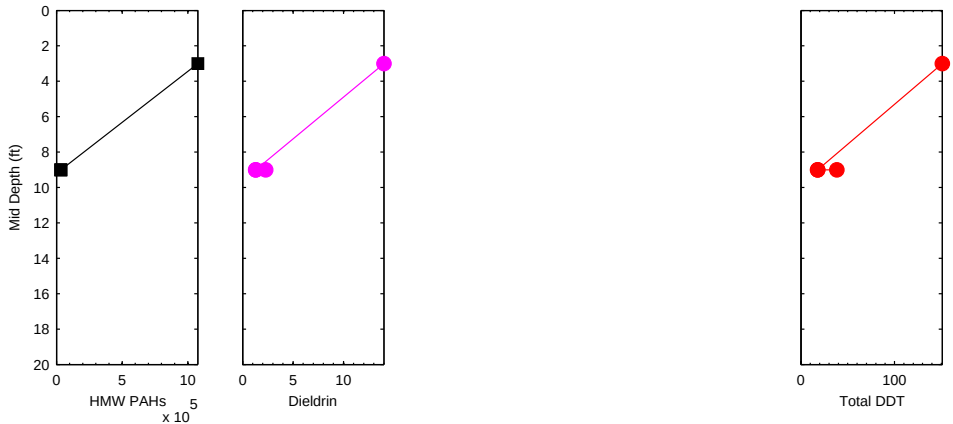
Sample ID: WTH−3 River Mile 4.36 PASSAIC 1995 RI Sampling Program



R2-0026768

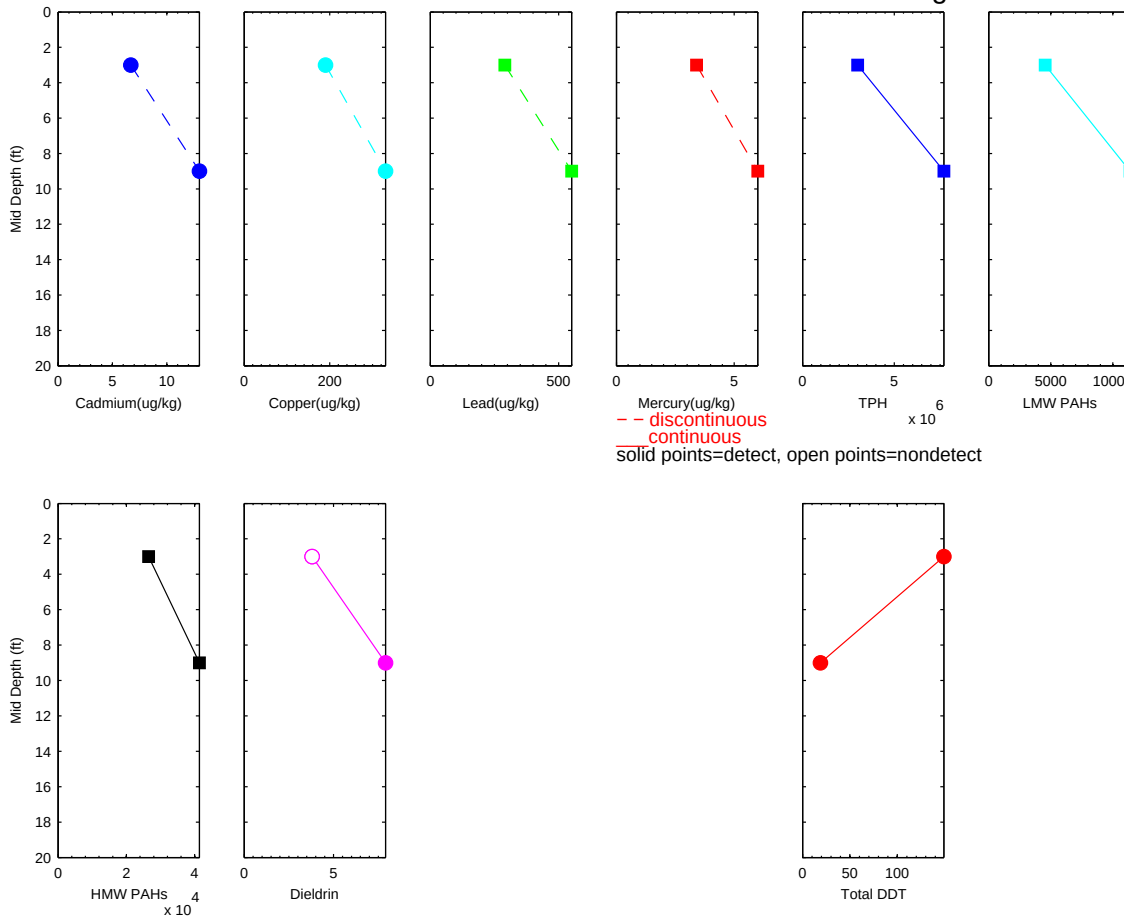
Sample ID: WTH−2 River Mile 4.04 PASSAIC 1995 USACE Minish Park Investigation





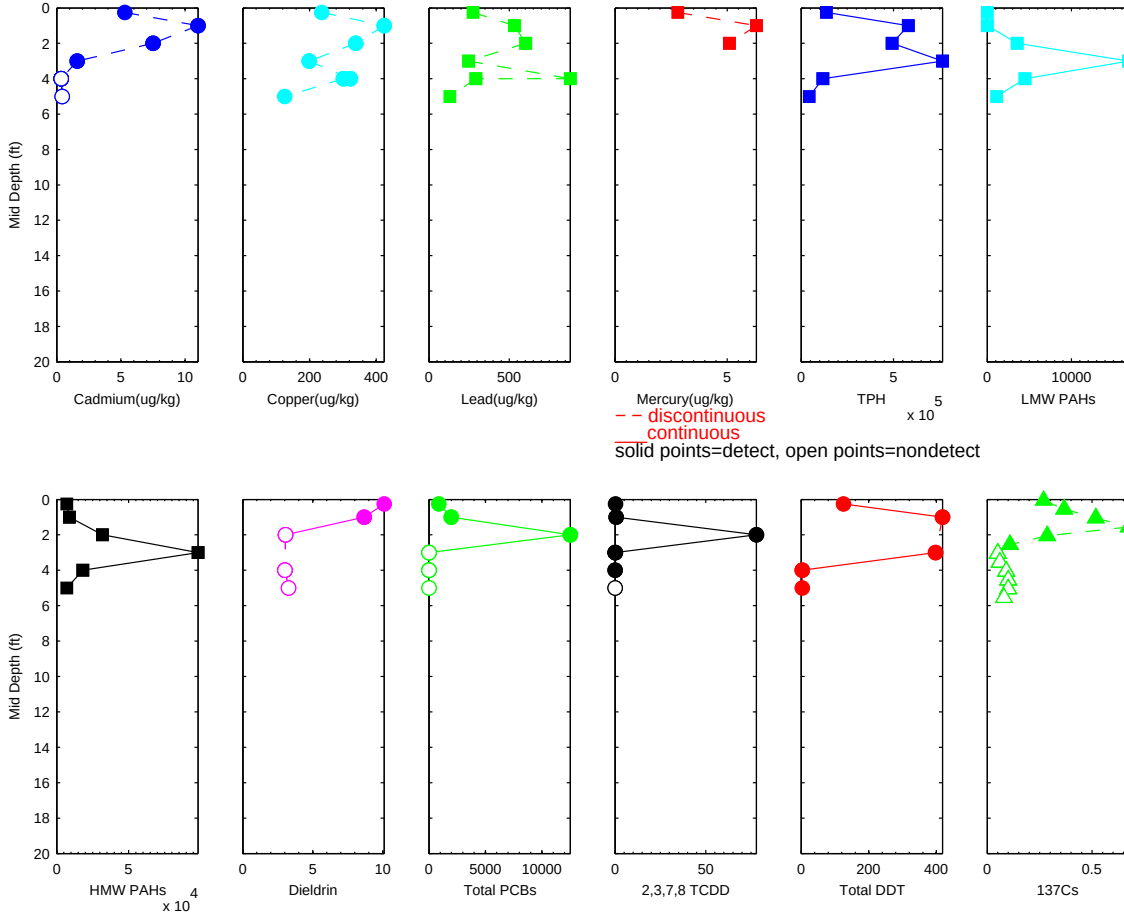
R2-0026769

Sample ID: WTH−1 River Mile 5.39 PASSAIC 1995 USACE Minish Park Investigation



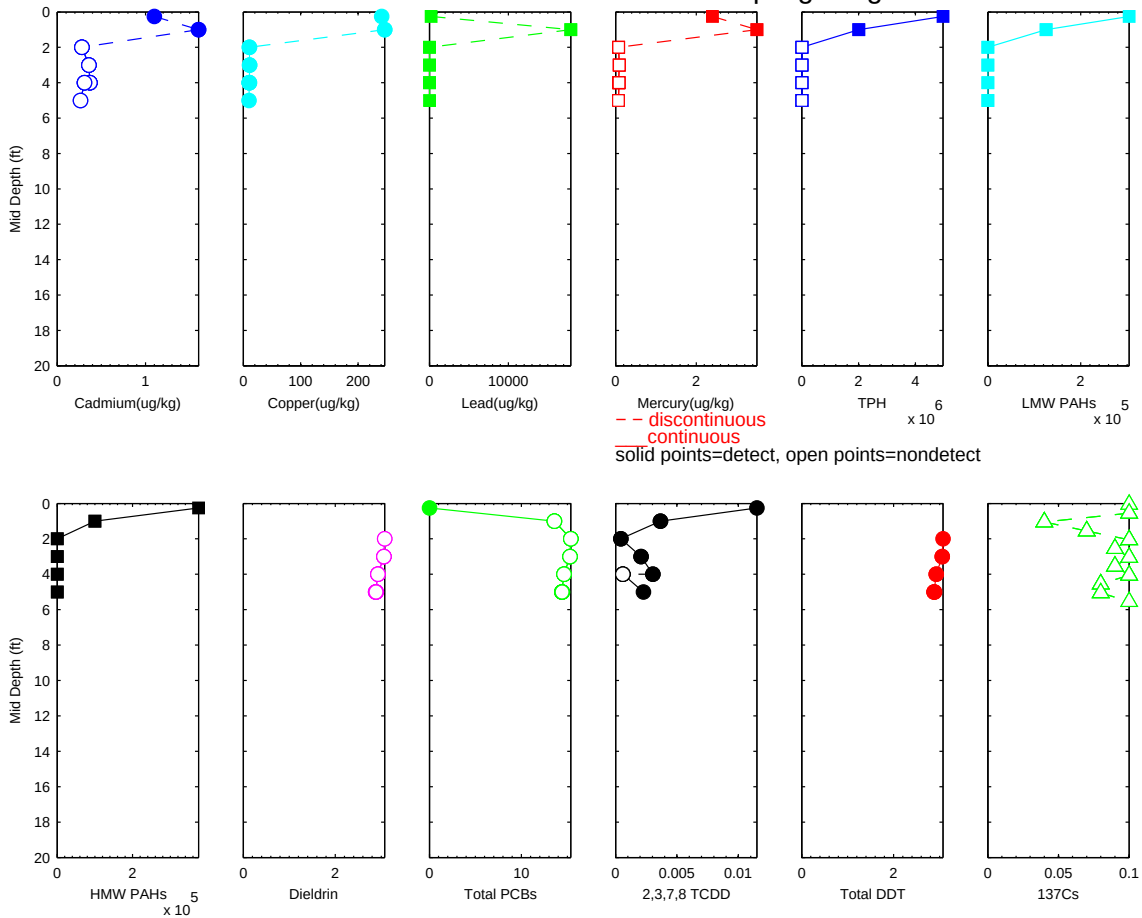
R2-0026770

Sample ID: D03 River Mile 2.65 PASSAIC 1995 RI Sampling Program



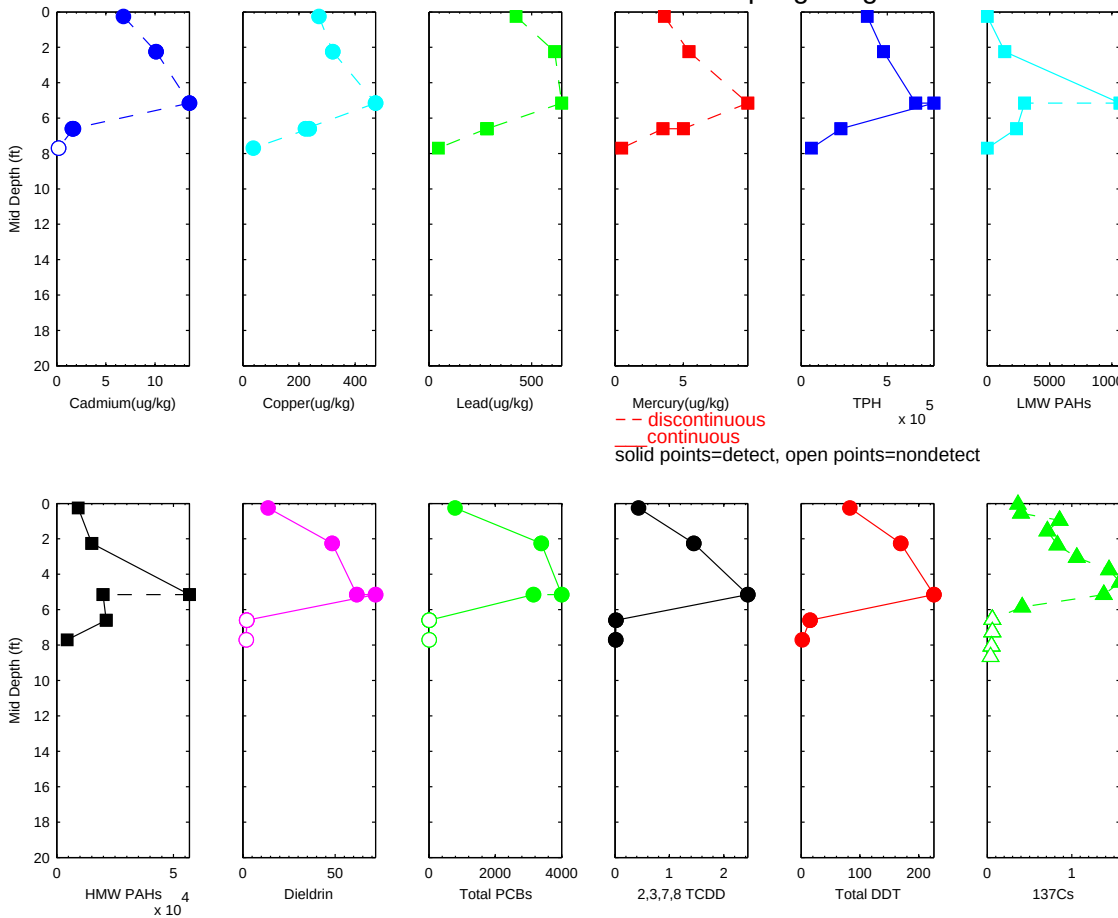
R2-0026771

Sample ID: D02 River Mile 3.64 PASSAIC 1995 RI Sampling Program



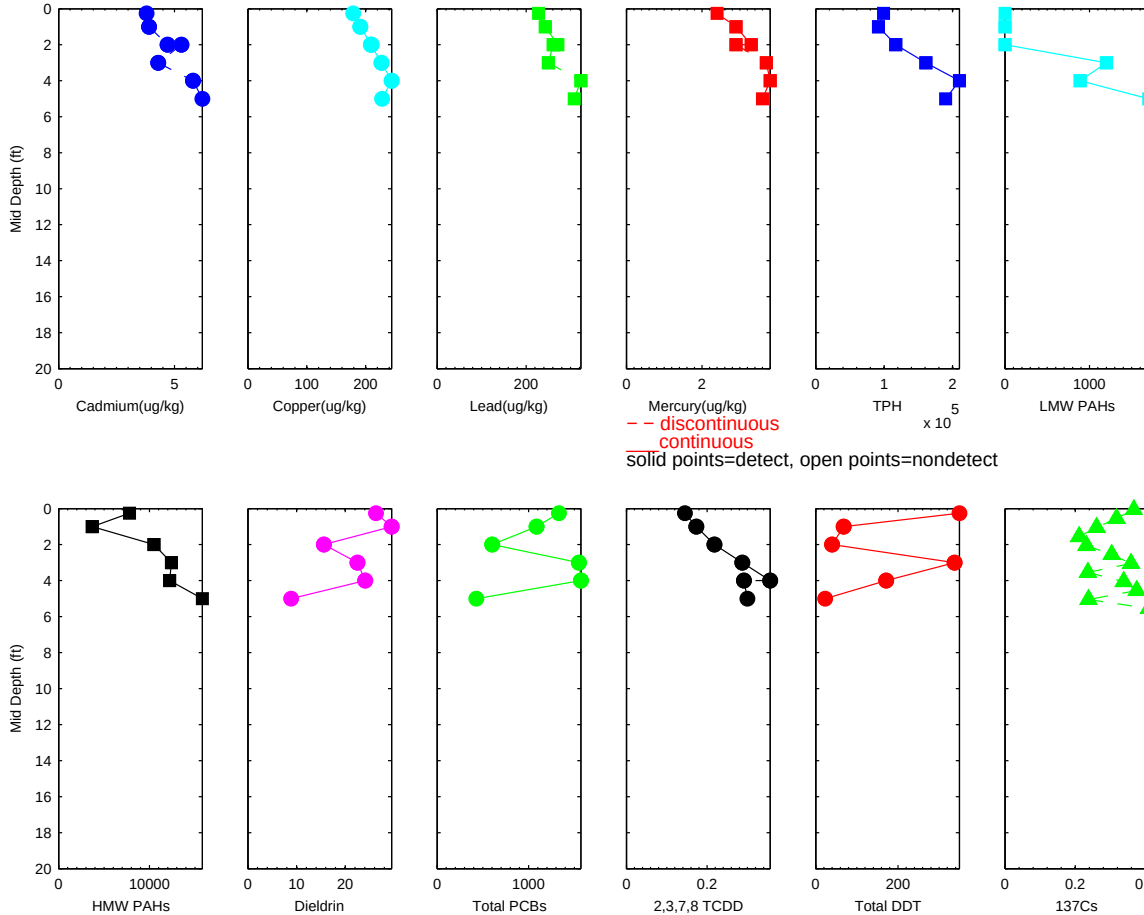
R2-0026772

Sample ID: D01 River Mile 5.16 PASSAIC 1995 RI Sampling Program



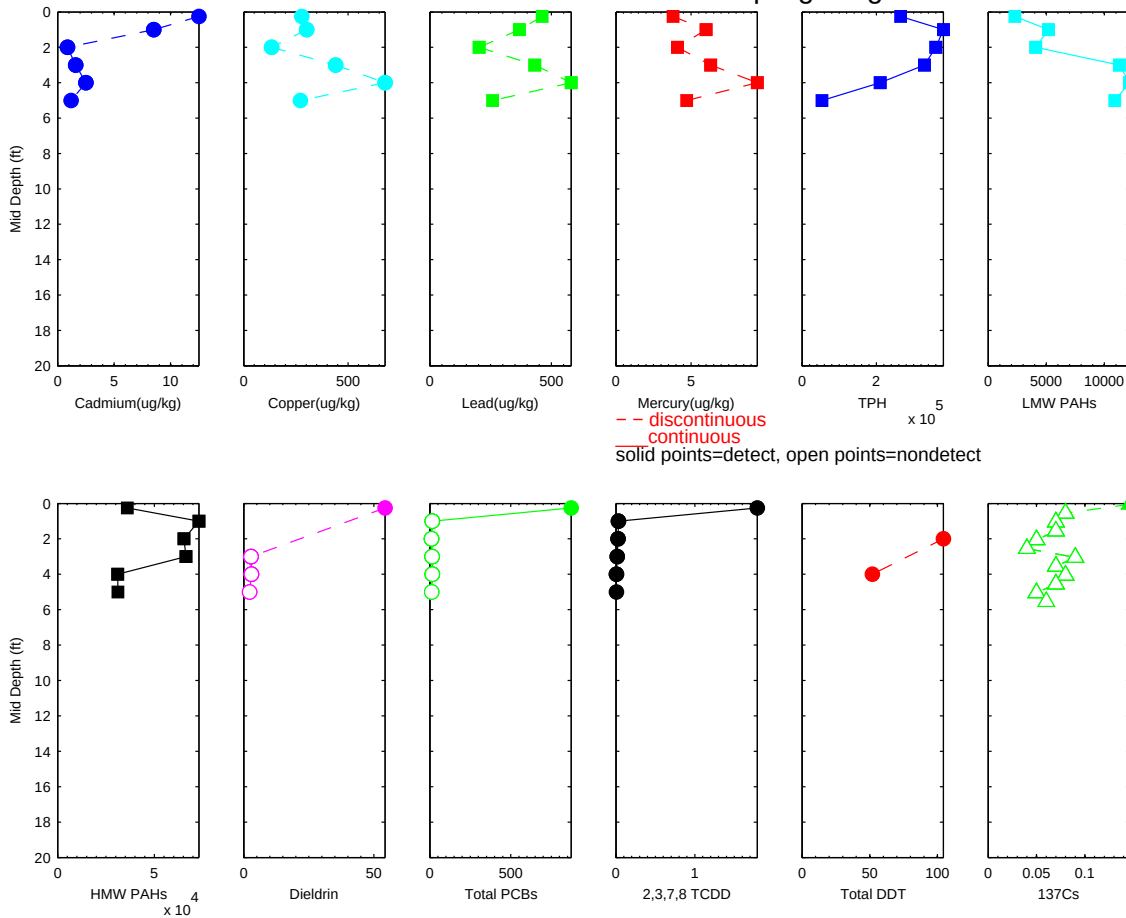
R2-0026773

Sample ID: 295 River Mile 2.01 PASSAIC 1995 RI Sampling Program



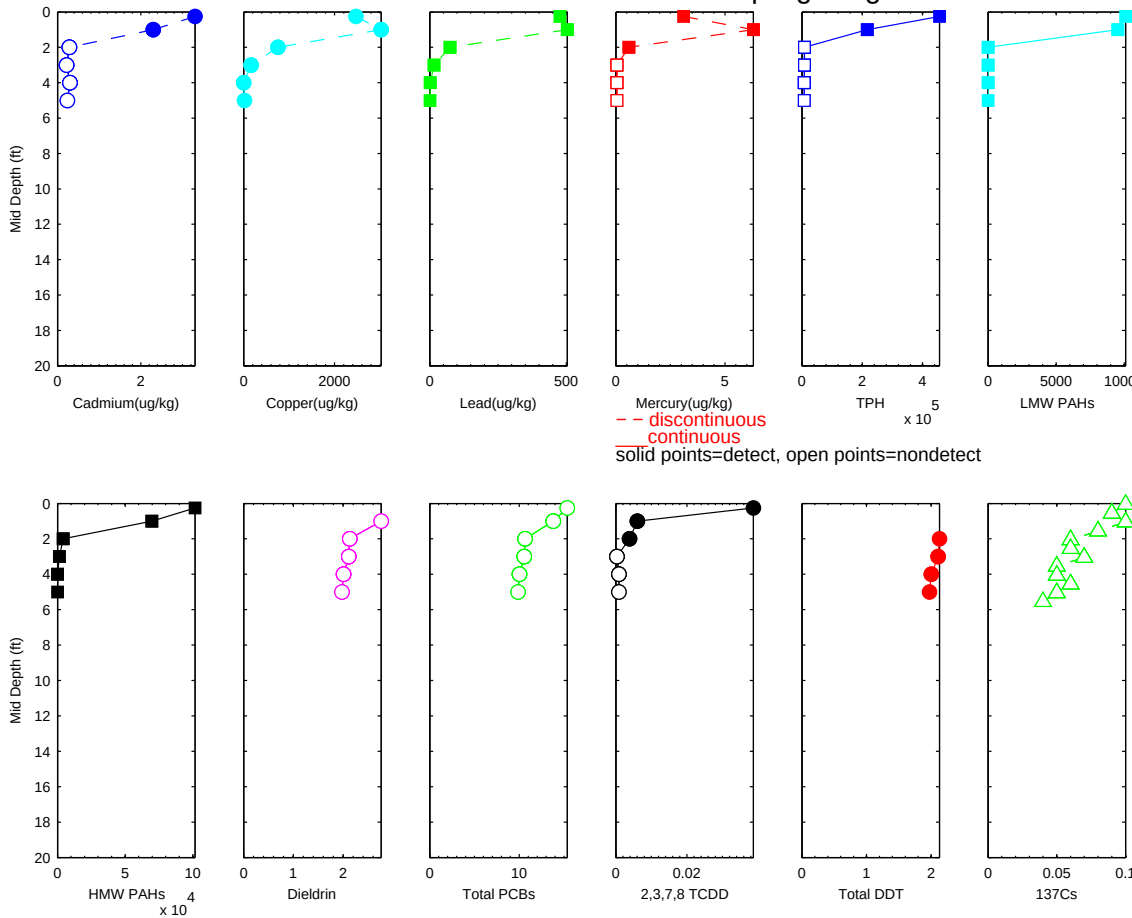
R2-0026774

Sample ID: 294 River Mile 3.13 PASSAIC 1995 RI Sampling Program



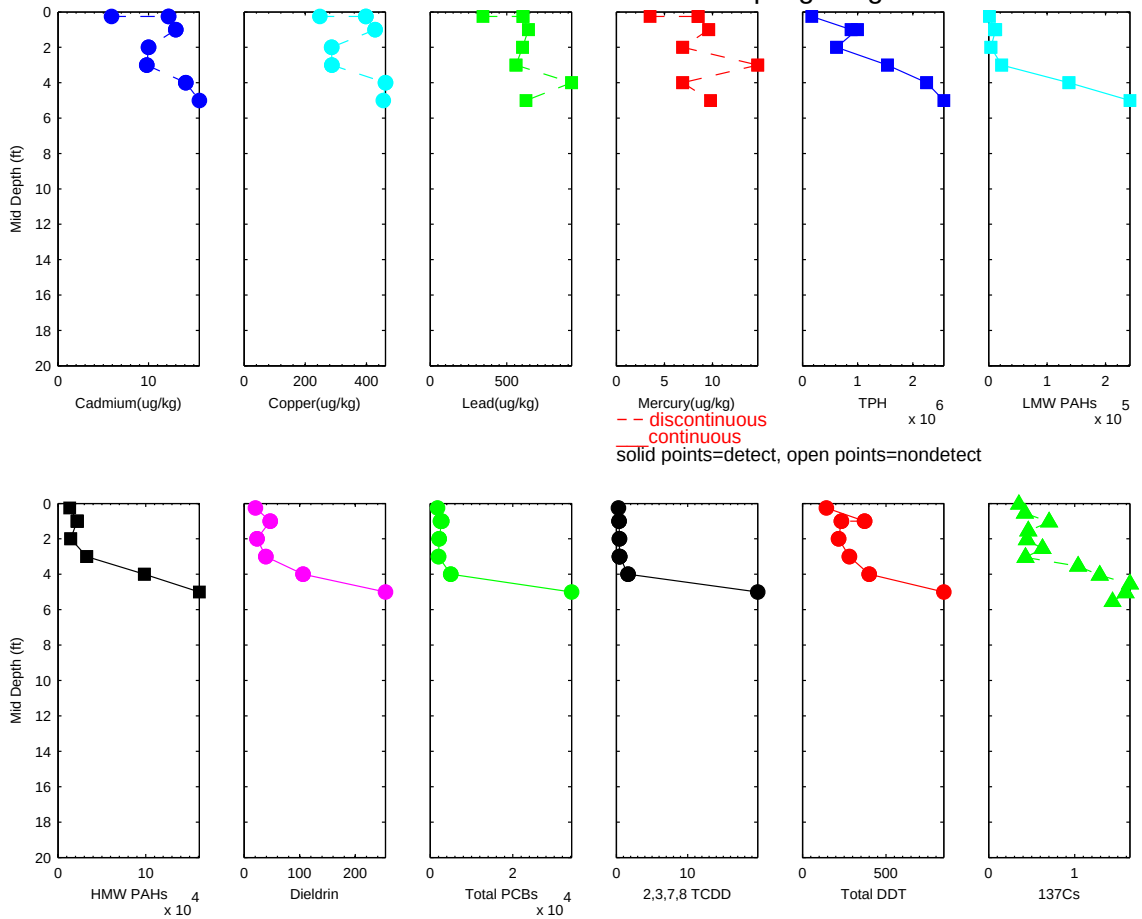
R2-0026775

Sample ID: 293 River Mile 5.08 PASSAIC 1995 RI Sampling Program



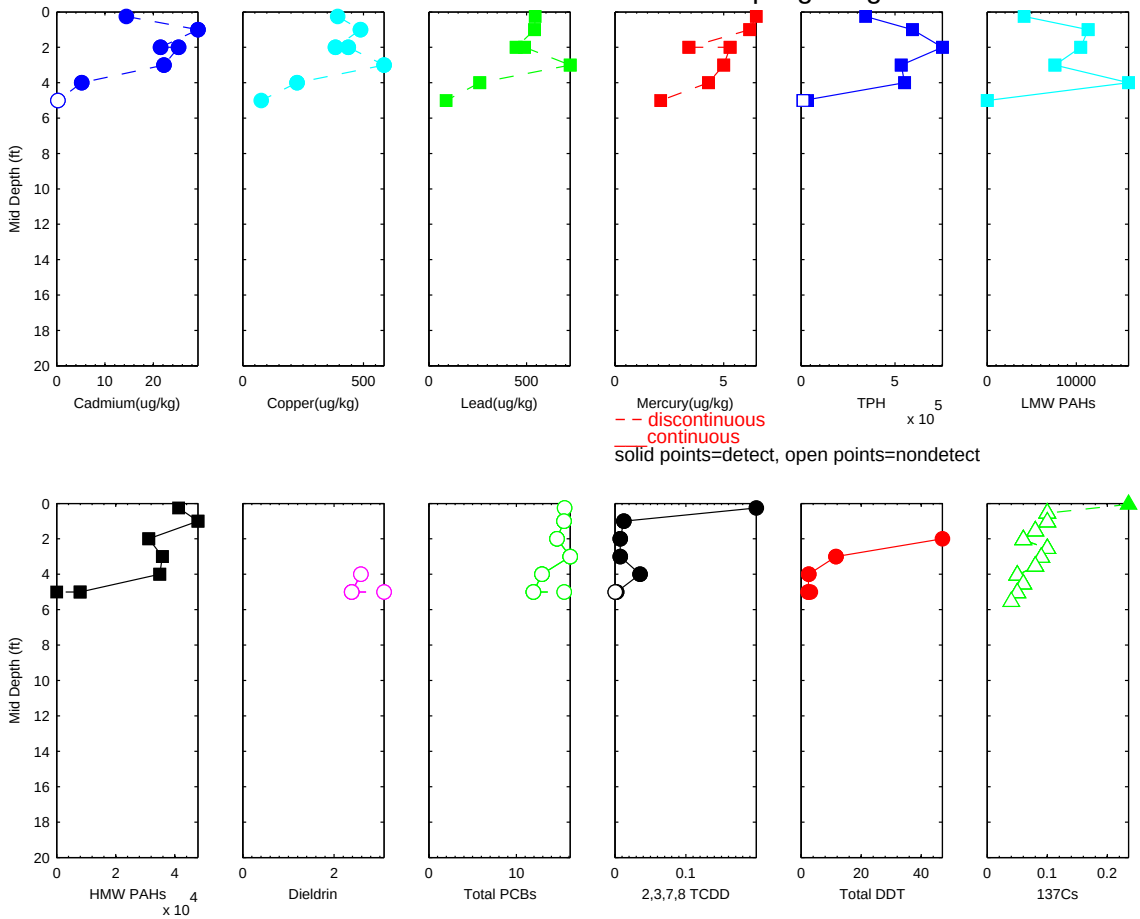
R2-0026776

Sample ID: 292 River Mile 4.37 PASSAIC 1995 RI Sampling Program



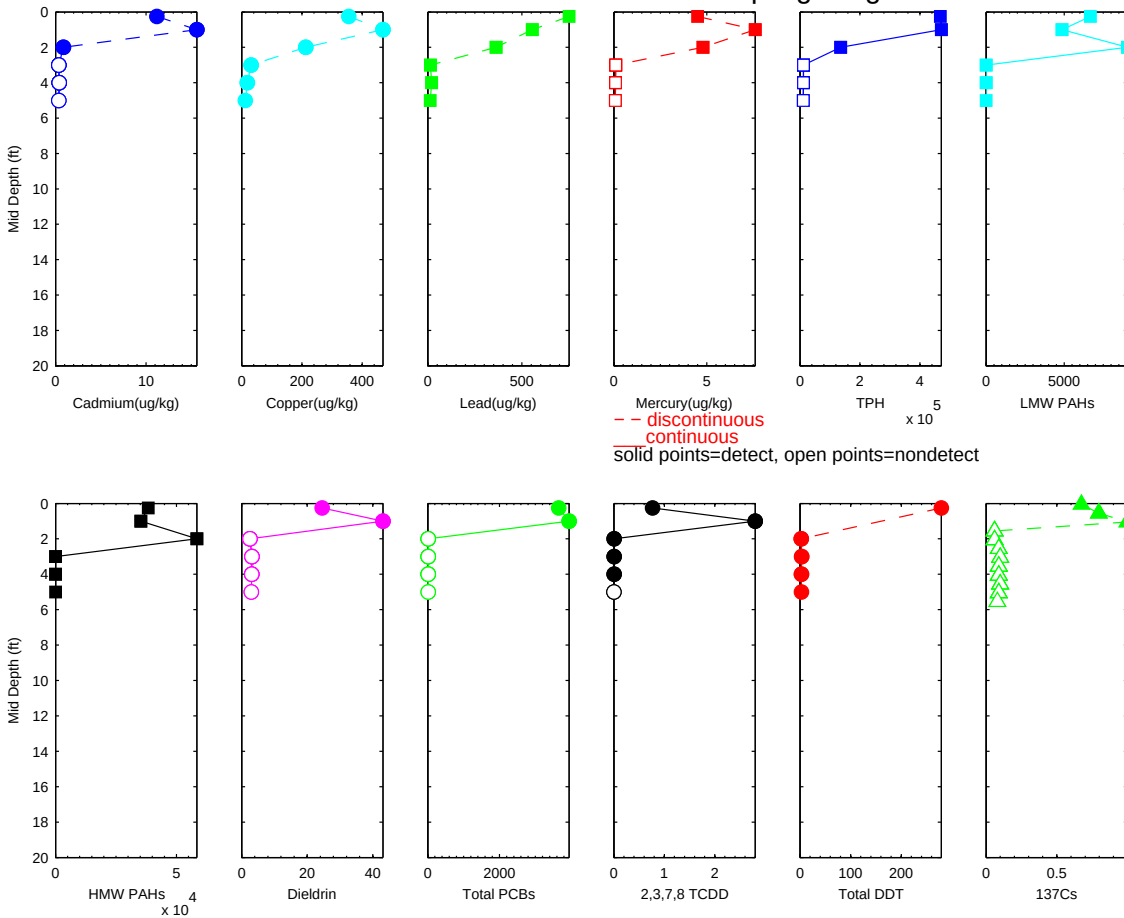
R2-0026777

Sample ID: 291 River Mile 4.3 PASSAIC 1995 RI Sampling Program



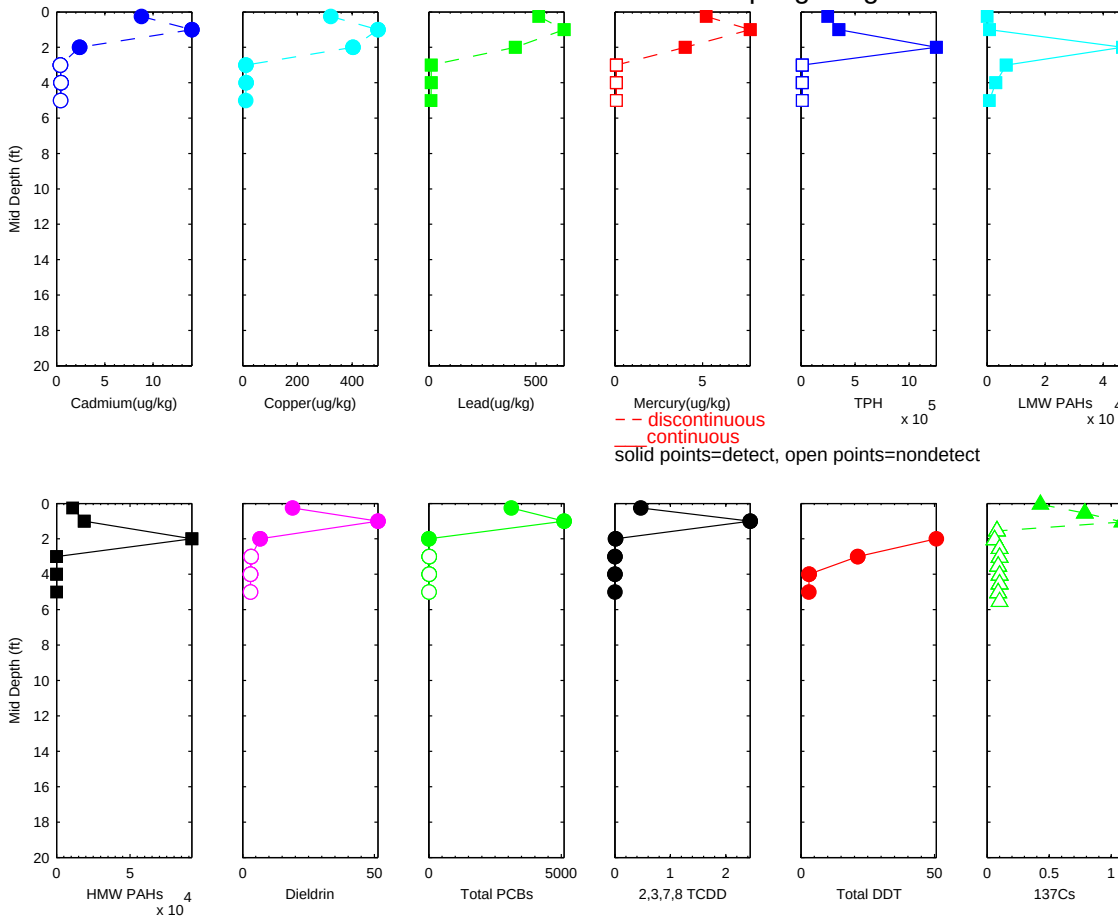
R2-0026778

Sample ID: 290 River Mile 4.24 PASSAIC 1995 RI Sampling Program



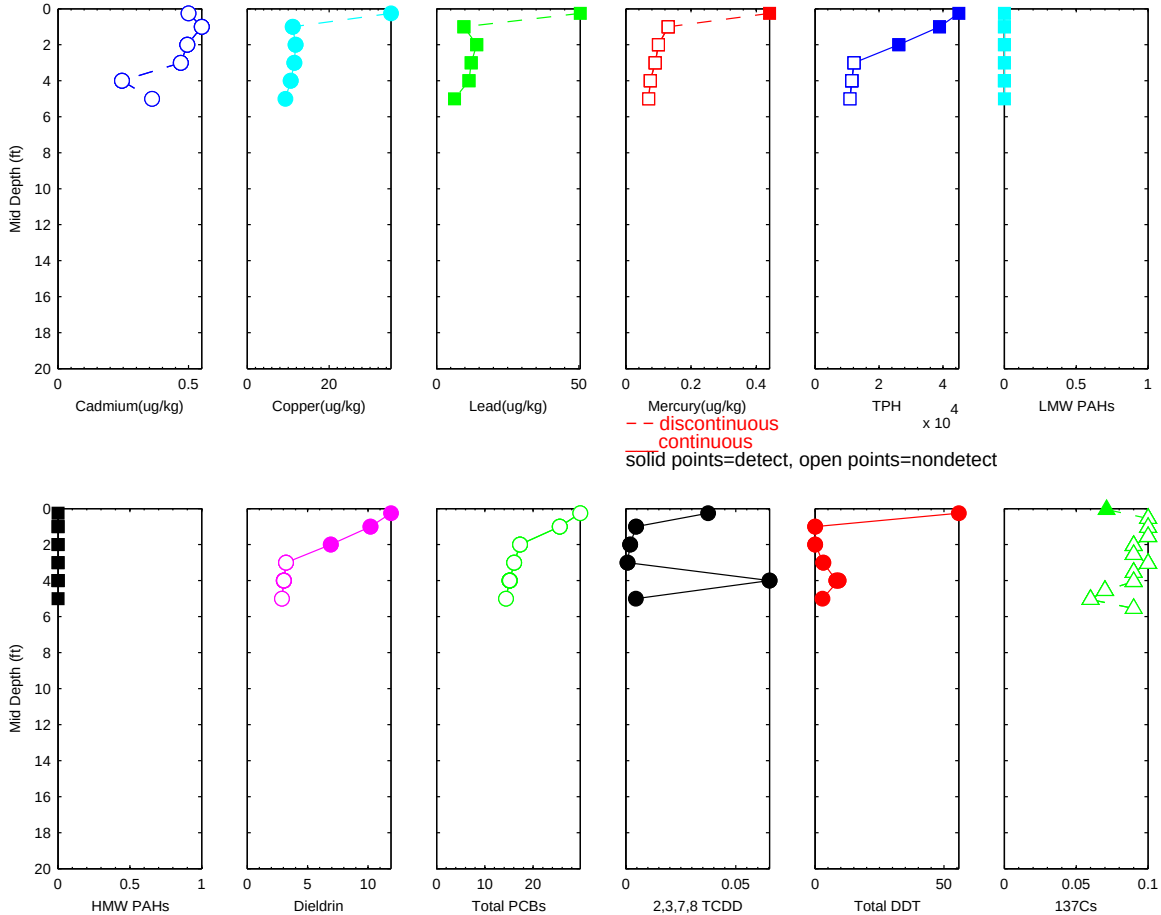
R2-0026779

Sample ID: 289 River Mile 4.17 PASSAIC 1995 RI Sampling Program



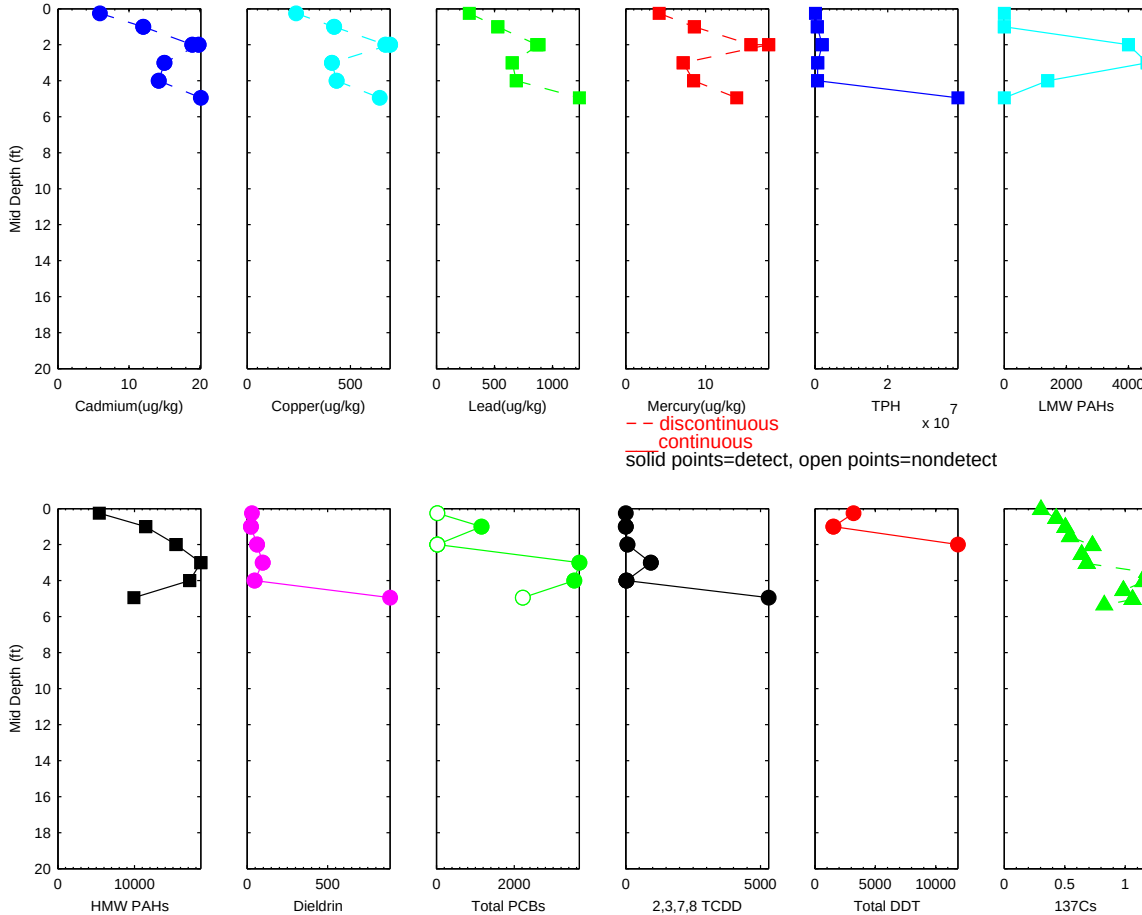
R2-0026780

Sample ID: 287 River Mile 3.58 PASSAIC 1995 RI Sampling Program



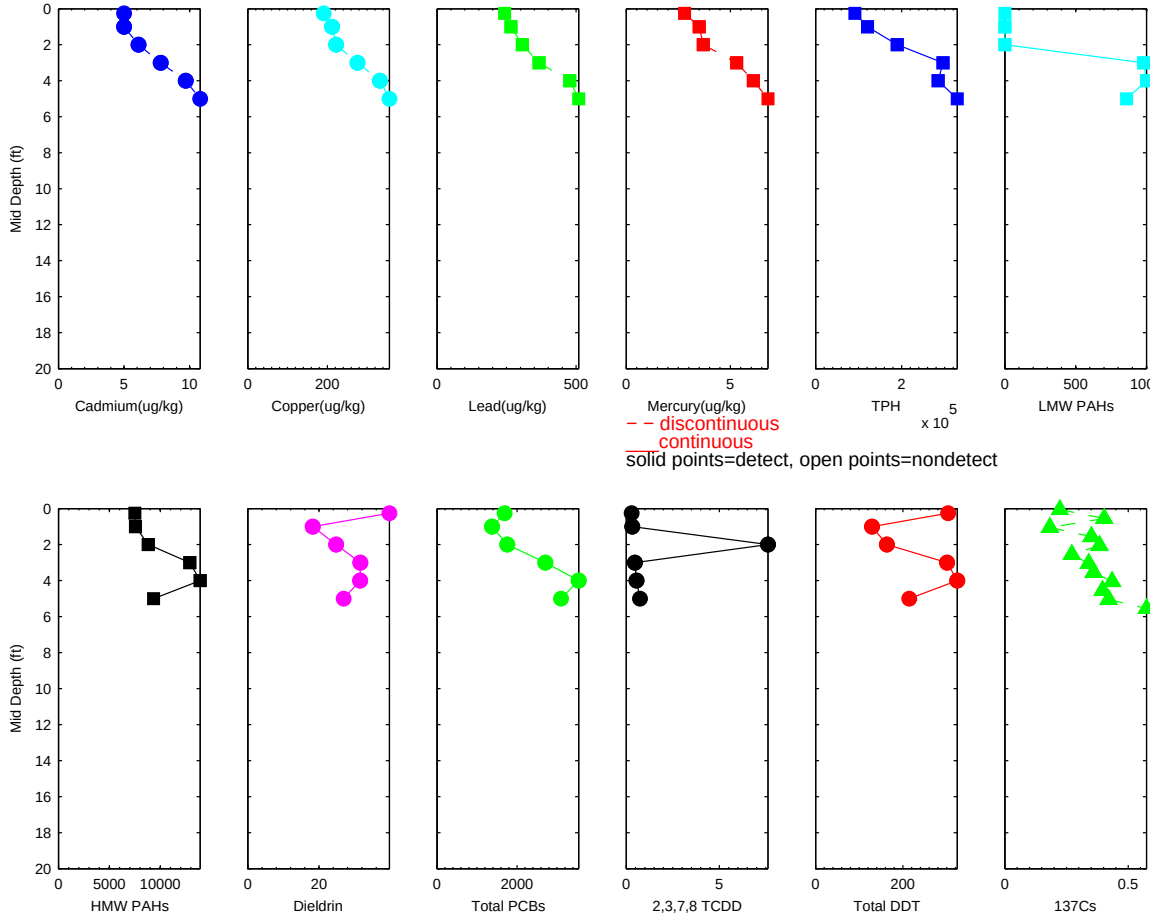
R2-0026781

Sample ID: 285 River Mile 3.14 PASSAIC 1995 RI Sampling Program



R2-0026782

Sample ID: 283 River Mile 2.24 PASSAIC 1995 RI Sampling Program



R2-0026783

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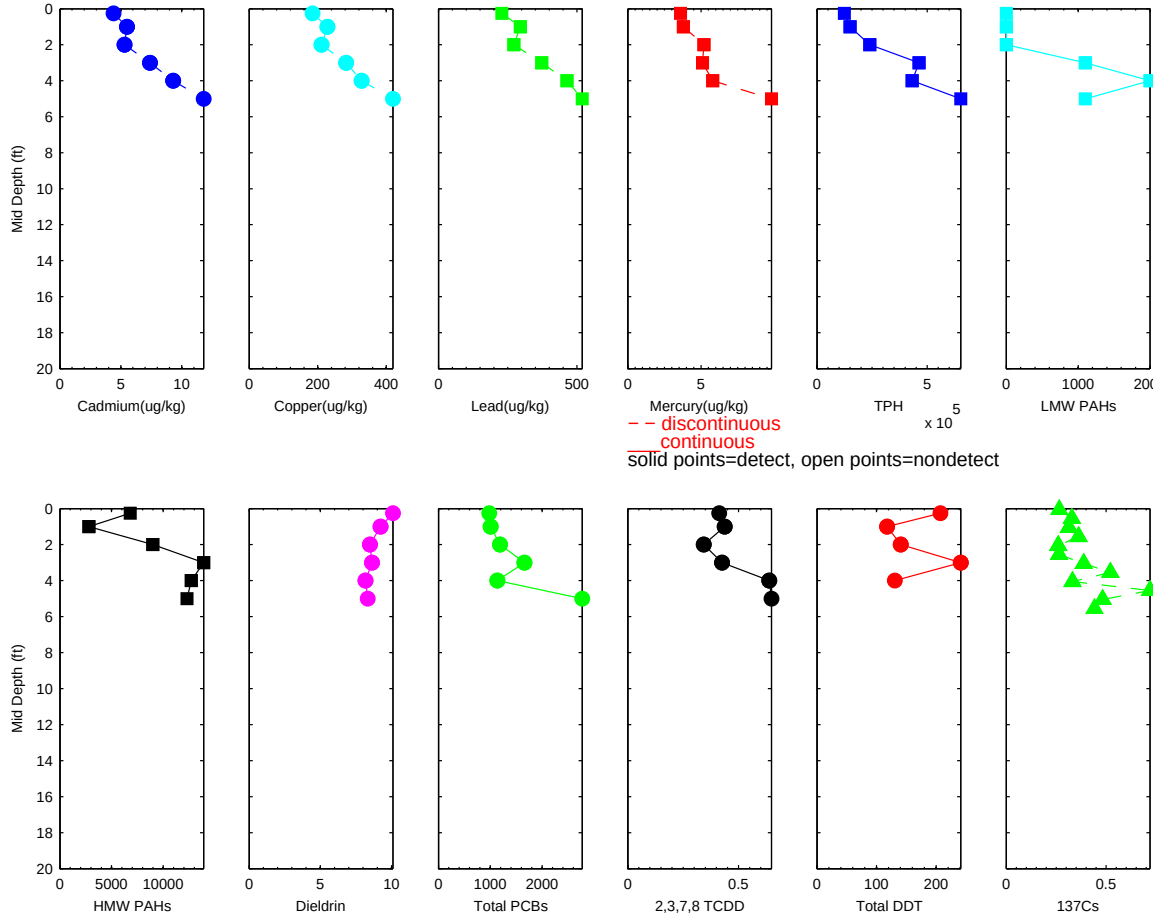
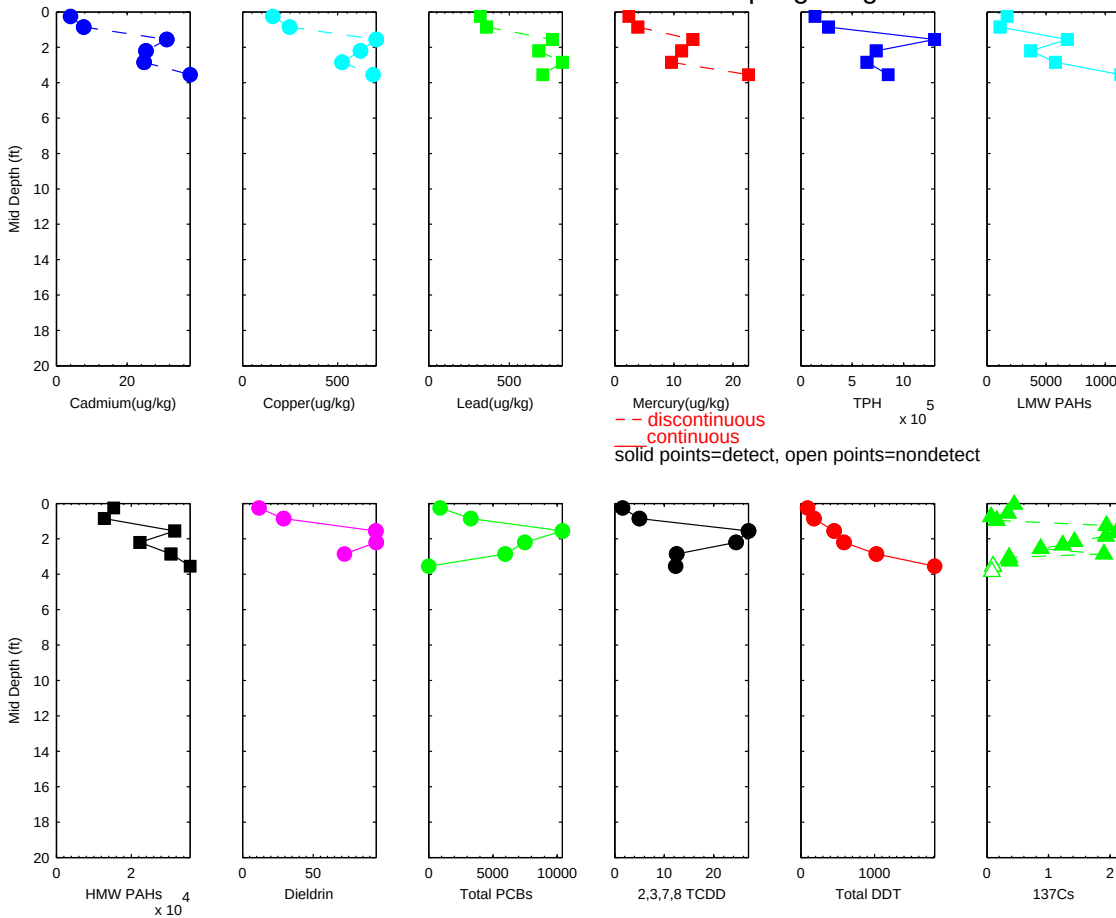


R2-0026784

Sample ID: 278 River Mile 6.74 PASSAIC 1995 RI Sampling Program



R2-0026785

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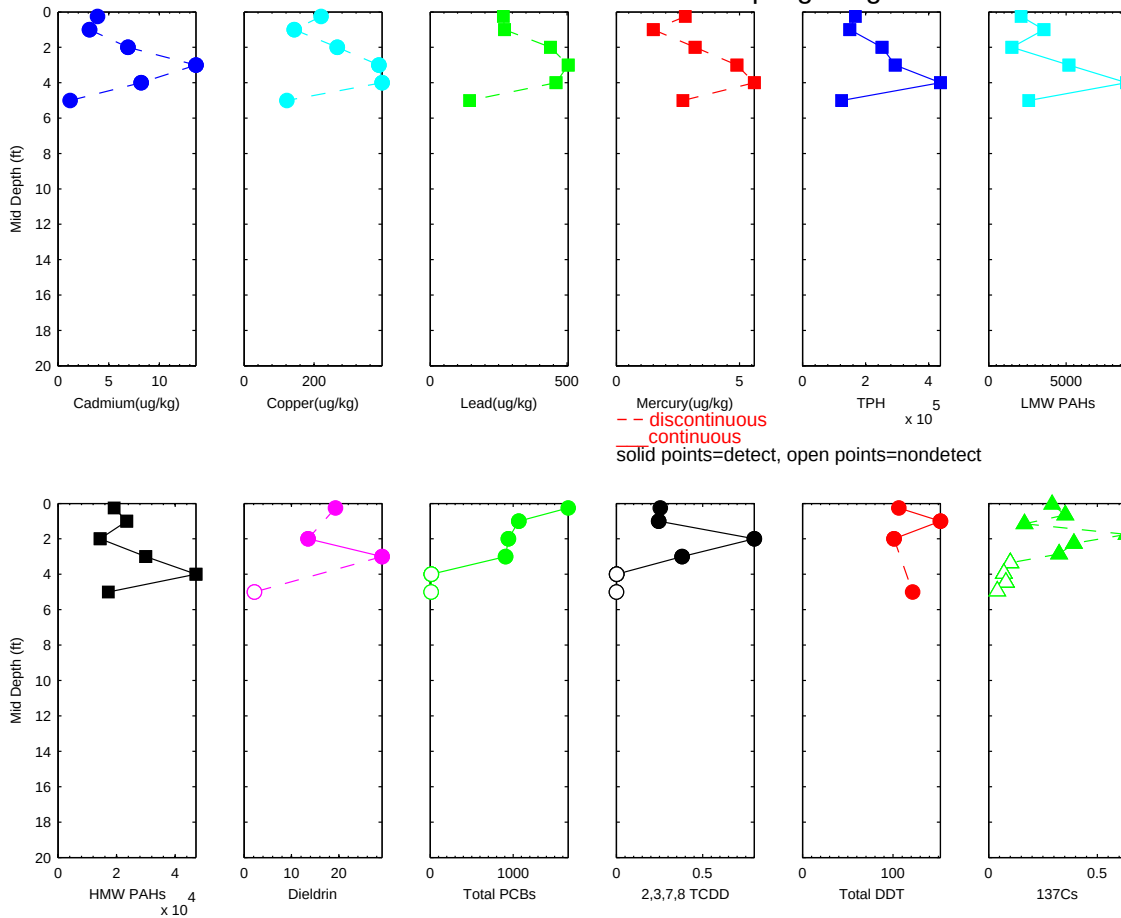
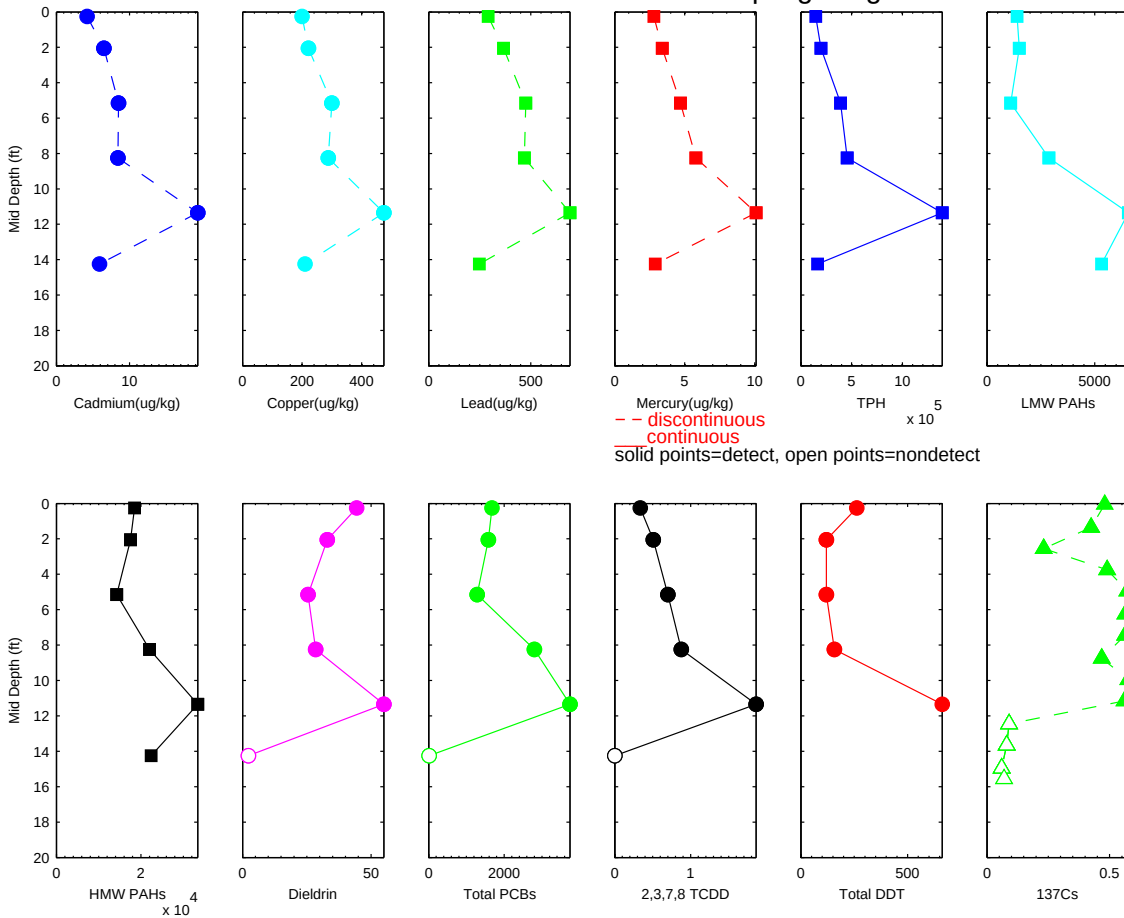


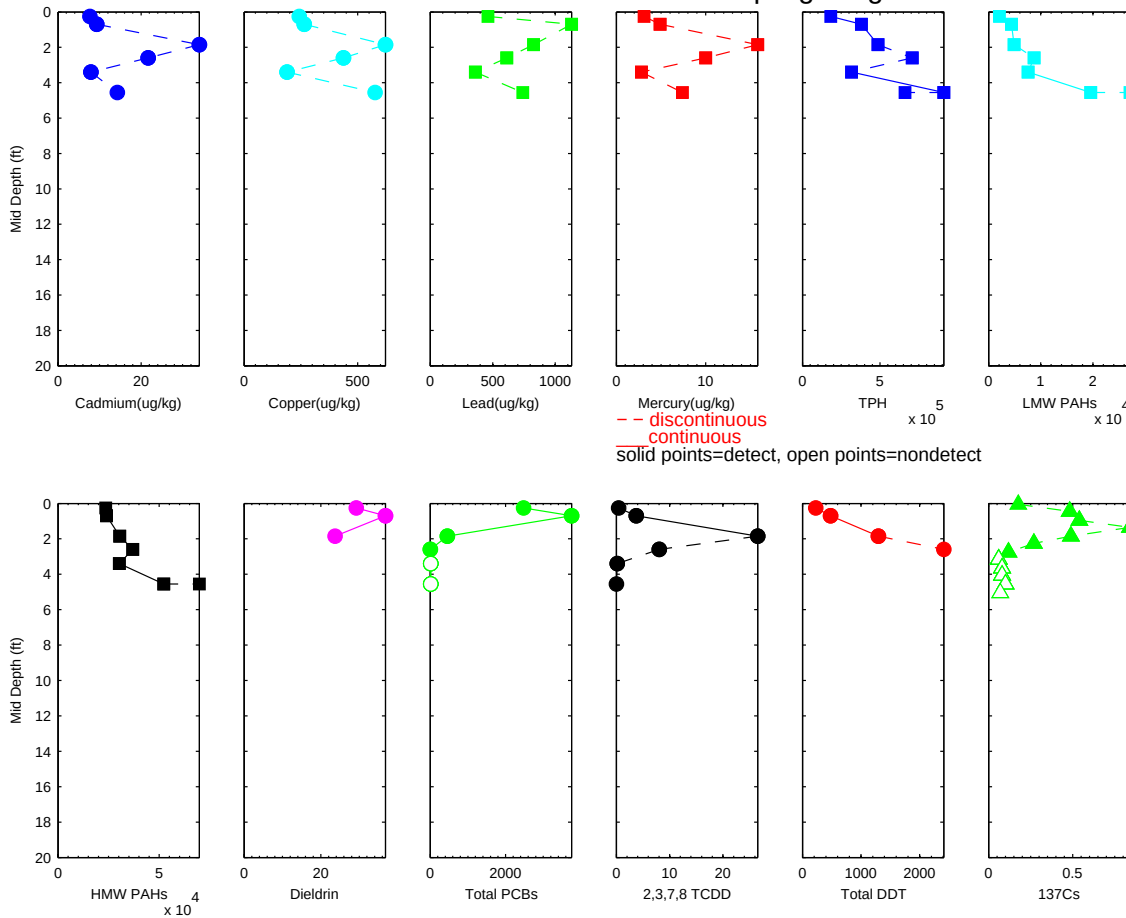
R2-0026786

Sample ID: 276 River Mile 6.74 PASSAIC 1995 RI Sampling Program



R2-0026787

Sample ID: 274 River Mile 6.51 PASSAIC 1995 RI Sampling Program



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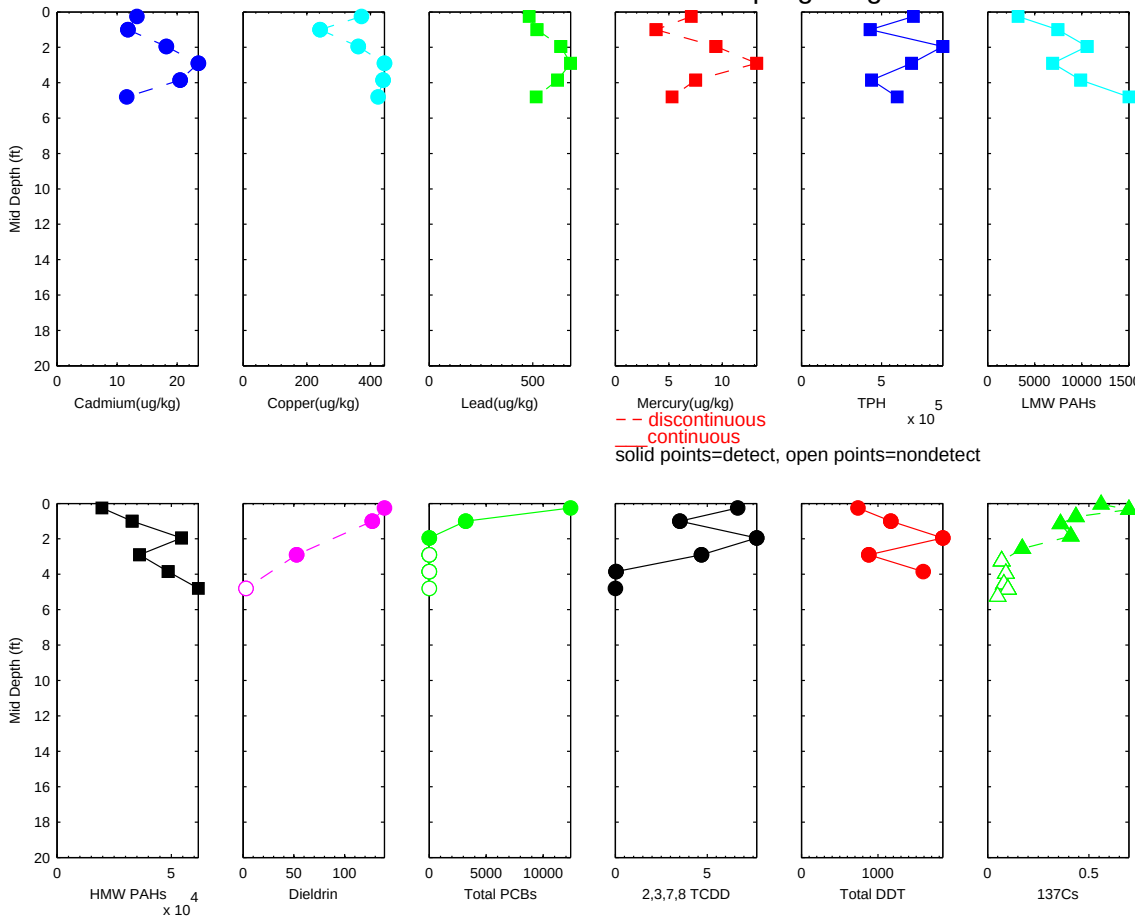
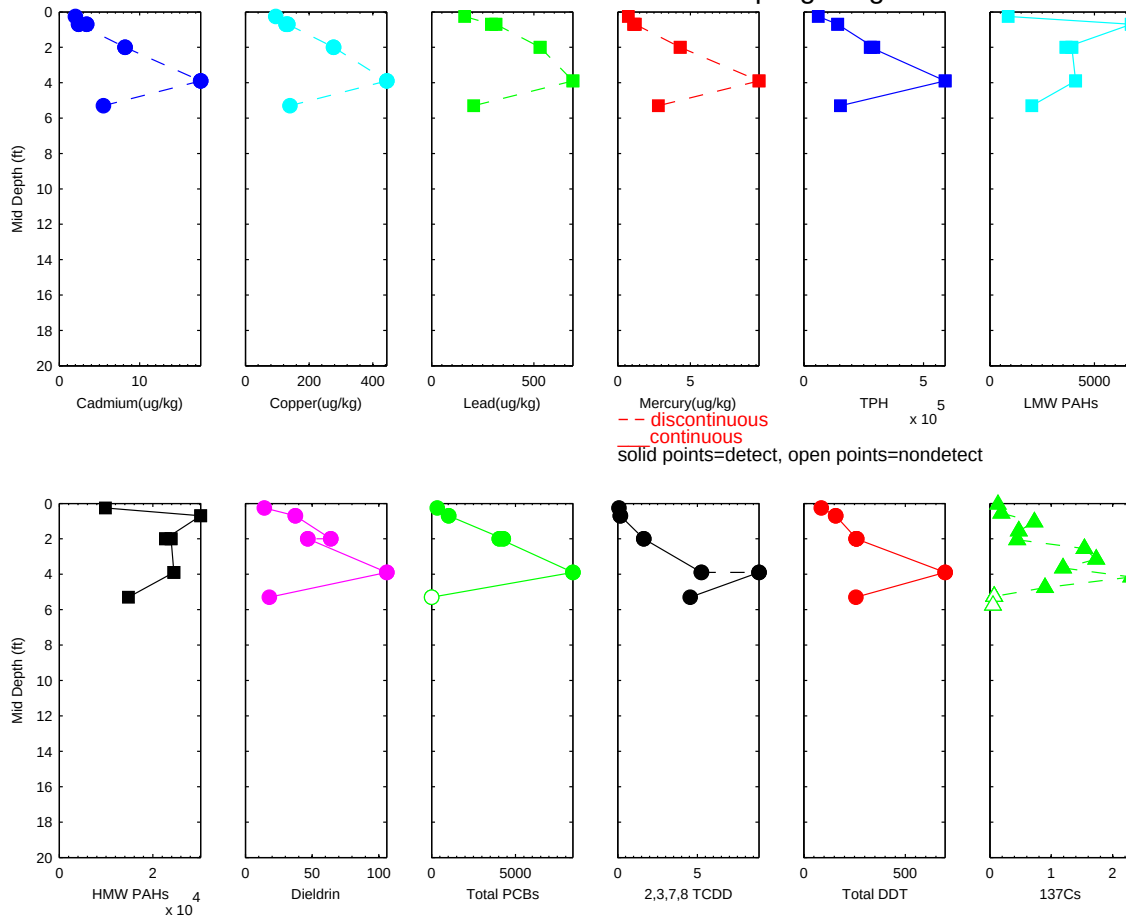


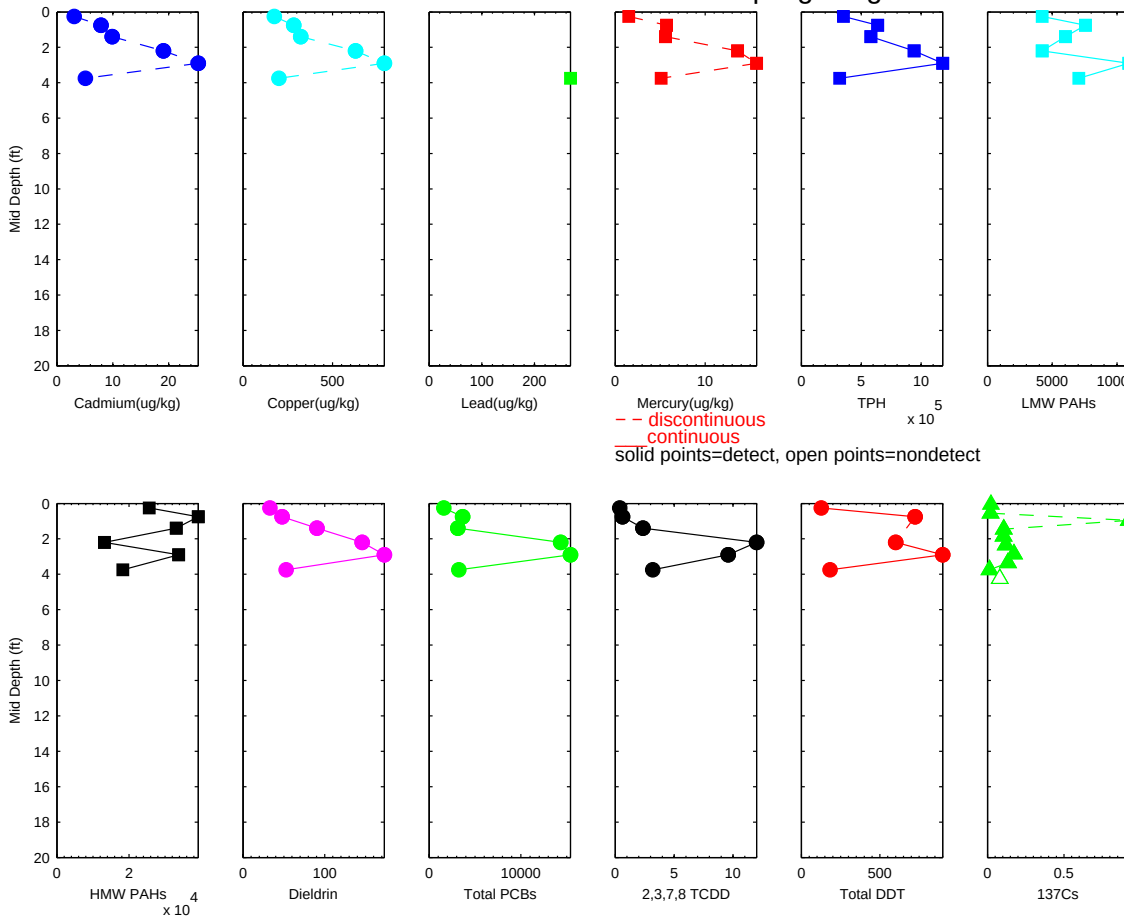
R2-0026789

Sample ID: 271 River Mile 6.28 PASSAIC 1995 RI Sampling Program



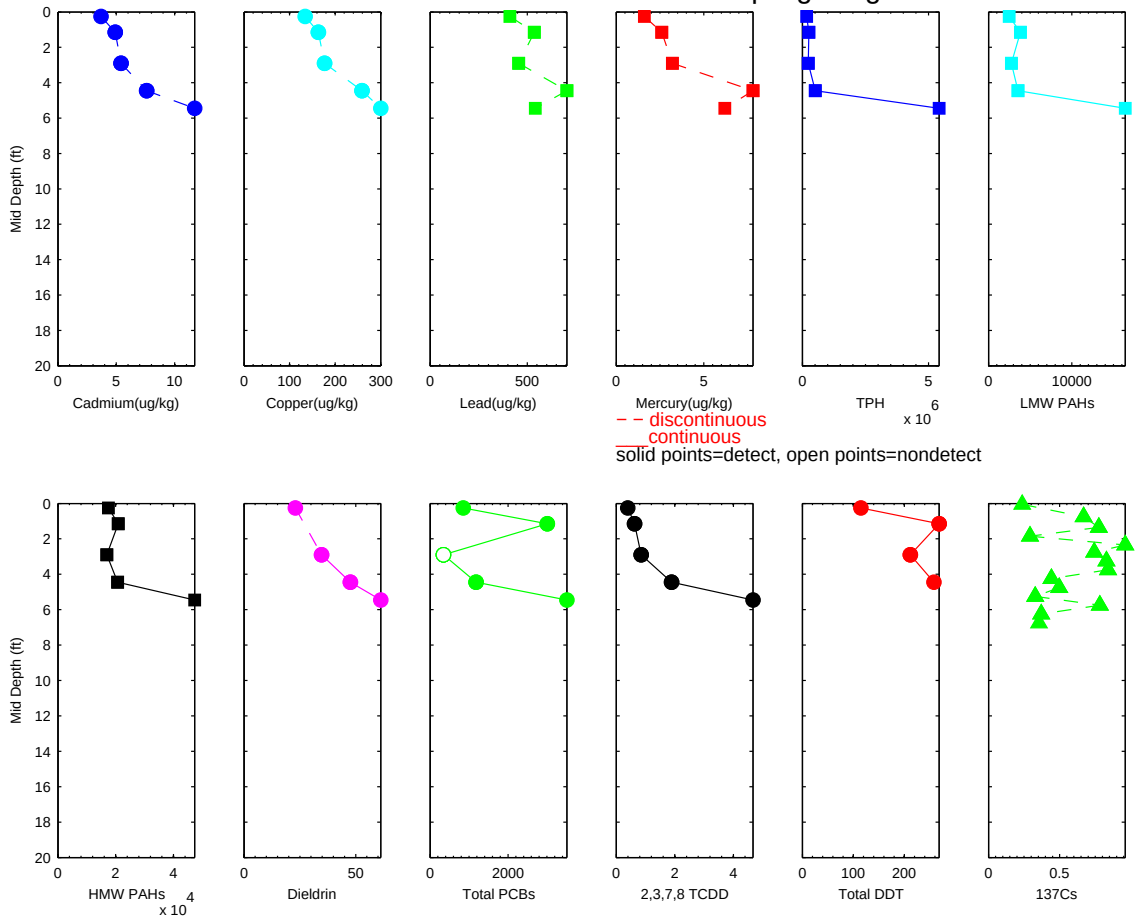
R2-0026790

Sample ID: 270 River Mile 6.28 PASSAIC 1995 RI Sampling Program



R2-0026791

Sample ID: 269 River Mile 5.96 PASSAIC 1995 RI Sampling Program



R2-0026792

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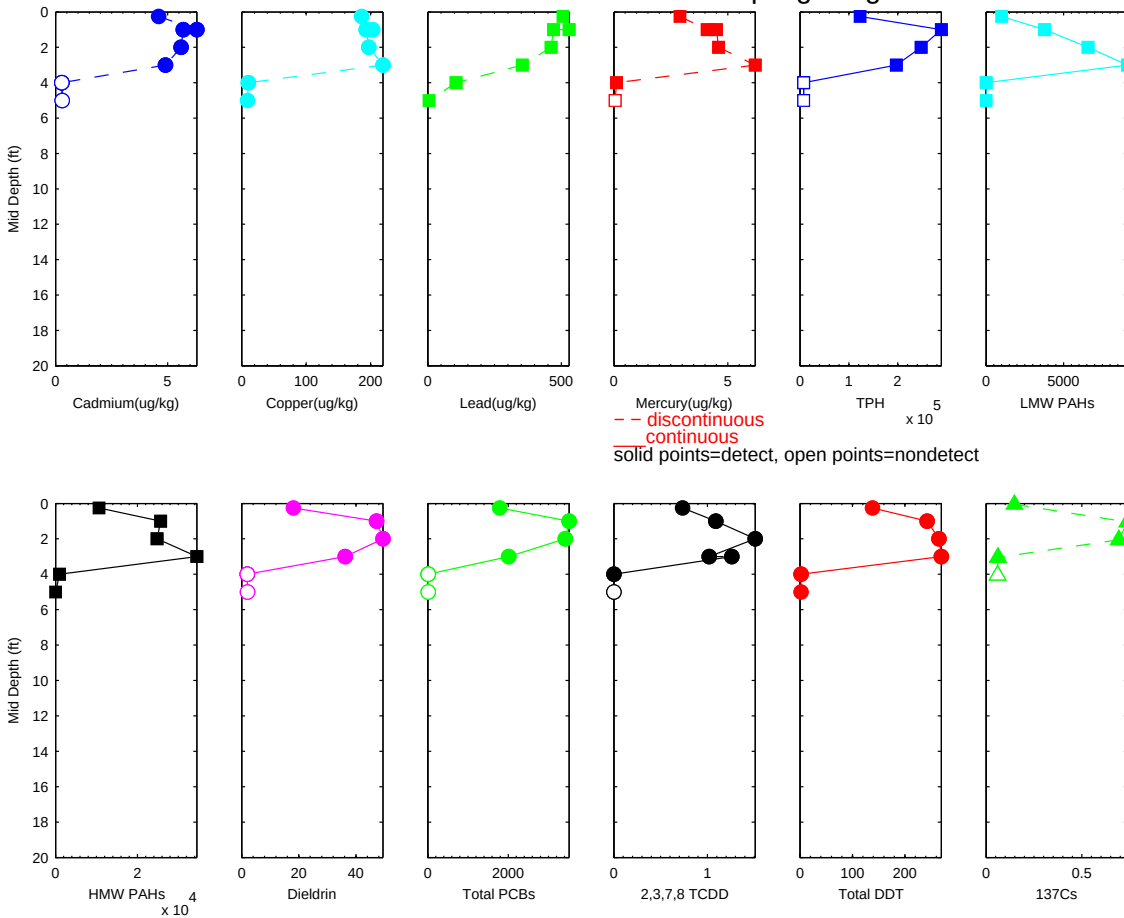

R2-0026793

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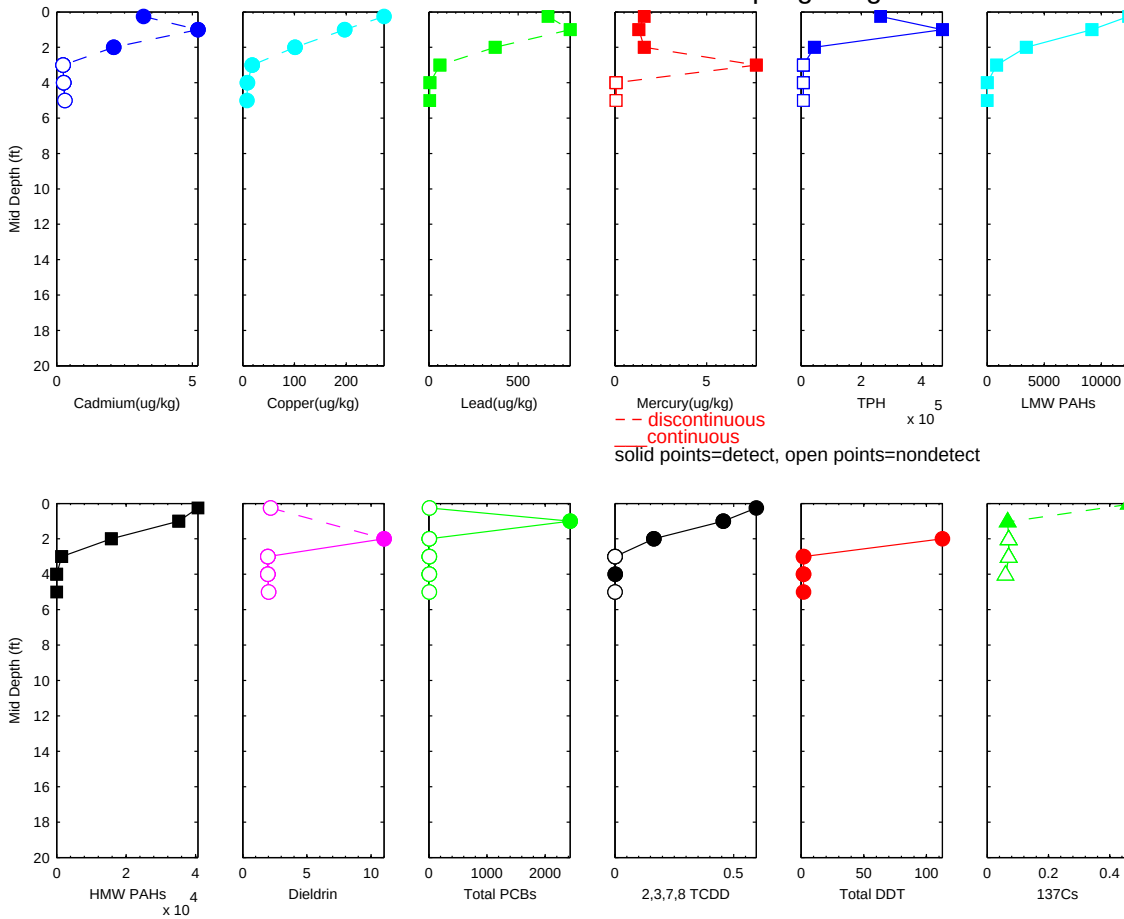
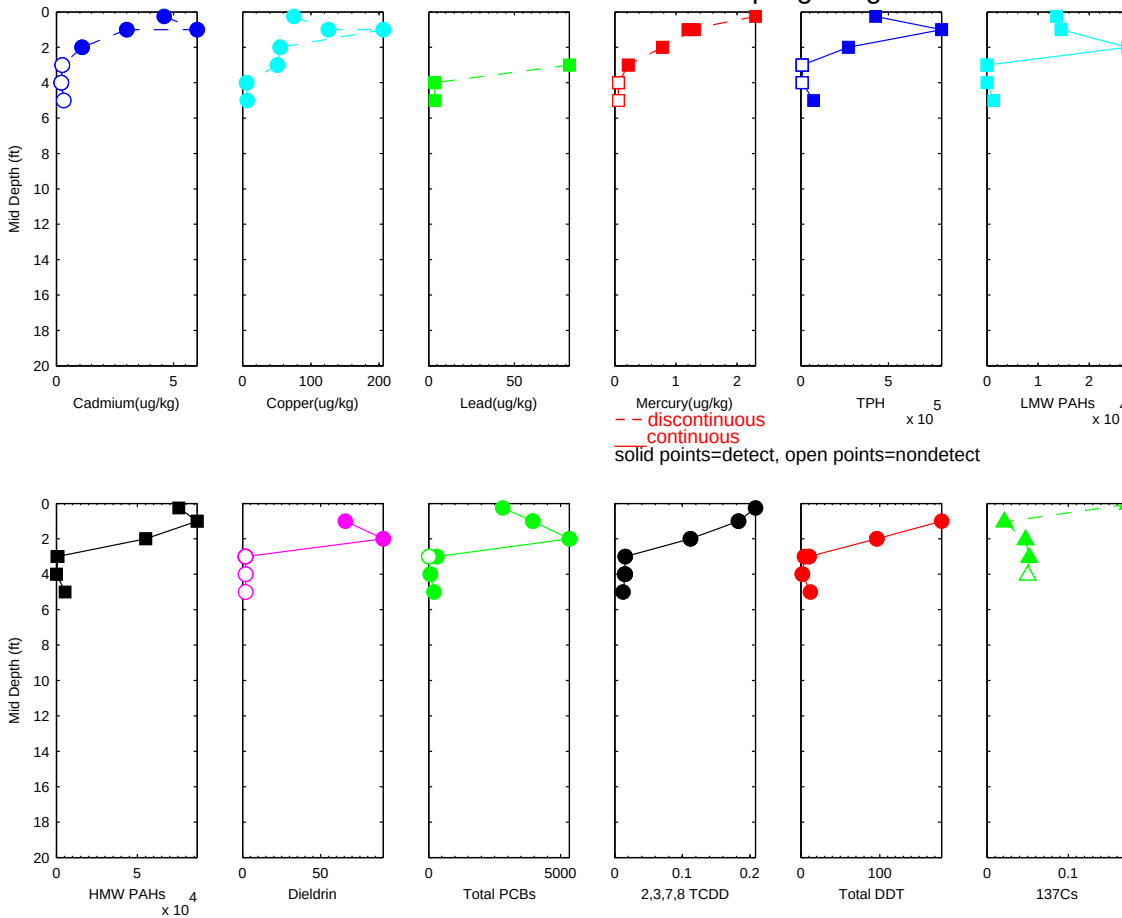


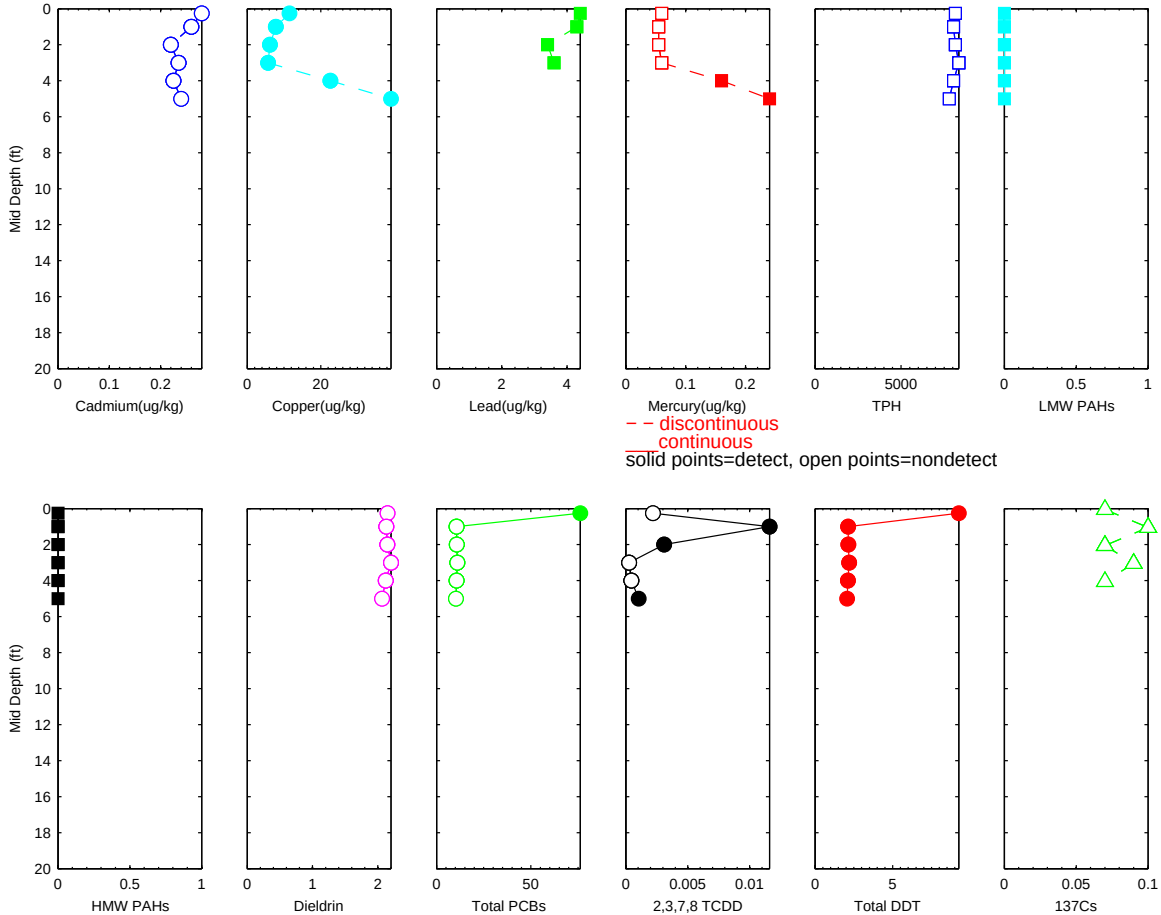
R2-0026794

Sample ID: 266 River Mile 5.74 PASSAIC 1995 RI Sampling Program



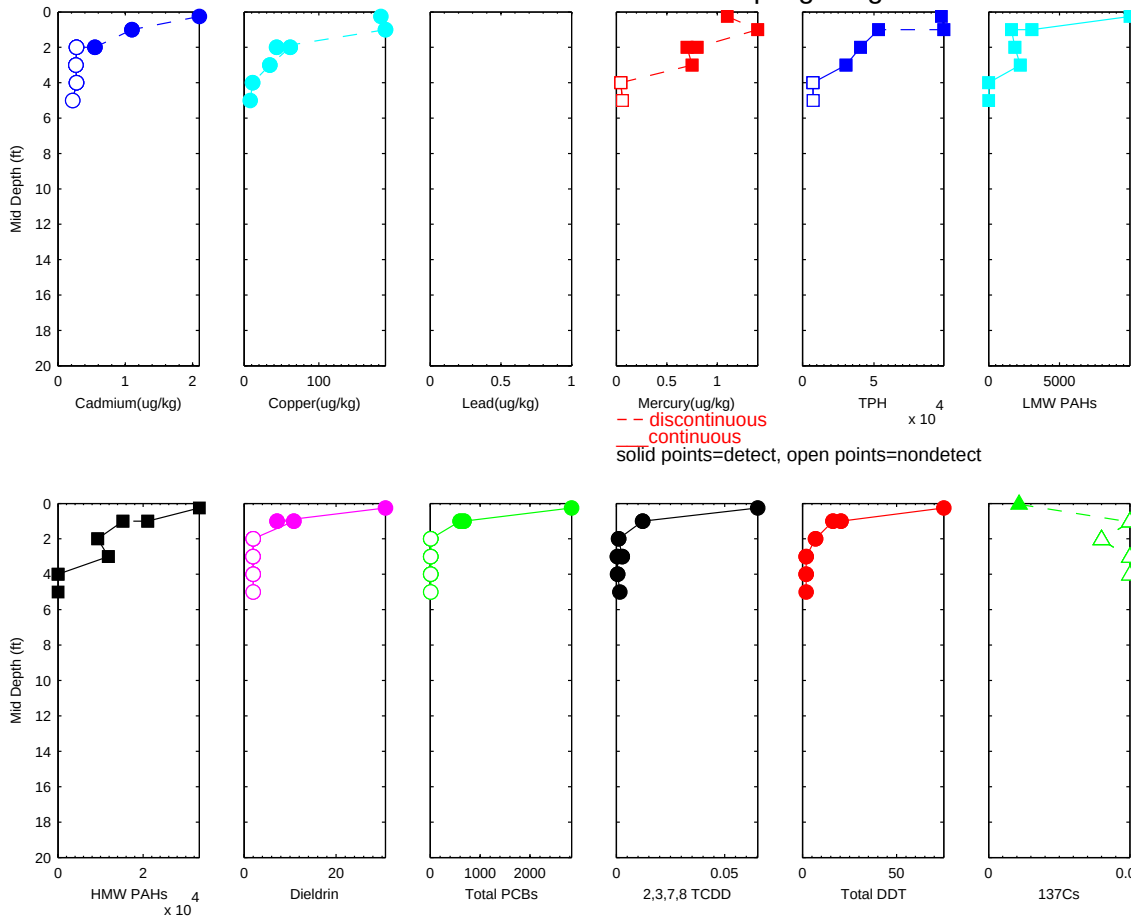
R2-0026795

Sample ID: 265 River Mile 5.74 PASSAIC 1995 RI Sampling Program



R2-0026796

Sample ID: 264 River Mile 5.74 PASSAIC 1995 RI Sampling Program



R2-0026797

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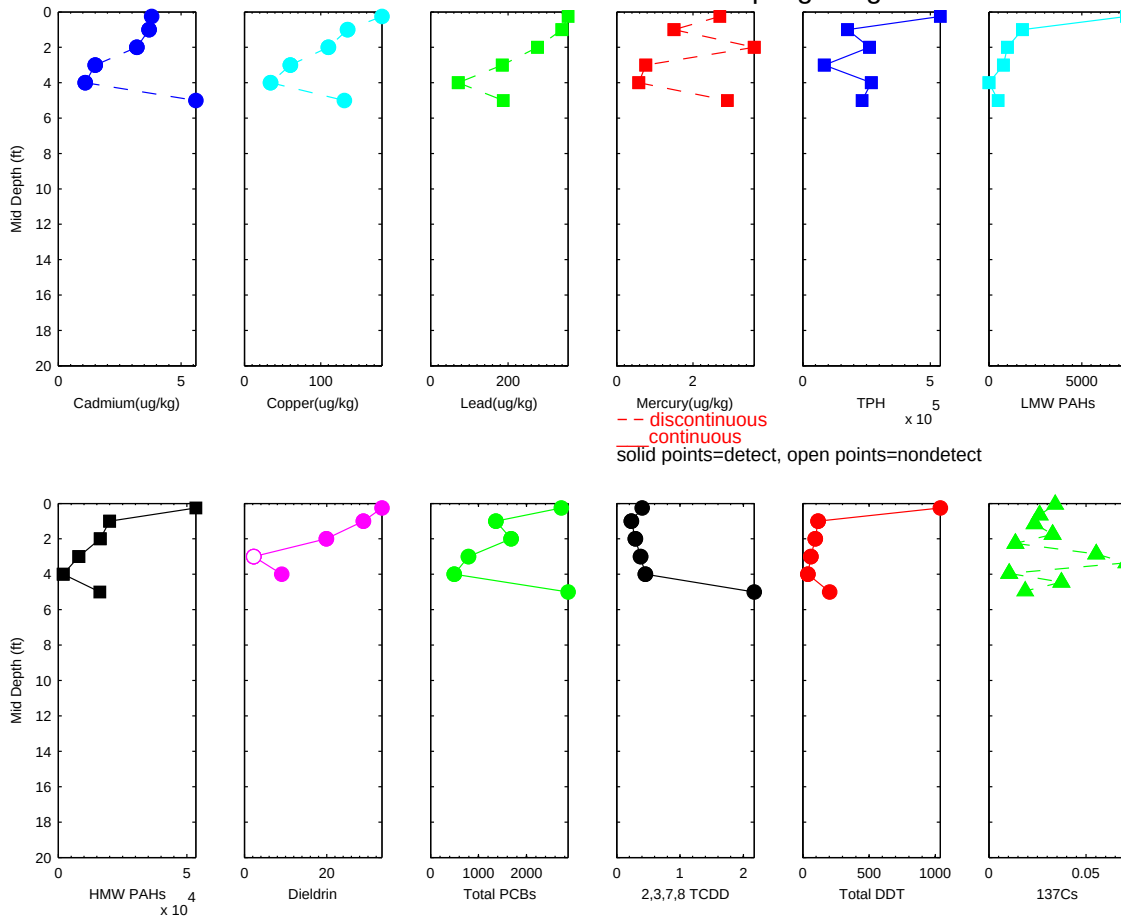
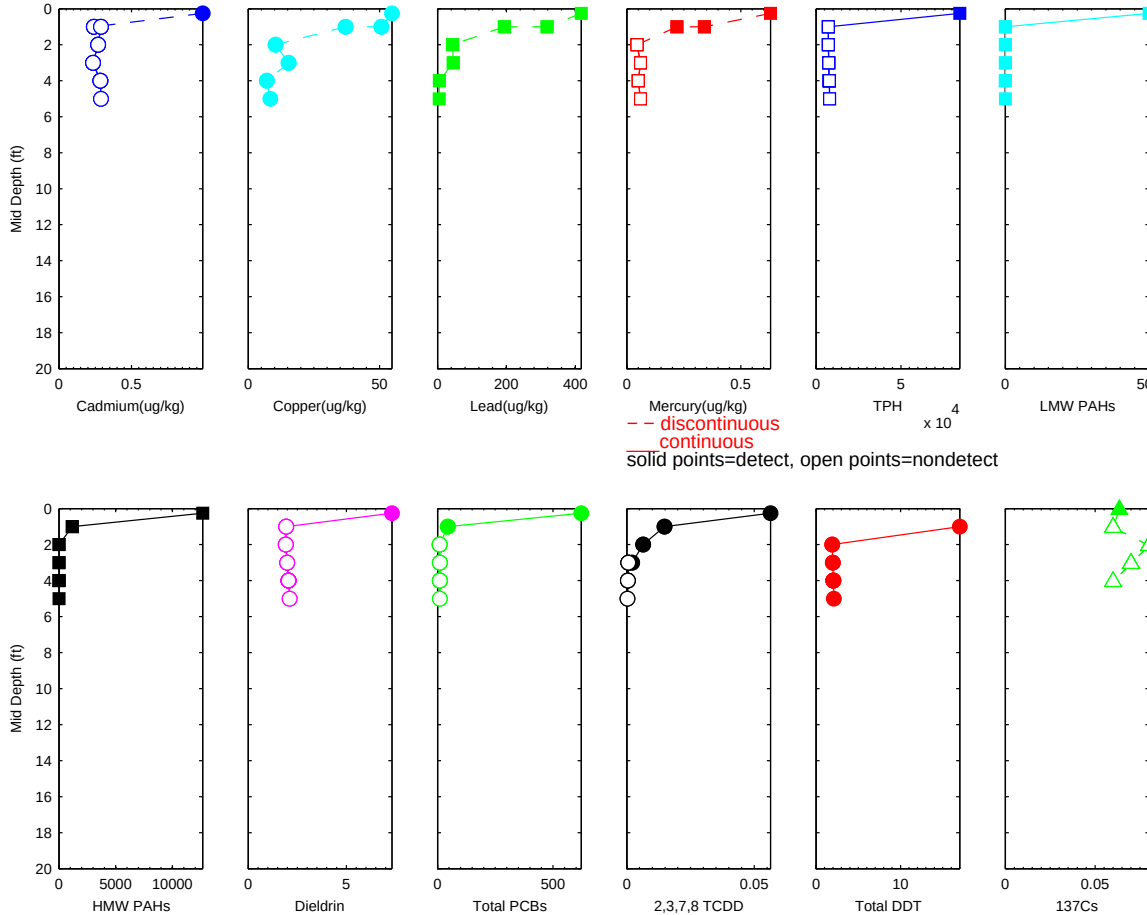


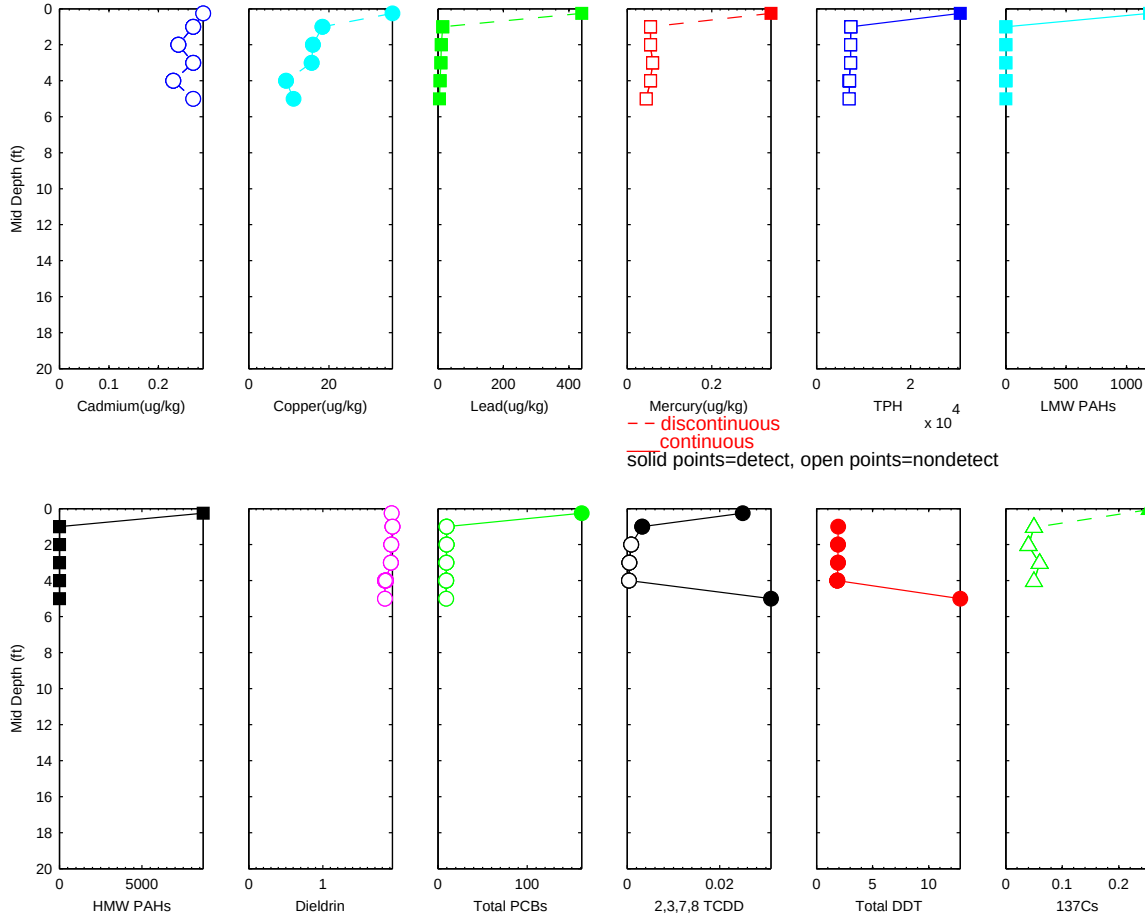
R2-0026798

Sample ID: 262 River Mile 5.53 PASSAIC 1995 RI Sampling Program



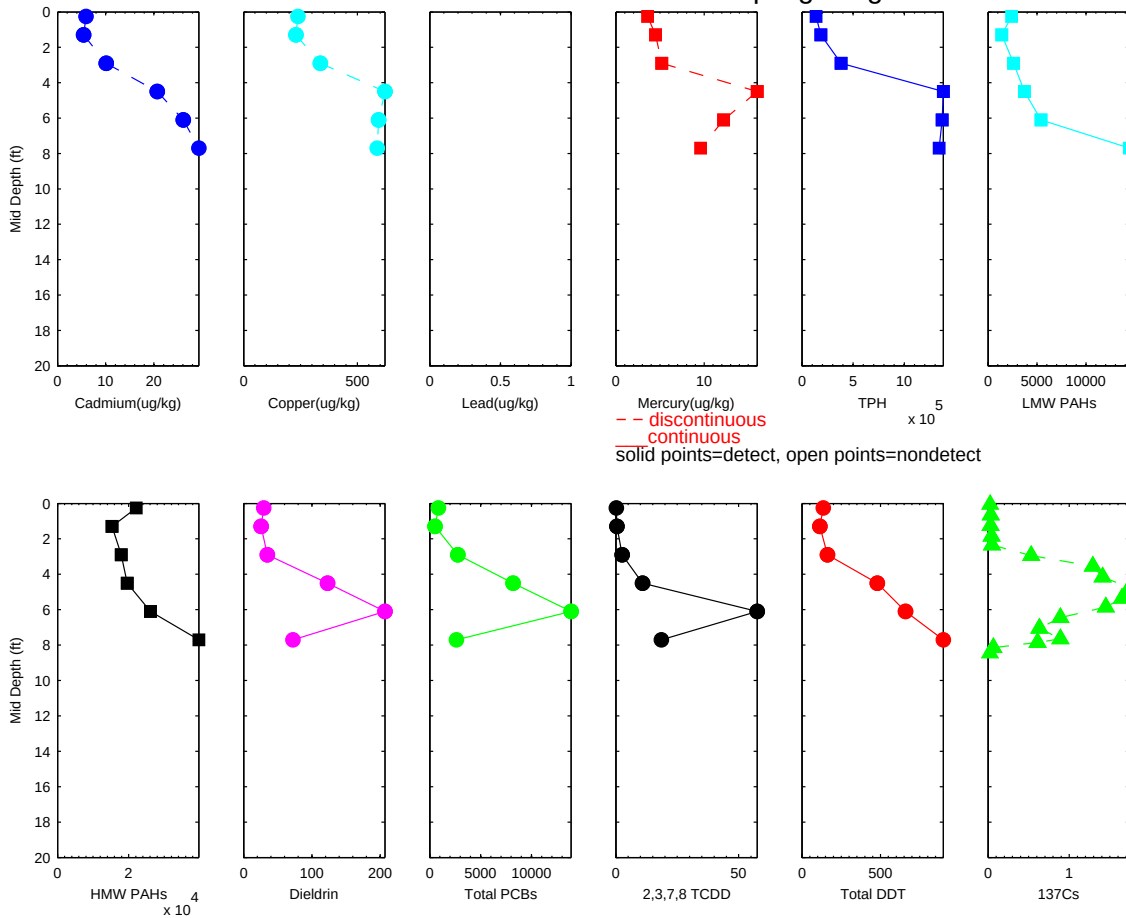
R2-0026799

Sample ID: 261 River Mile 5.52 PASSAIC 1995 RI Sampling Program



R2-0026800

Sample ID: 260 River Mile 5.36 PASSAIC 1995 RI Sampling Program



R2-0026801

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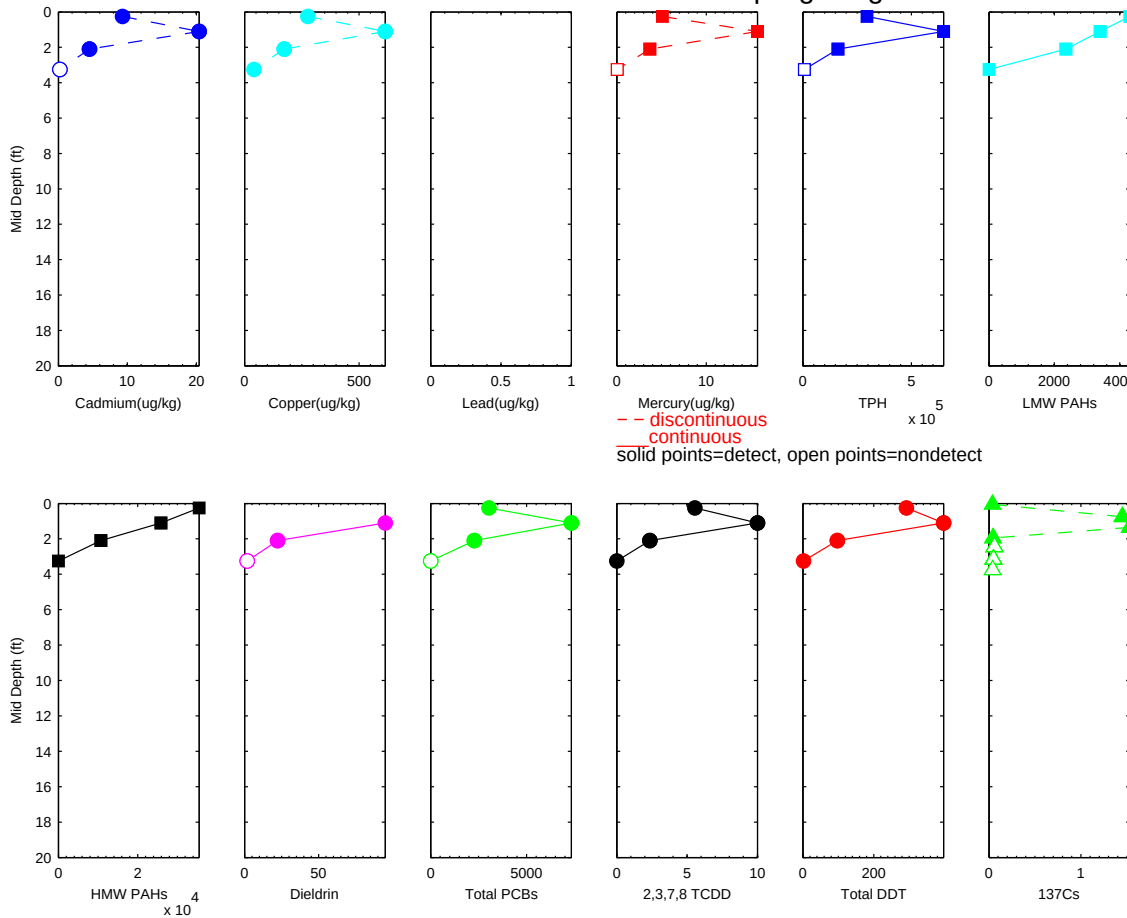
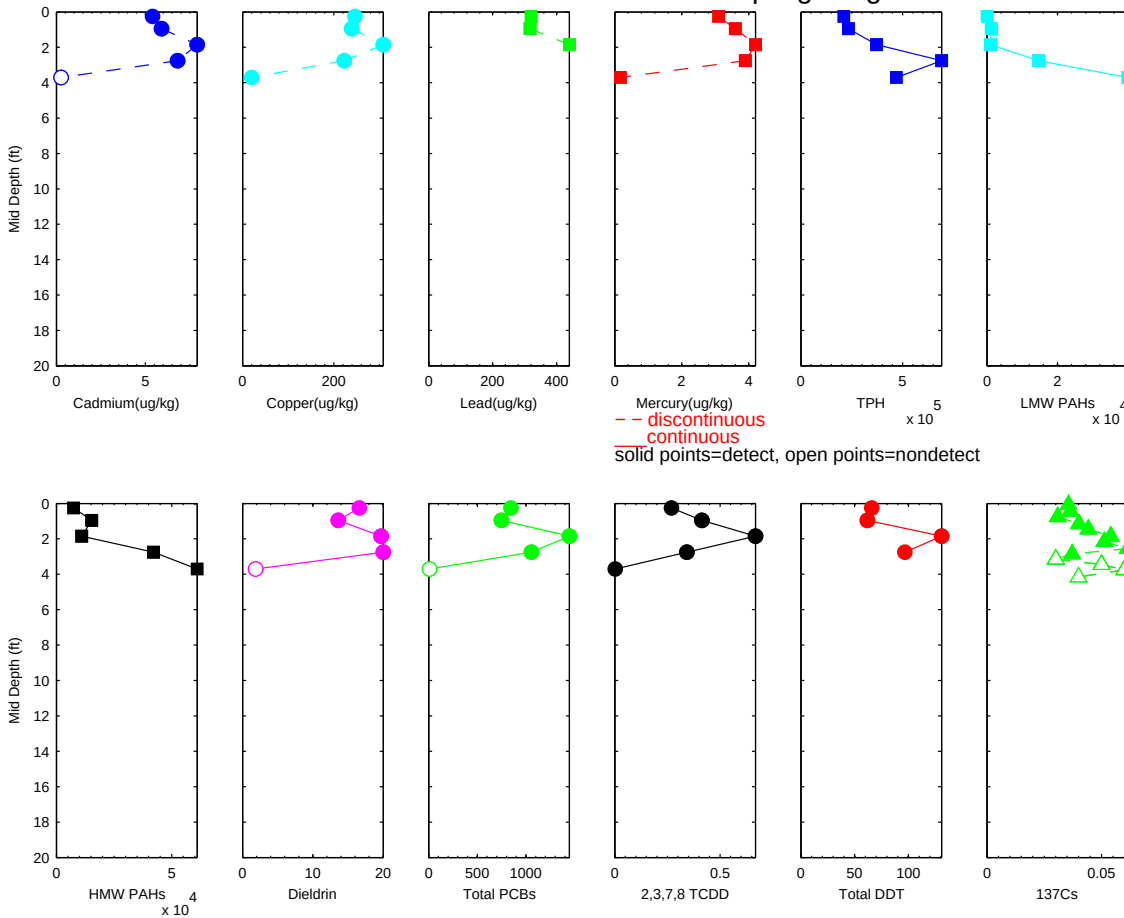


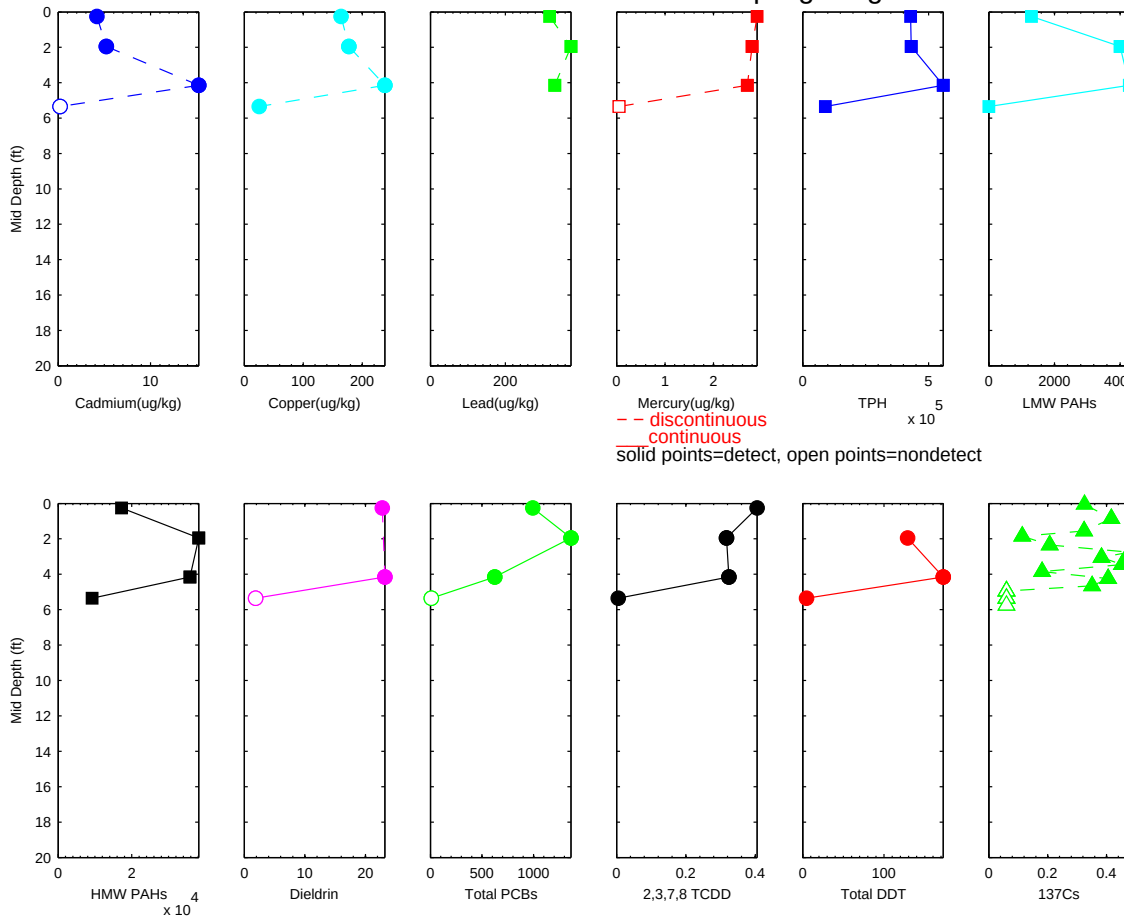
R2-0026802

Sample ID: 258 River Mile 5.35 PASSAIC 1995 RI Sampling Program



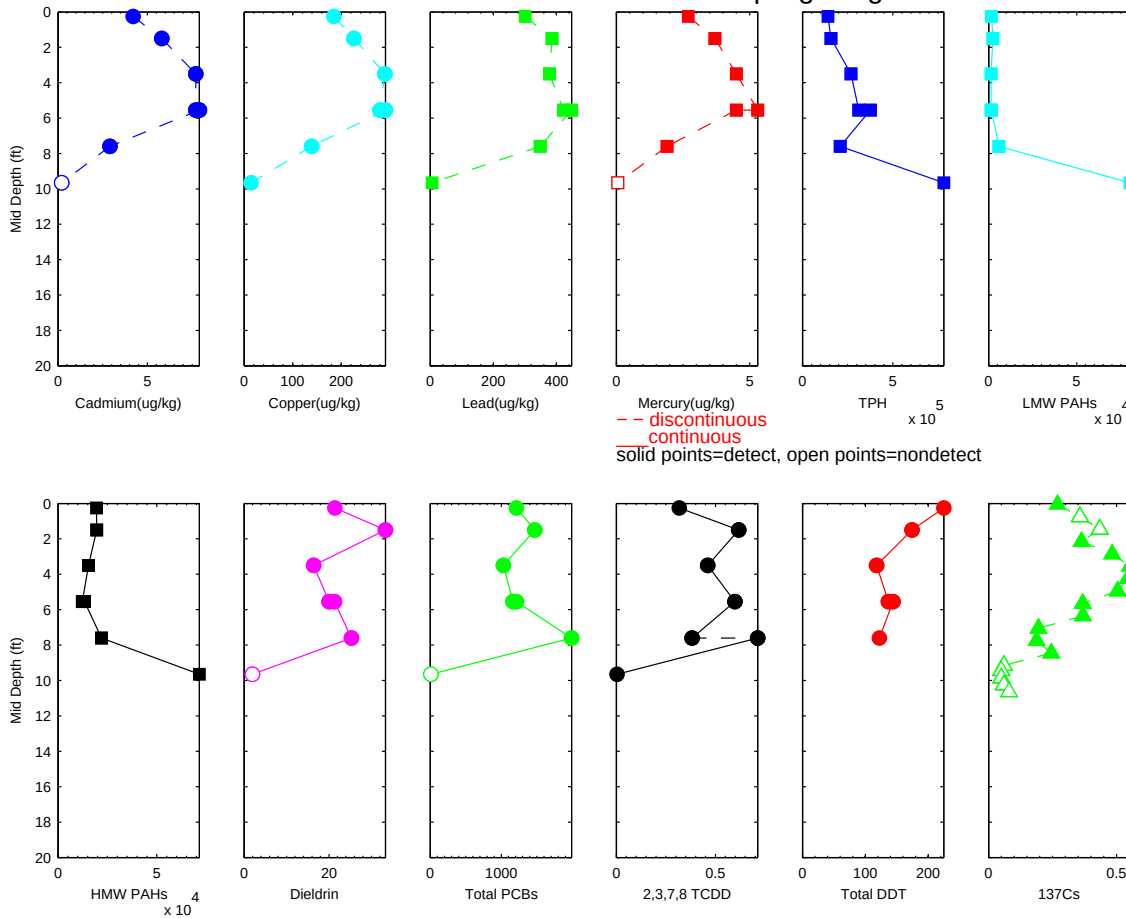
R2-0026803

Sample ID: 256 River Mile 5.16 PASSAIC 1995 RI Sampling Program



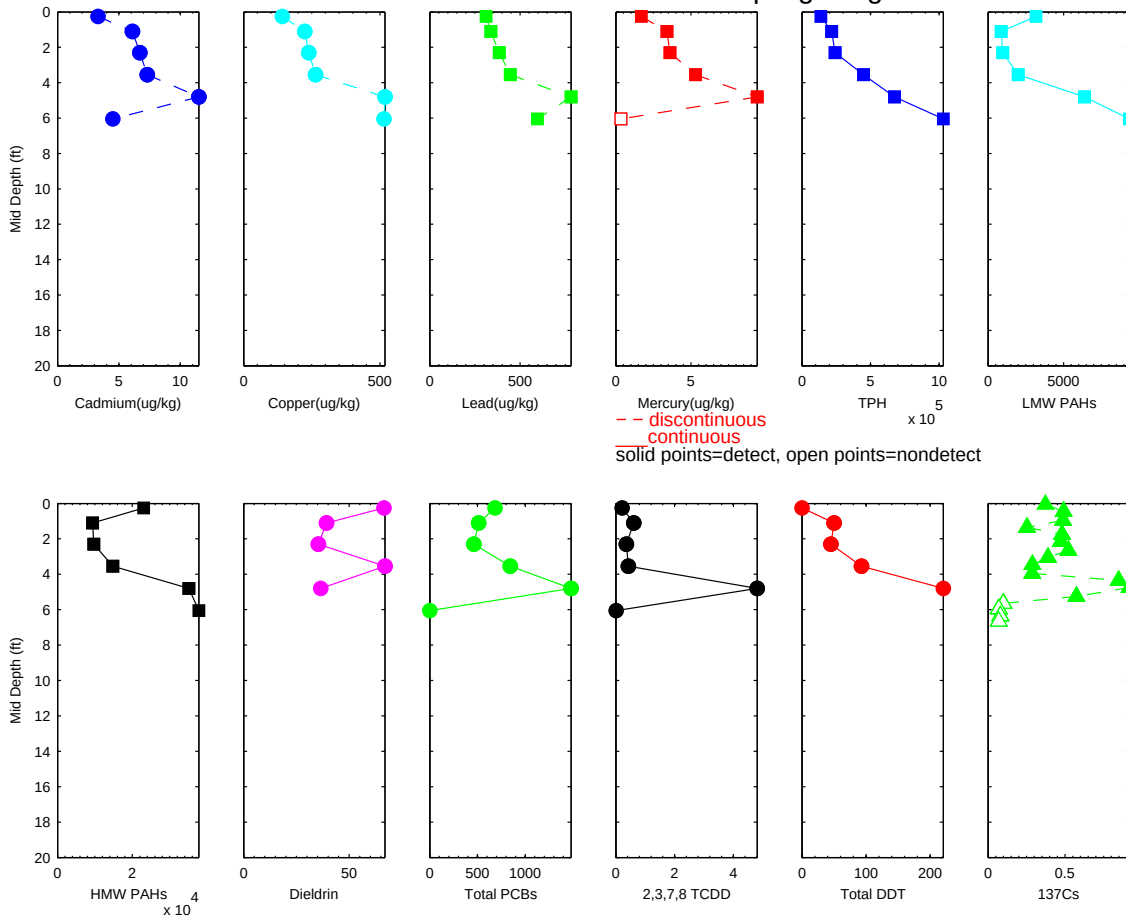
R2-0026804

Sample ID: 255 River Mile 5.16 PASSAIC 1995 RI Sampling Program



R2-0026805

Sample ID: 254 River Mile 4.92 PASSAIC 1995 RI Sampling Program



R2-0026806

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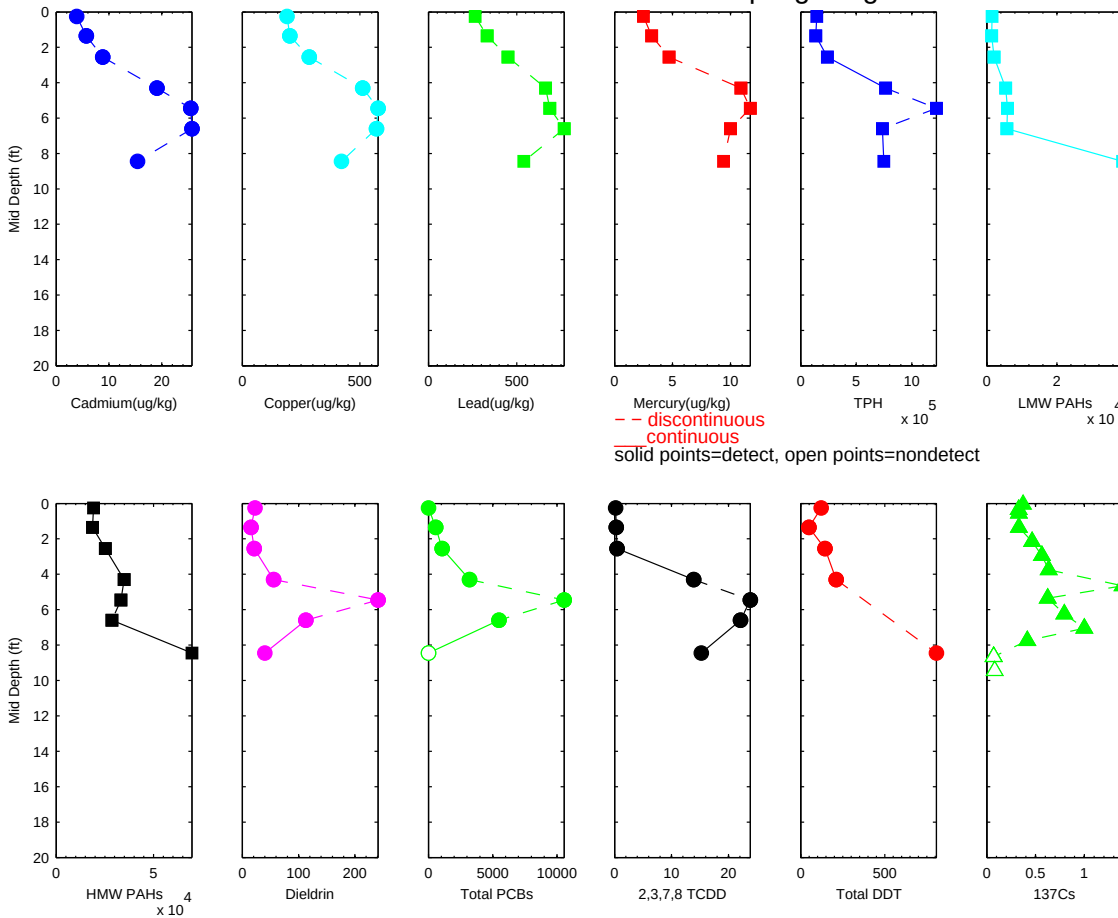

R2-0026807

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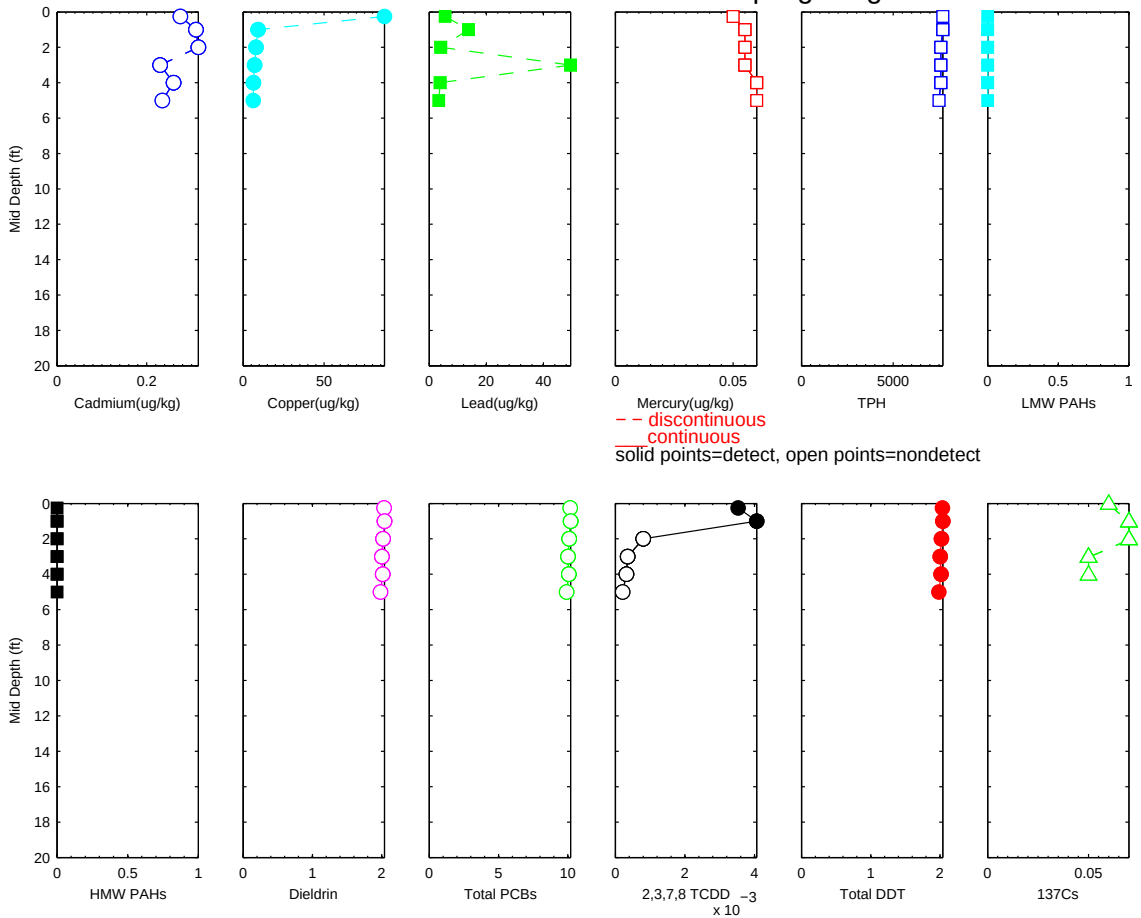
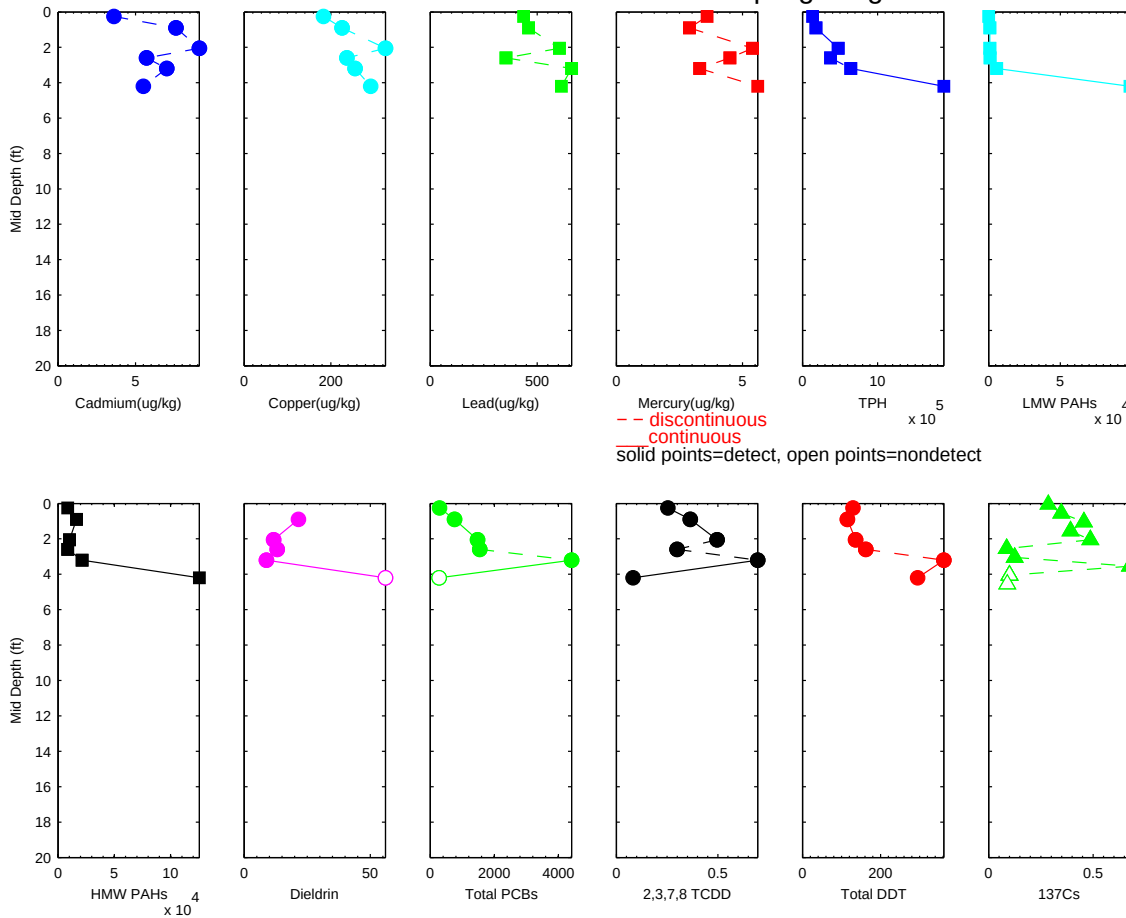


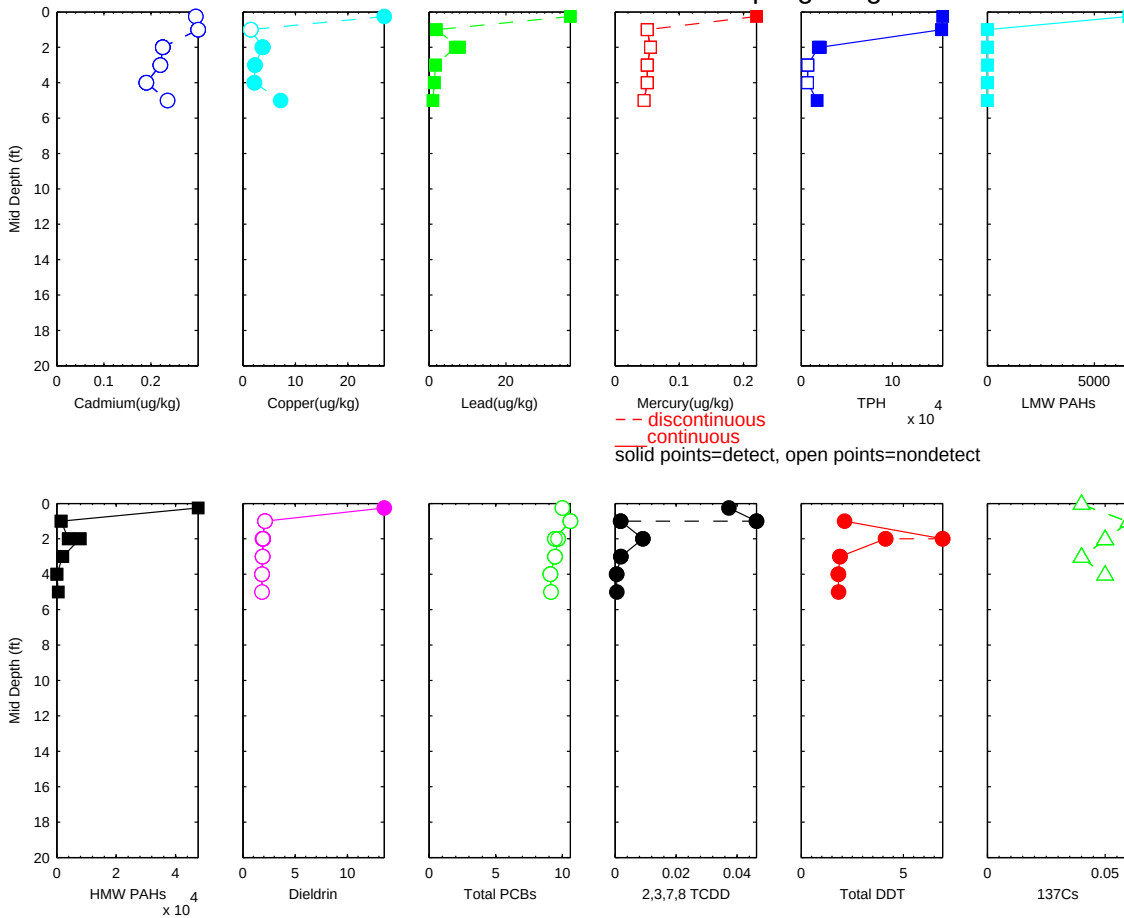
R2-0026808

Sample ID: 249 River Mile 4.68 PASSAIC 1995 RI Sampling Program



R2-0026809

Sample ID: 247 River Mile 4.46 PASSAIC 1995 RI Sampling Program



R2-0026810

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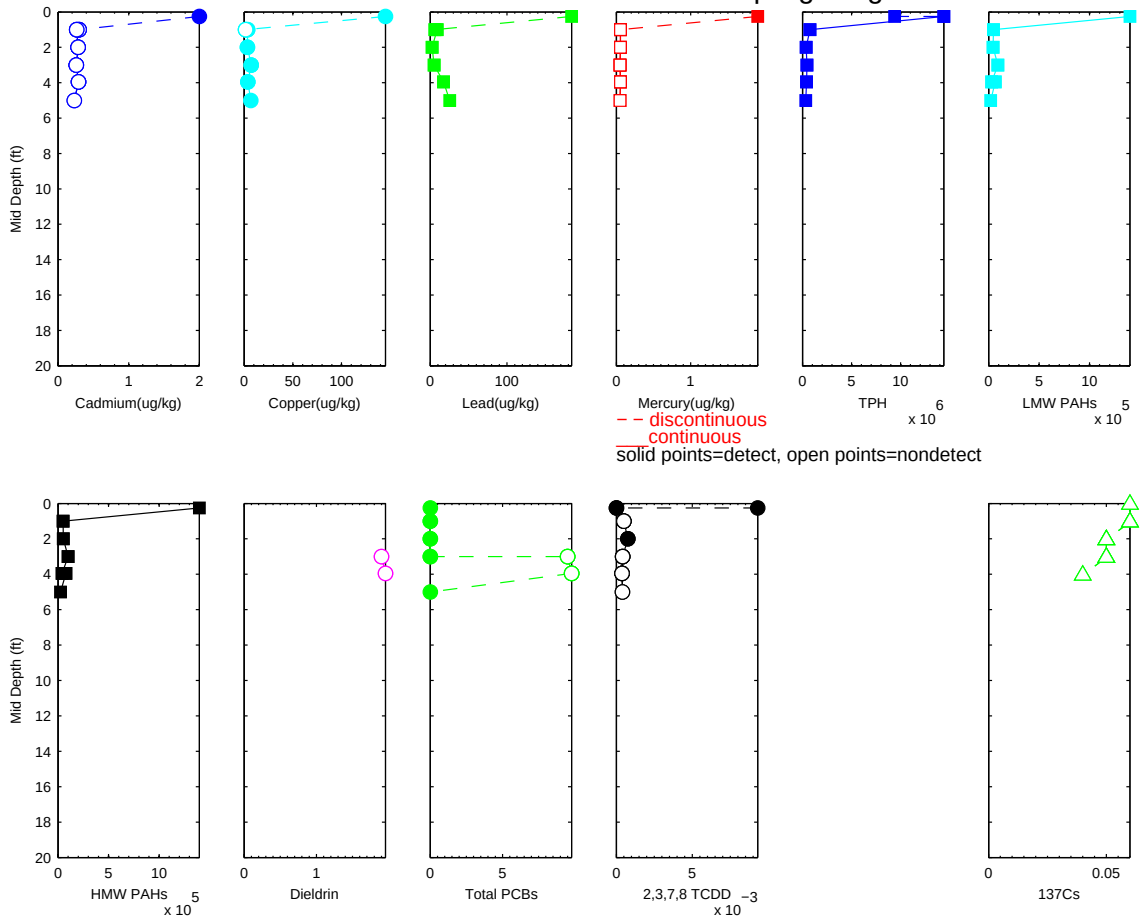
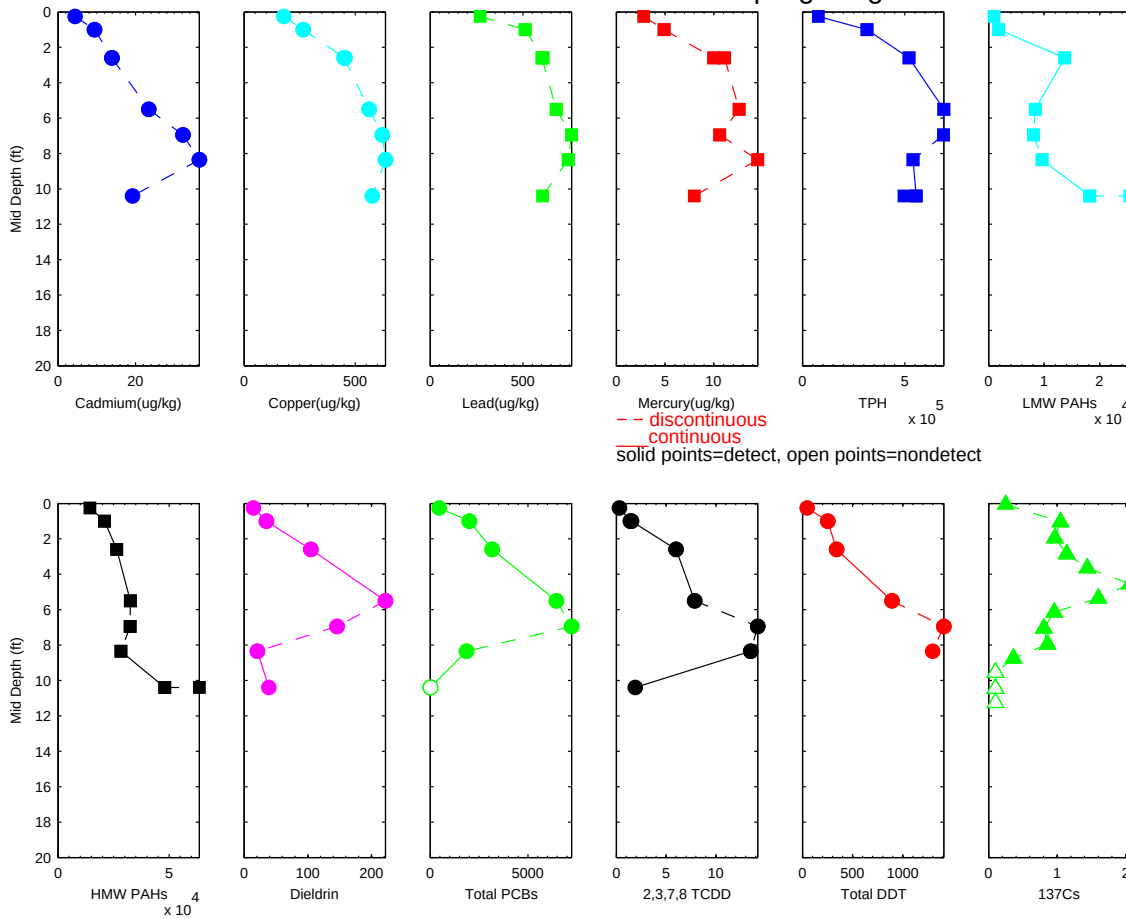


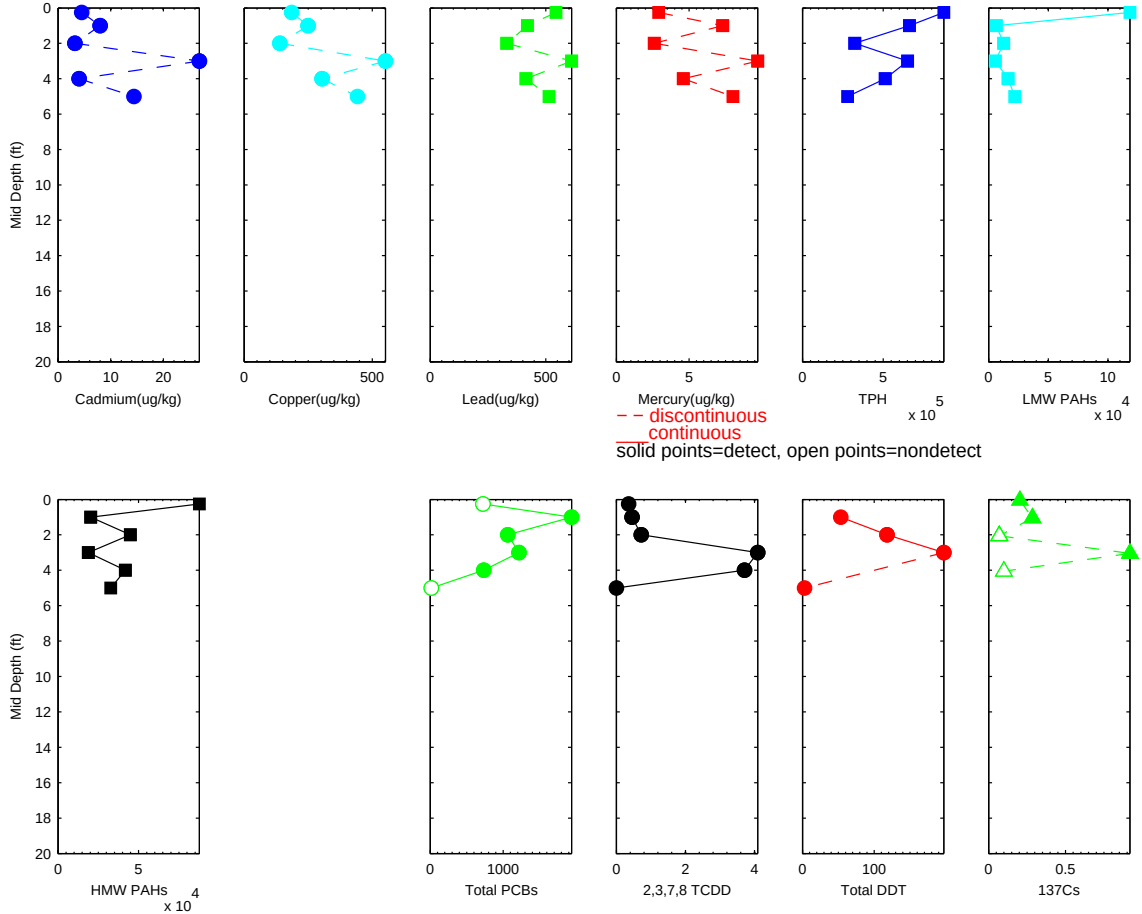
R2-0026811

Sample ID: 245 River Mile 4.23 PASSAIC 1995 RI Sampling Program



R2-0026812

Sample ID: 244 River Mile 4.23 PASSAIC 1995 RI Sampling Program



R2-0026813

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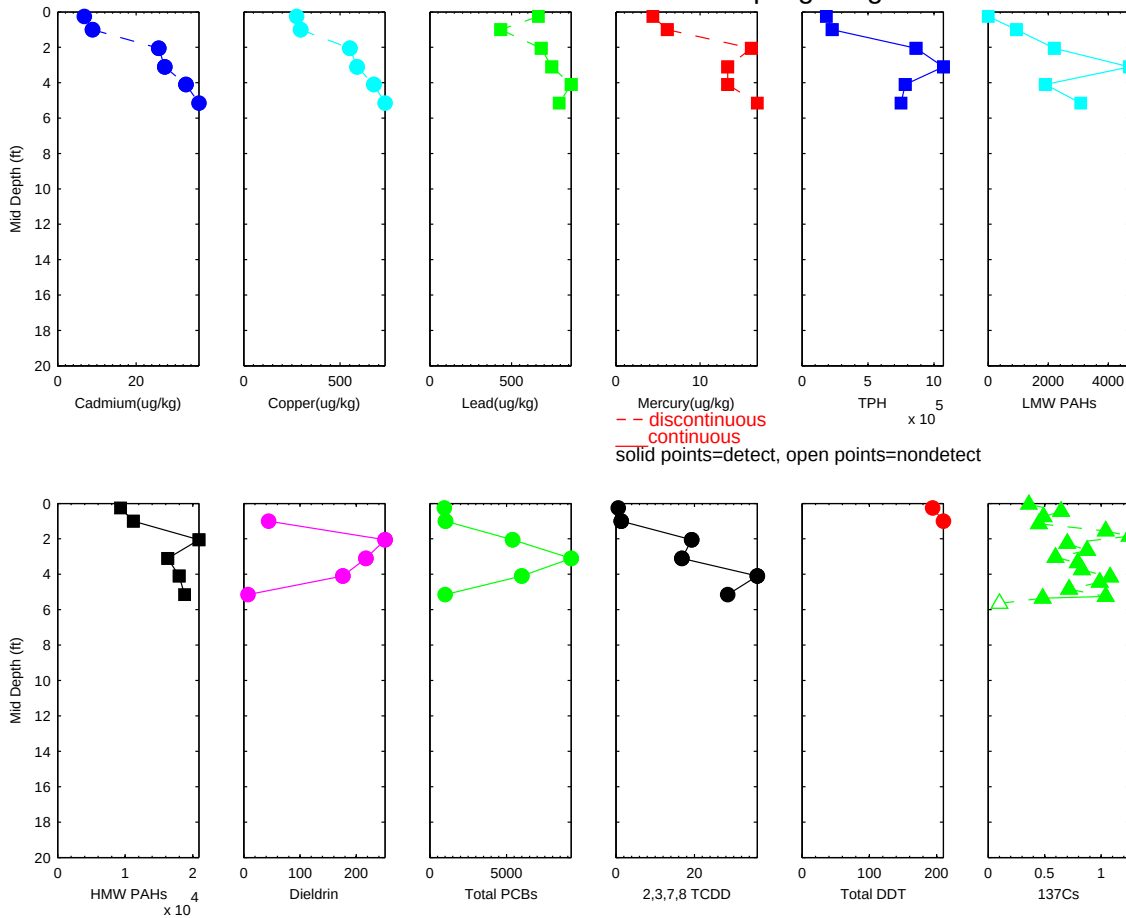
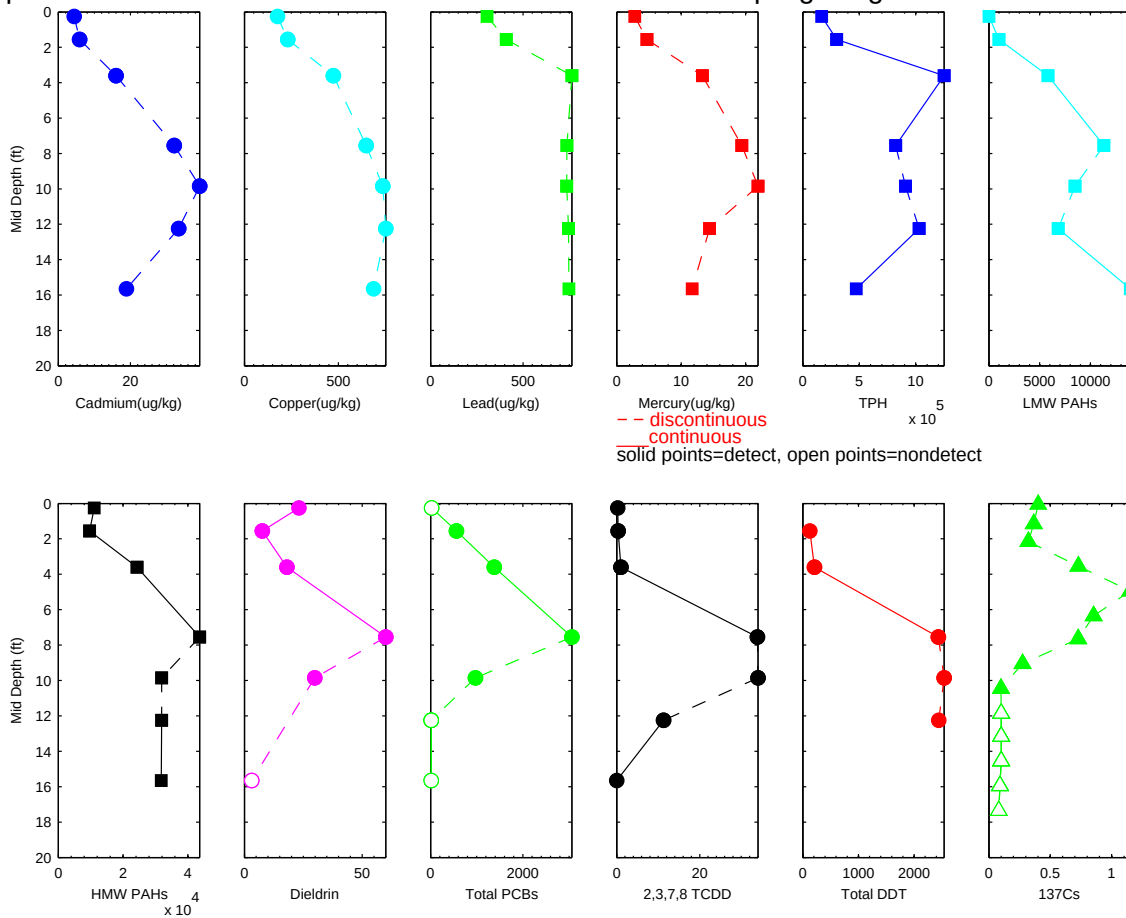


R2-0026814

Sample ID: 242 River Mile 4 PASSAIC 1995 RI Sampling Program



R2-0026815

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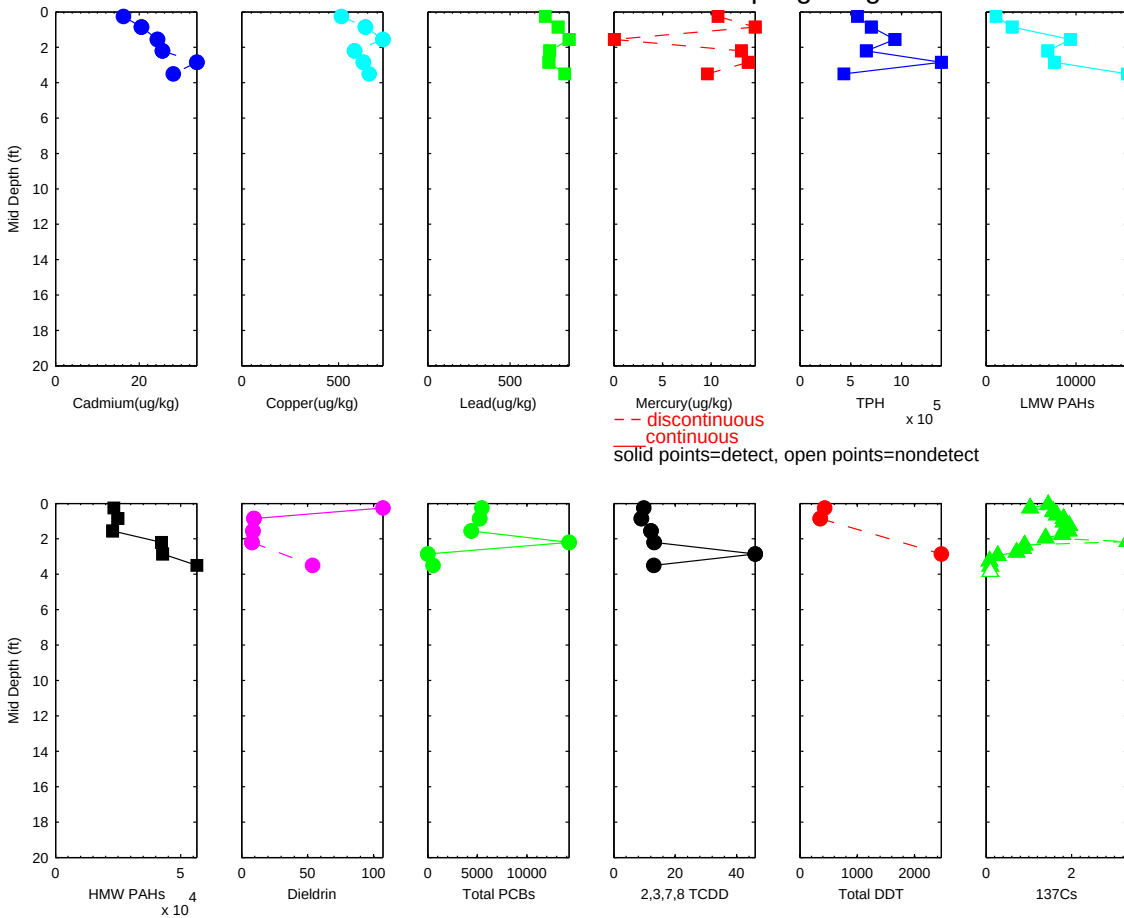

R2-0026816

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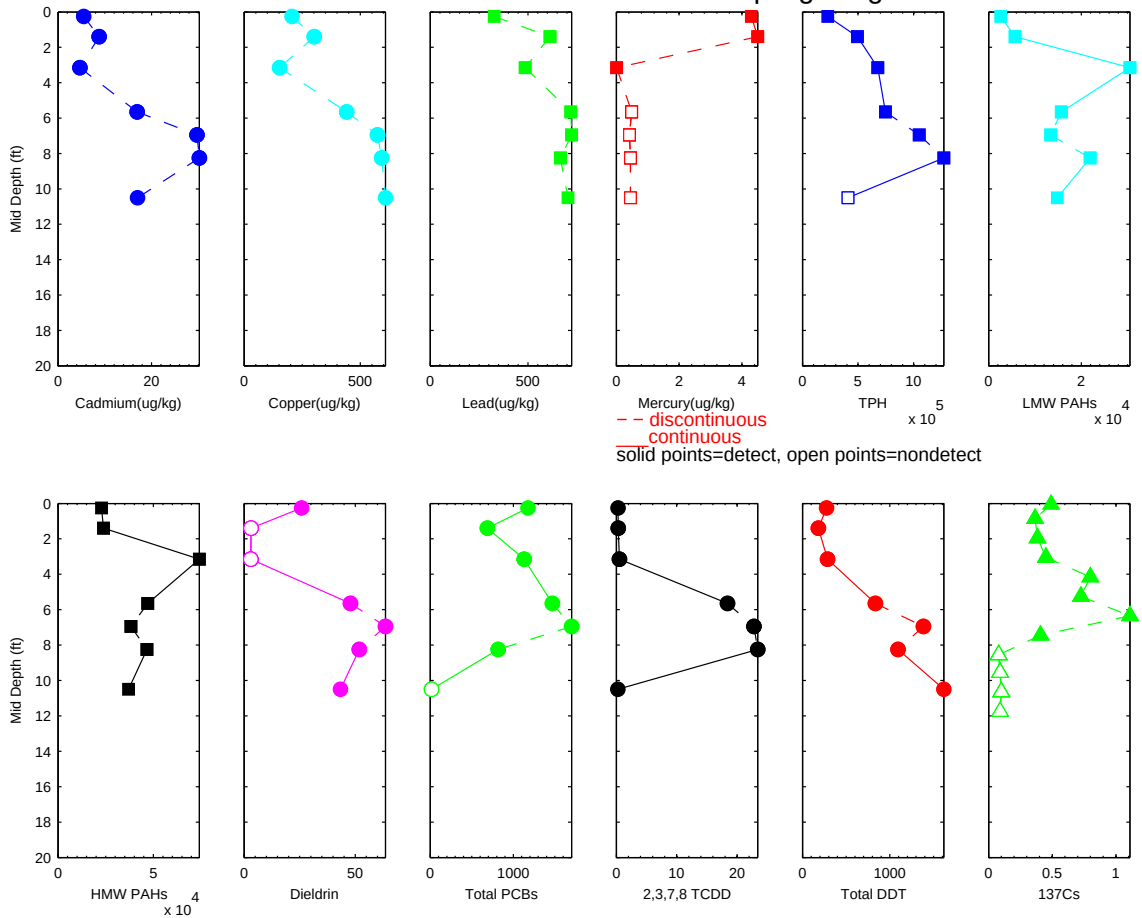

R2-0026817

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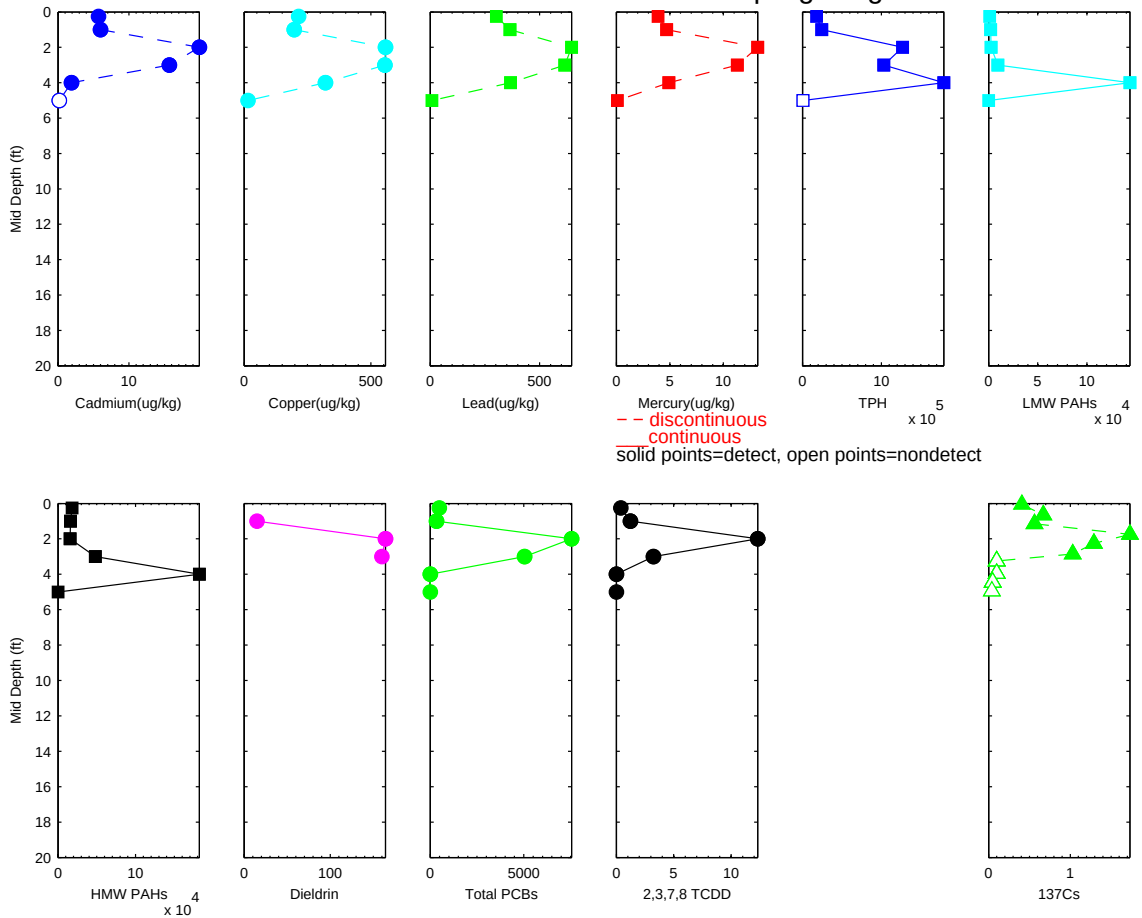

R2-0026818

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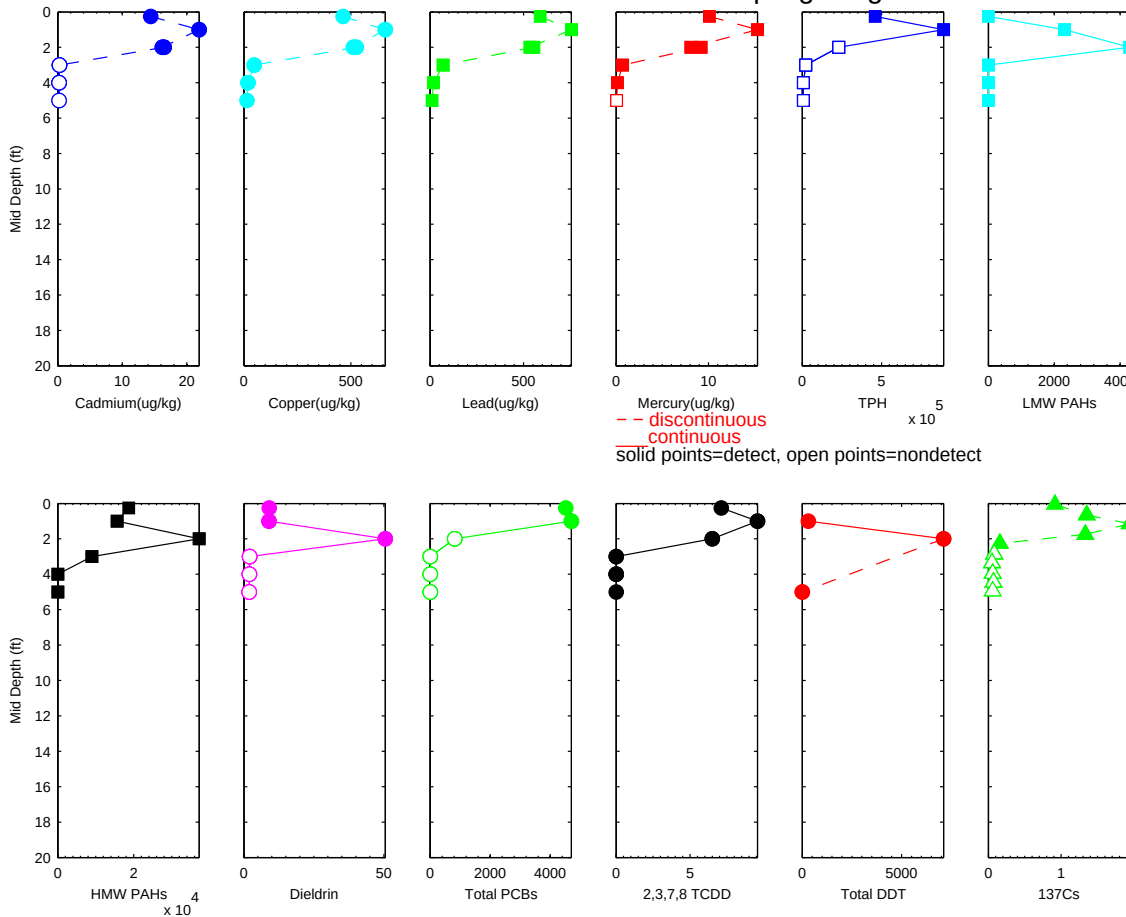

R2-0026819

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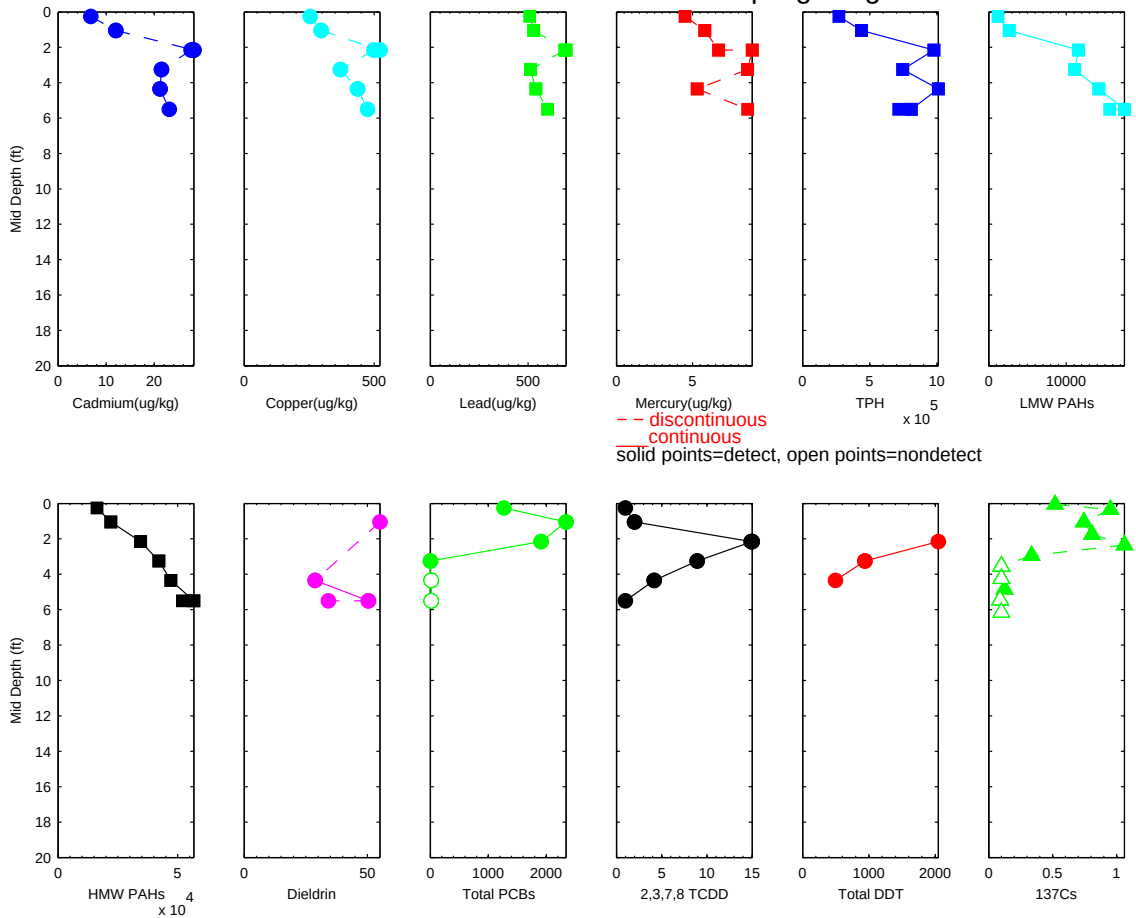

R2-0026820

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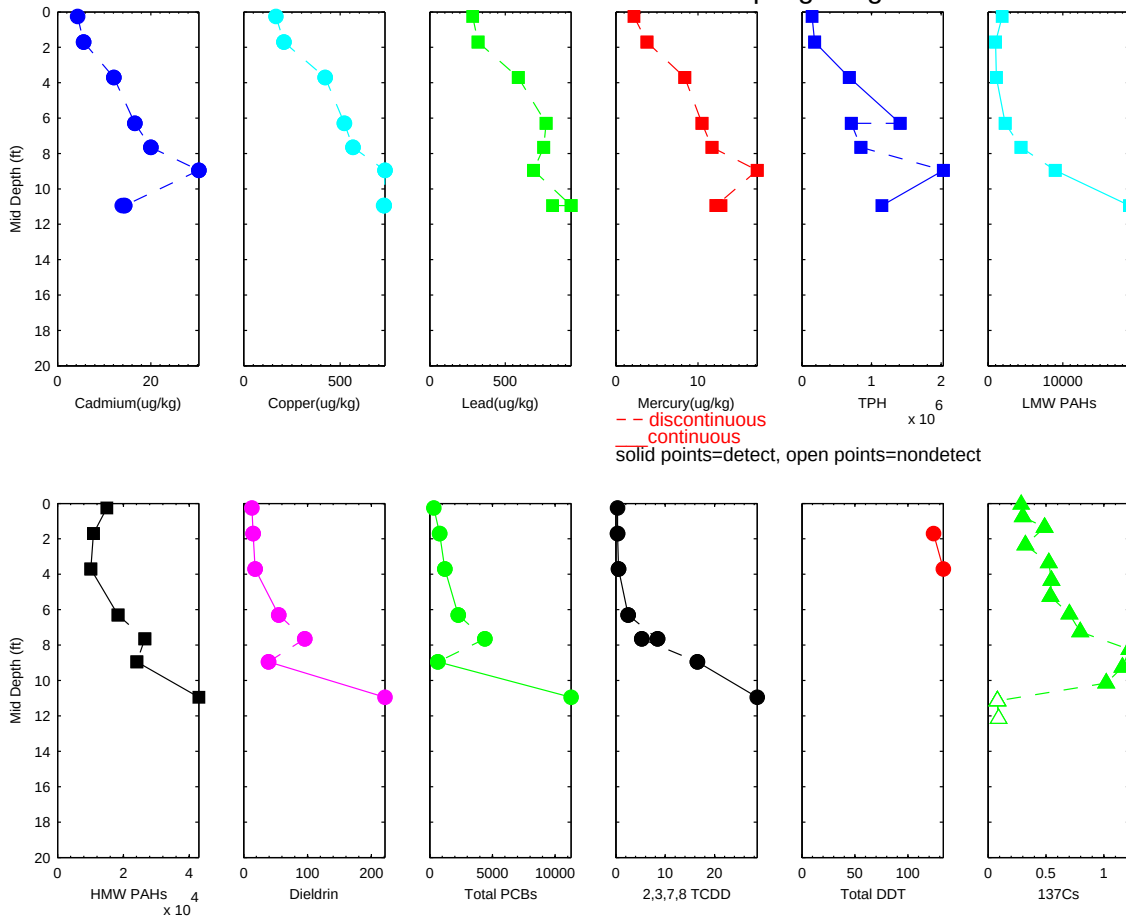

R2-0026821

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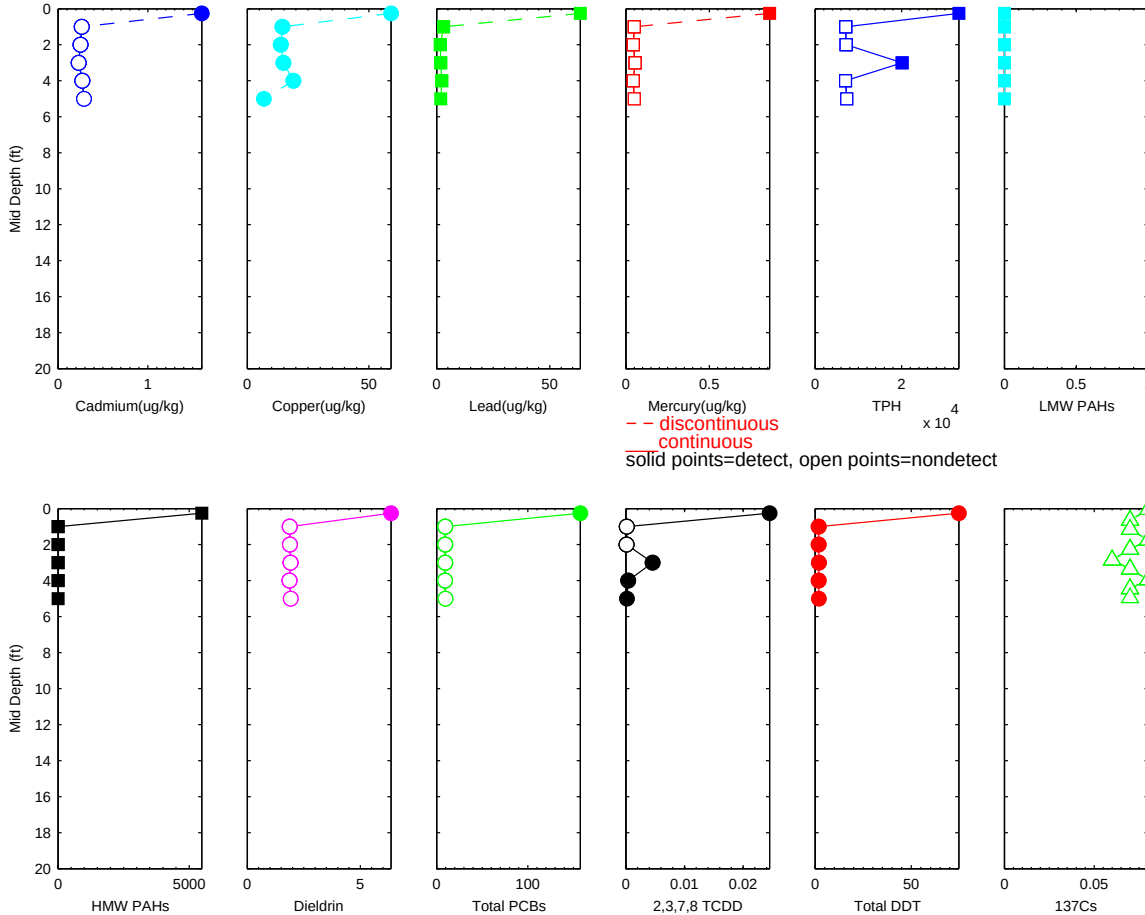

R2-0026822

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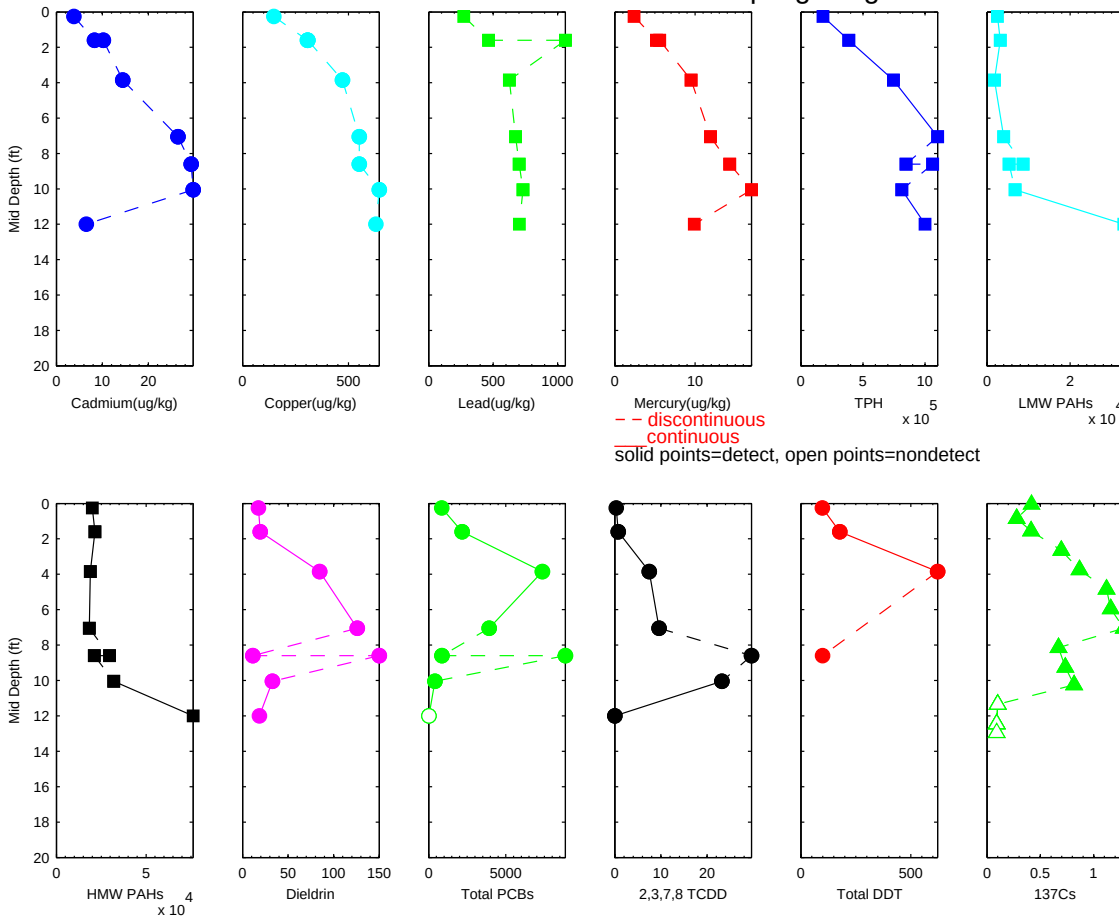

R2-0026823

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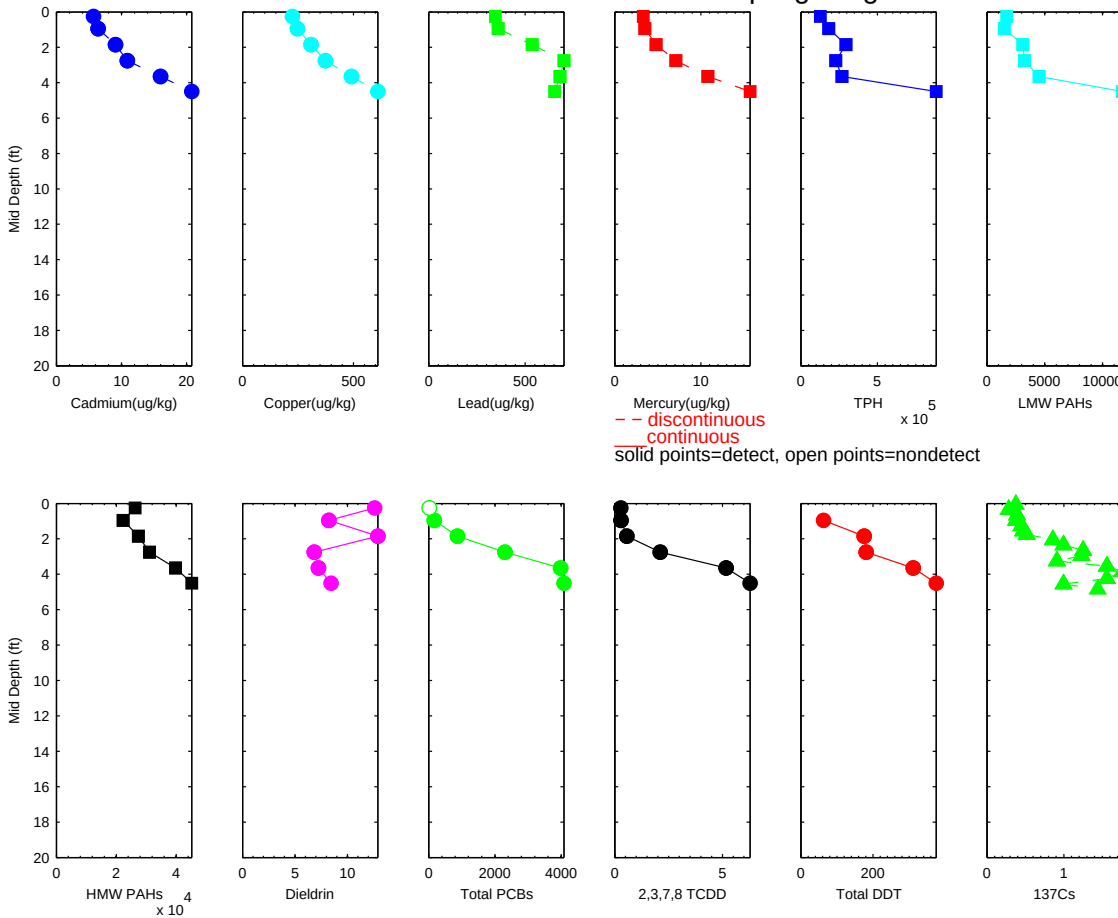
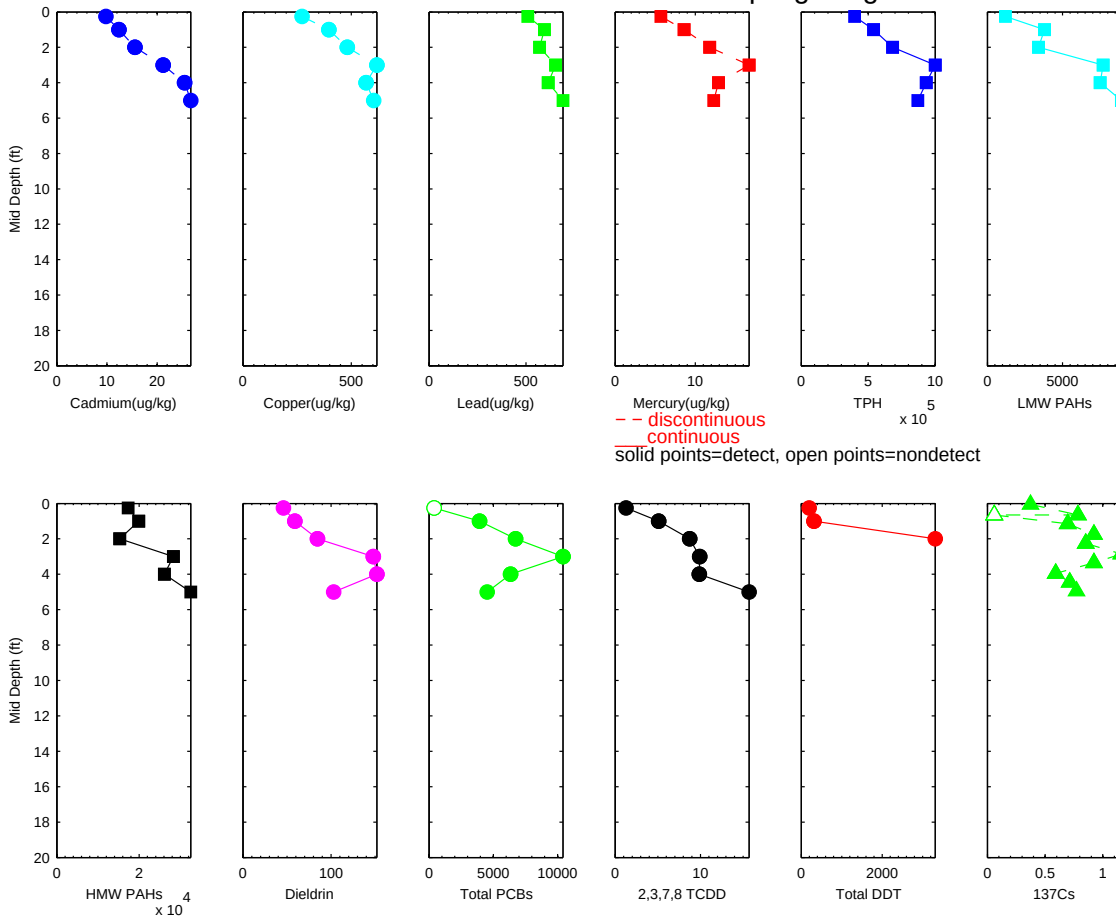


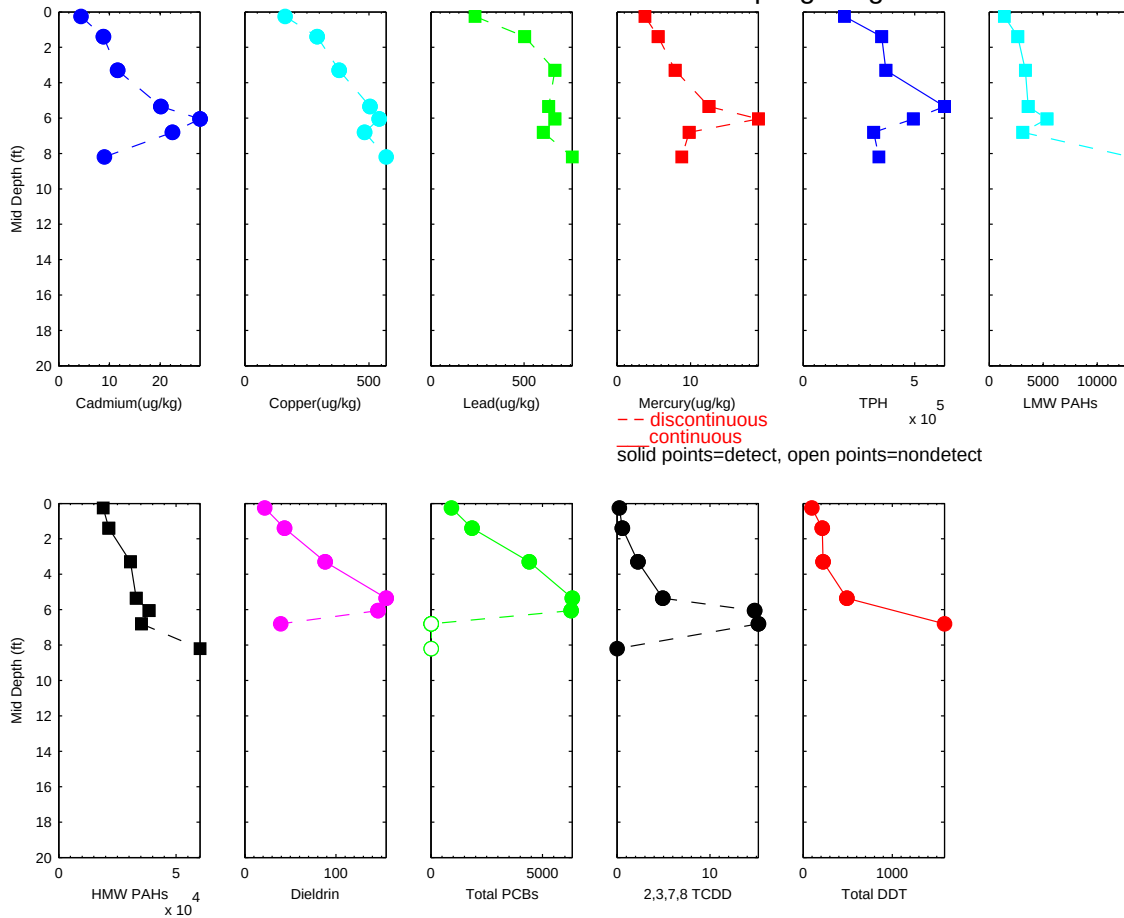
R2-0026824

Sample ID: 227 River Mile 2.86 PASSAIC 1995 RI Sampling Program



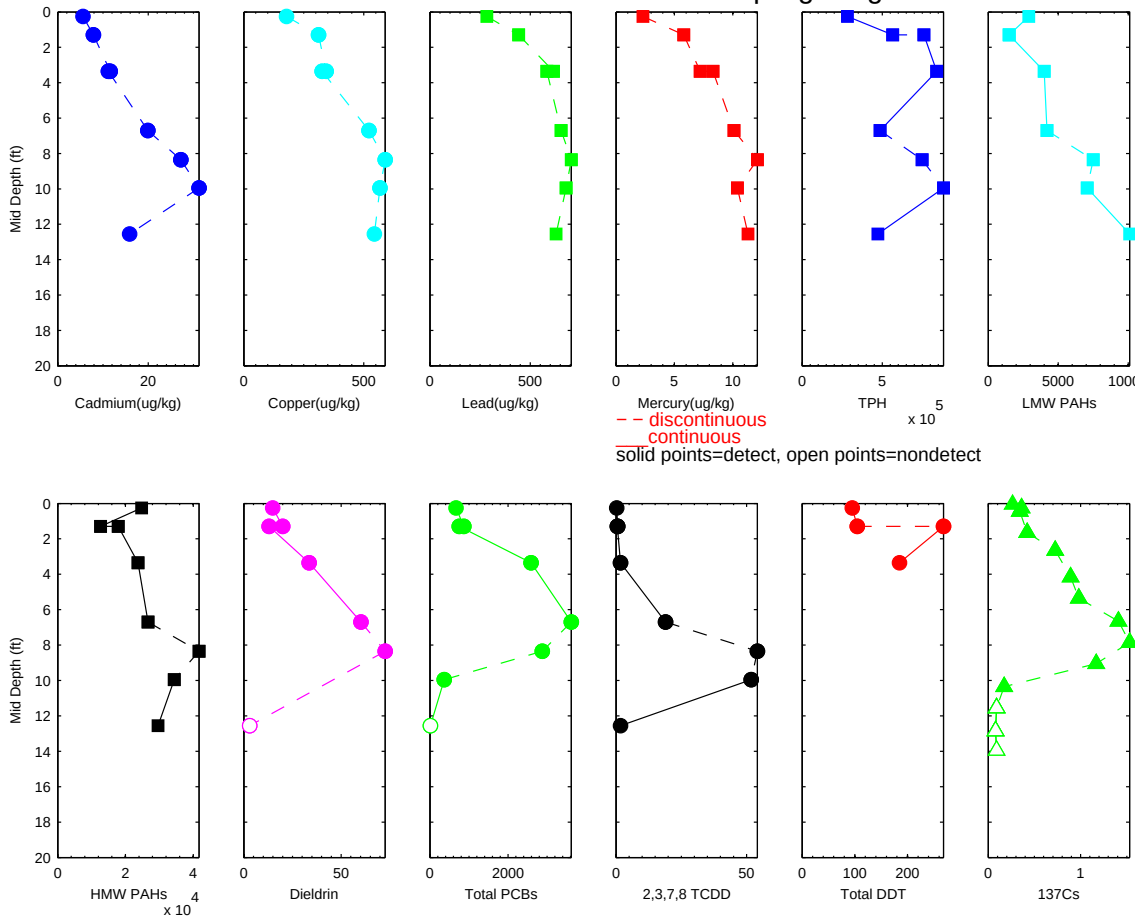
R2-0026825

Sample ID: 226 River Mile 2.86 PASSAIC 1995 RI Sampling Program



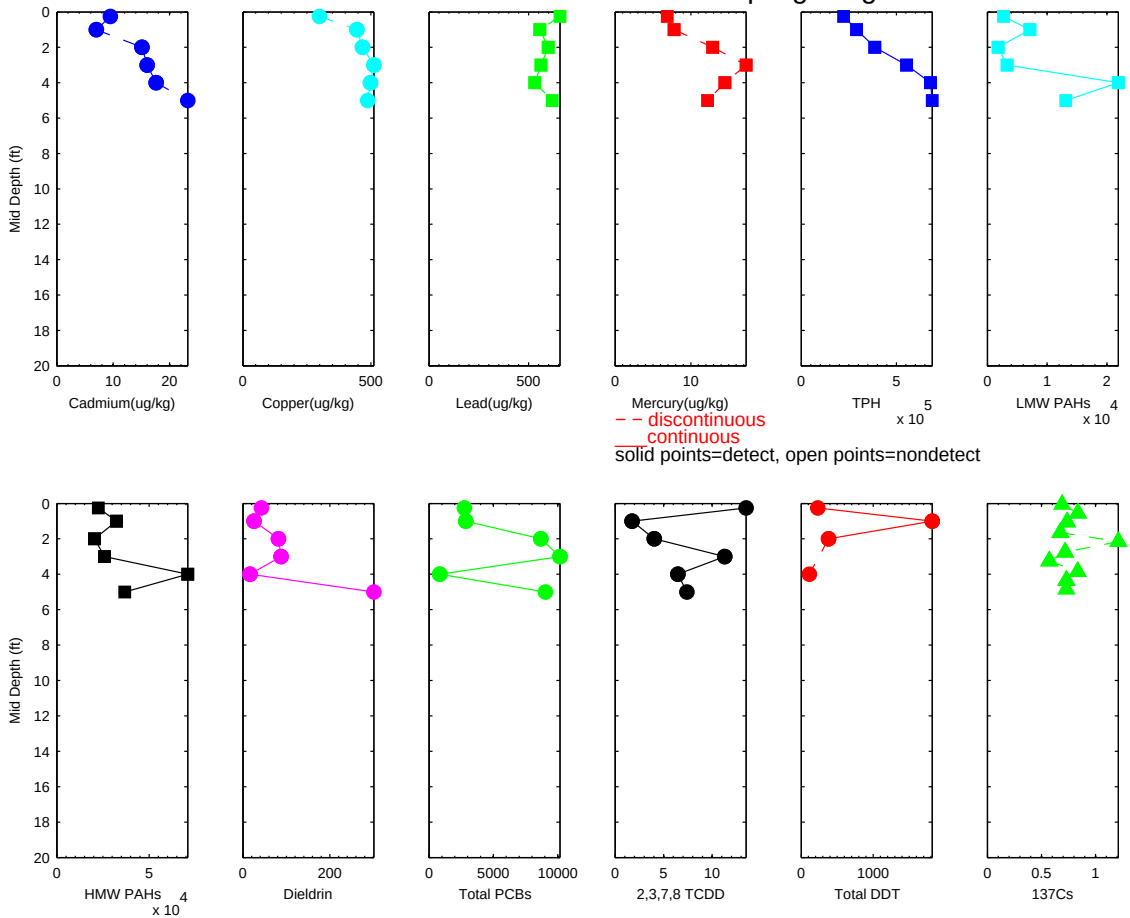
R2-0026826

Sample ID: 225 River Mile 2.86 PASSAIC 1995 RI Sampling Program



R2-0026827

Sample ID: 224 River Mile 2.63 PASSAIC 1995 RI Sampling Program



R2-0026828

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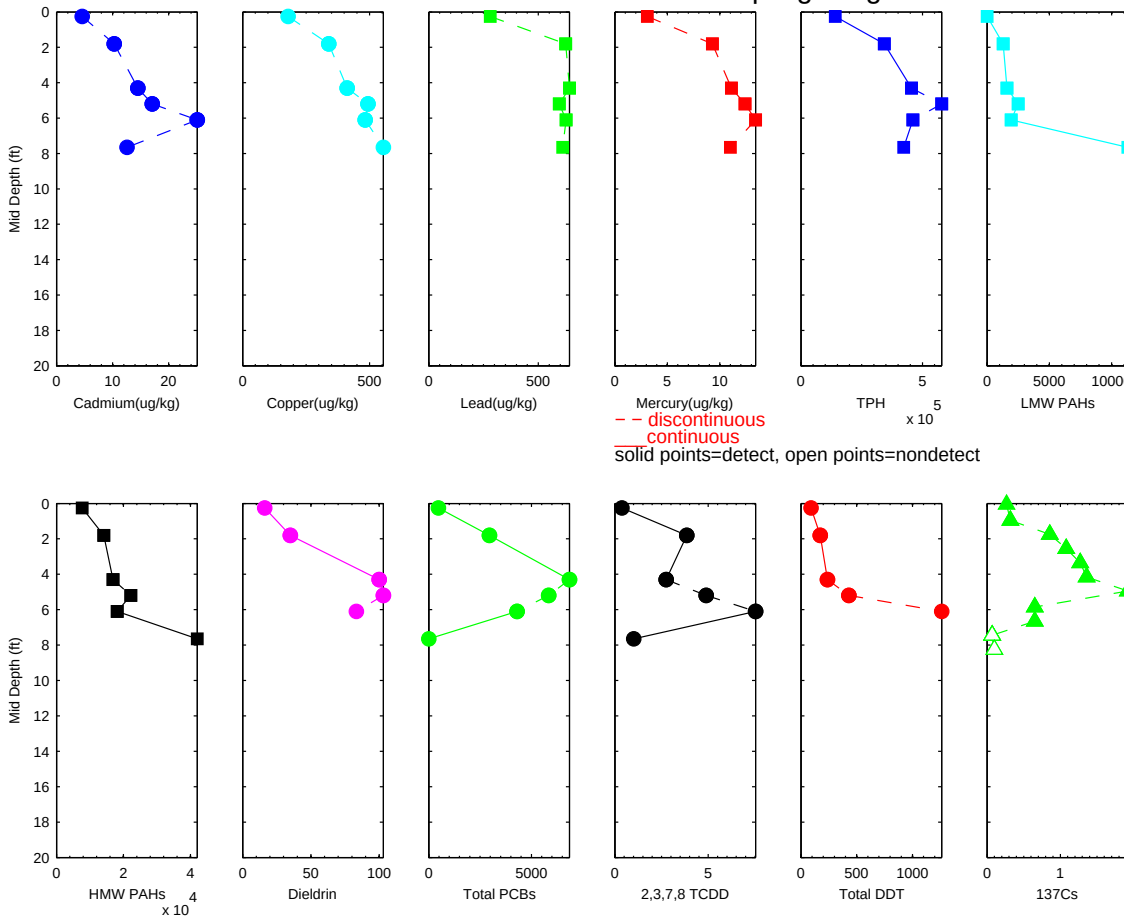

R2-0026829

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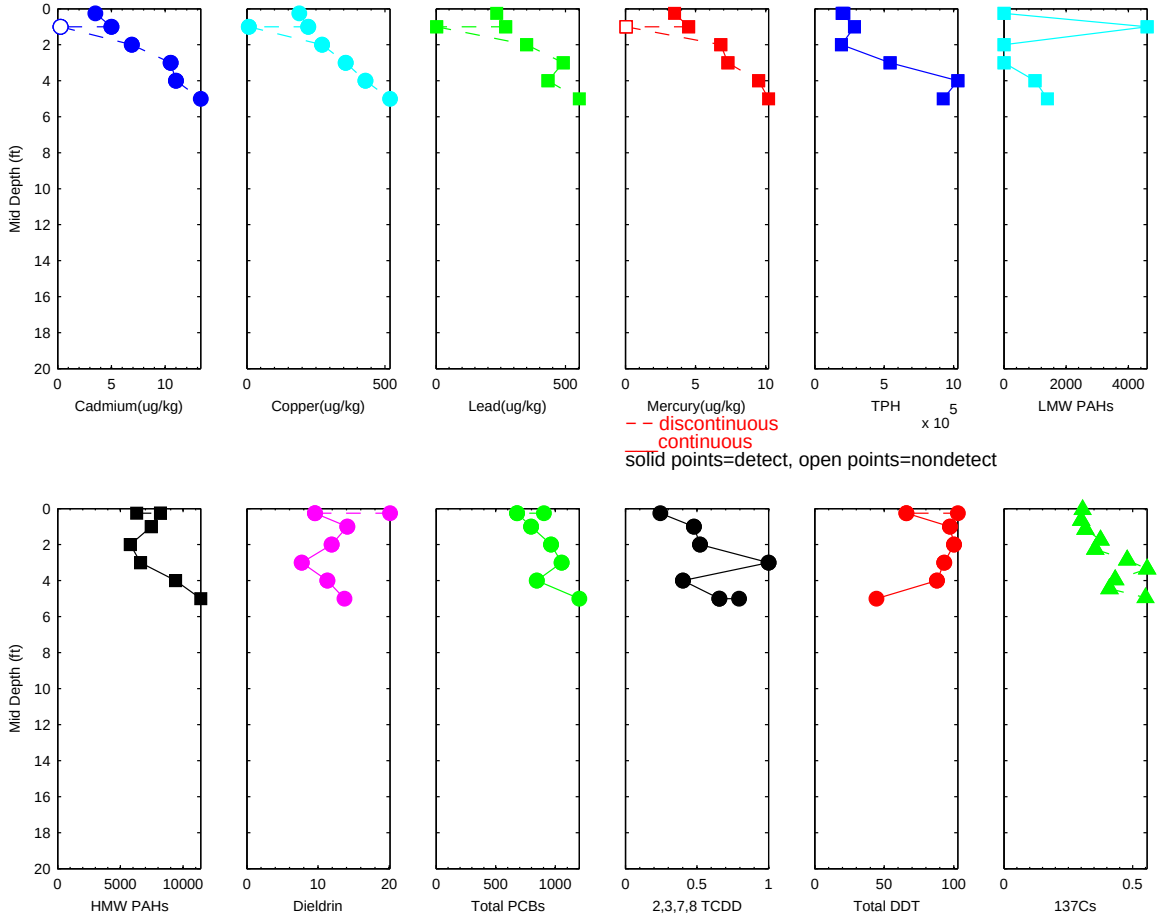
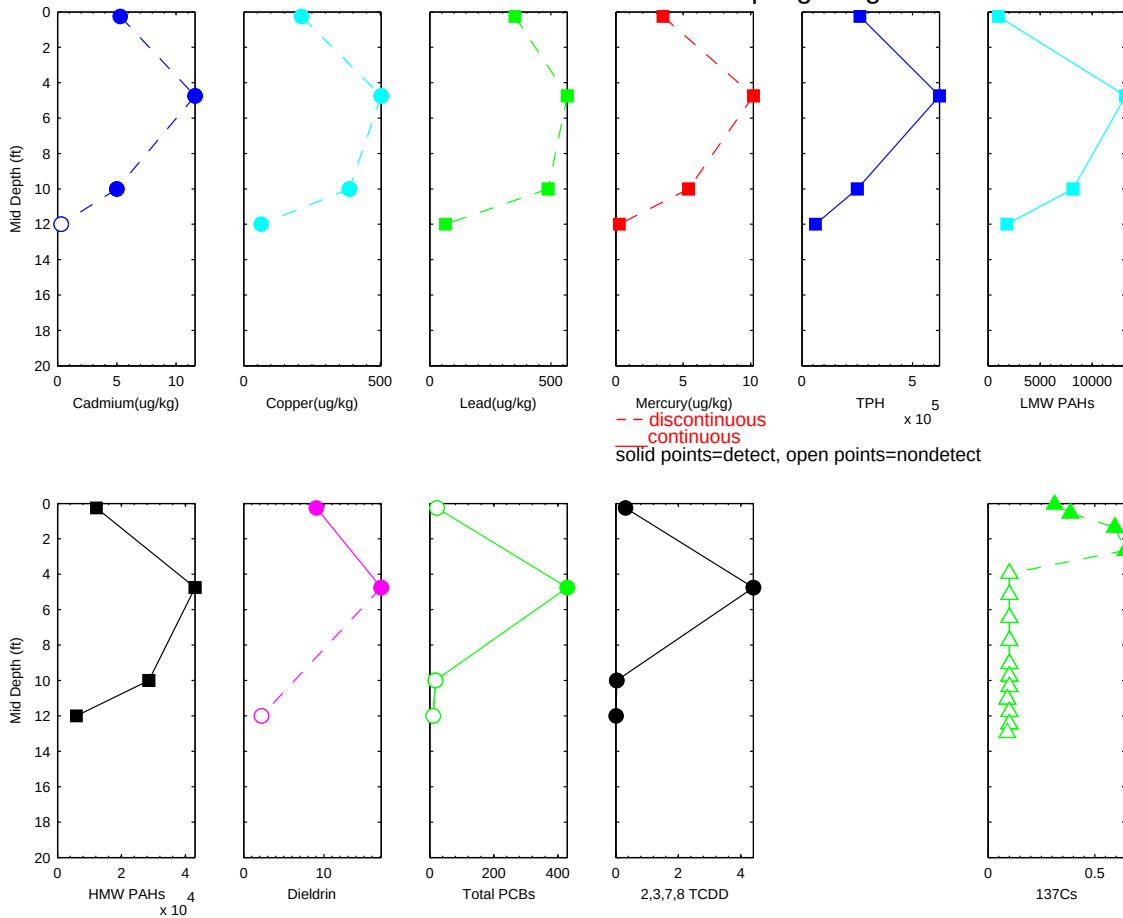


R2-0026830

Sample ID: 217 River Mile 2.2 PASSAIC 1995 RI Sampling Program



R2-0026831

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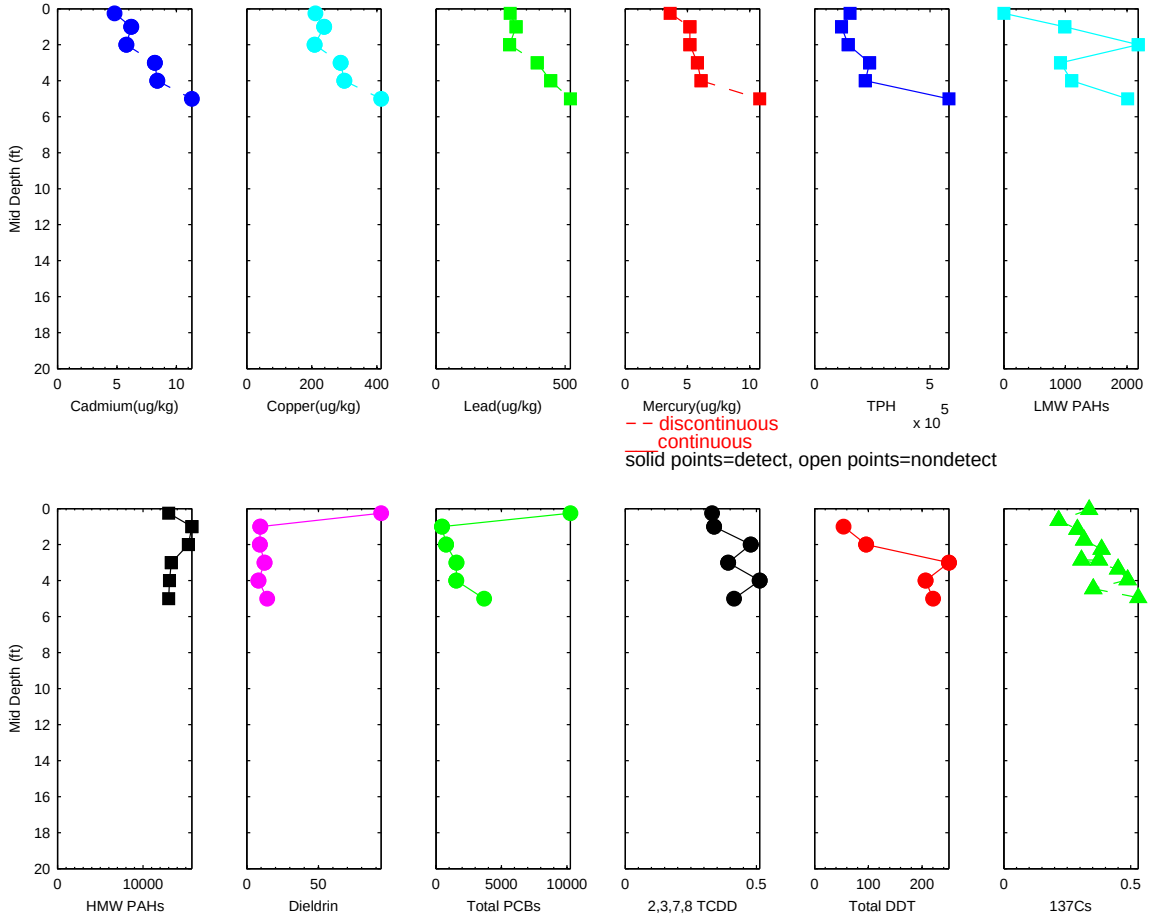

R2-0026832

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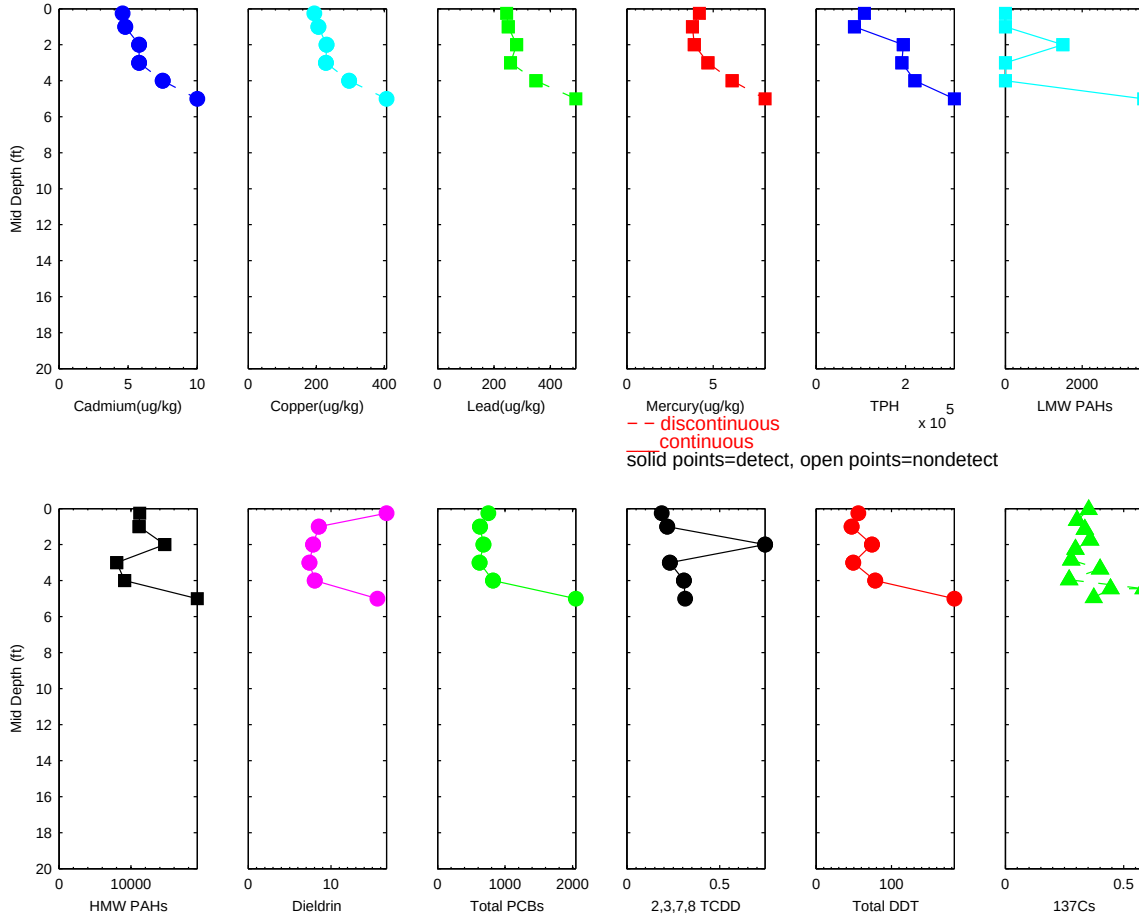

R2-0026833

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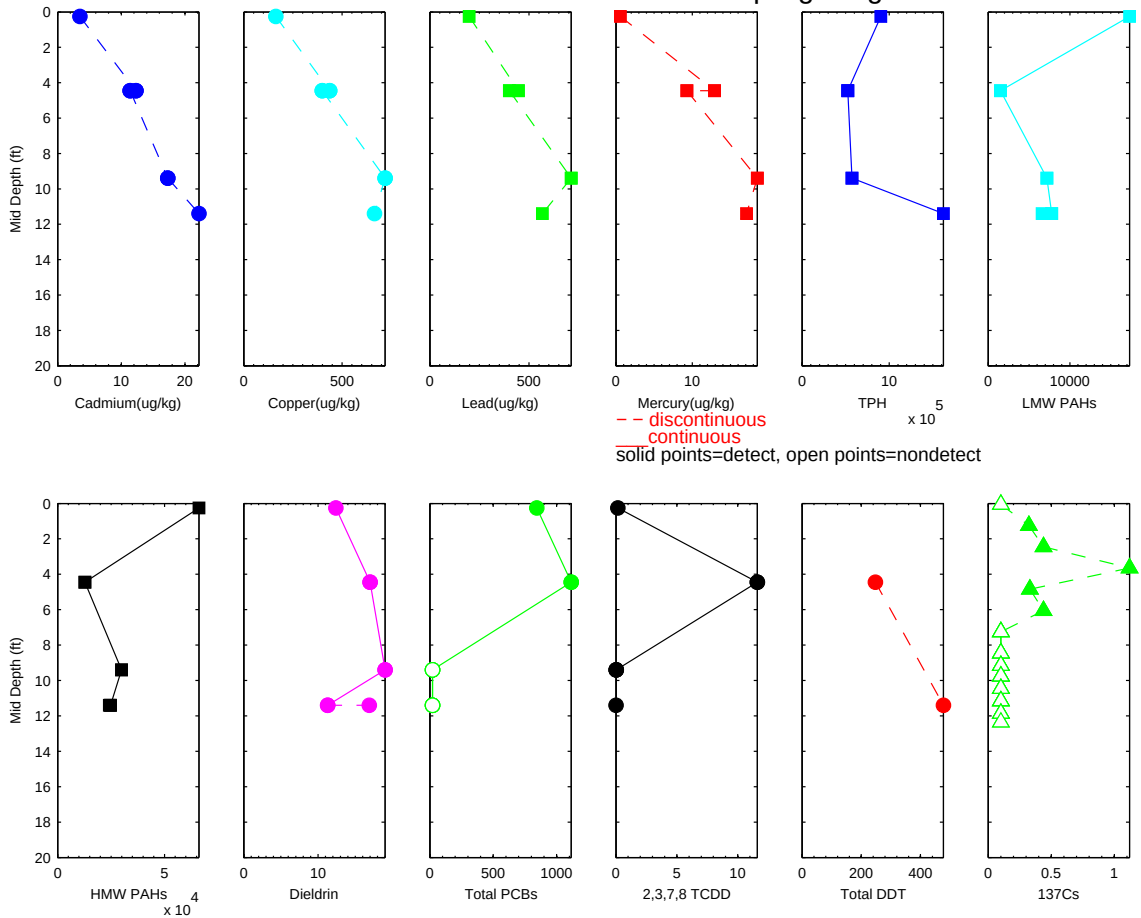

R2-0026834

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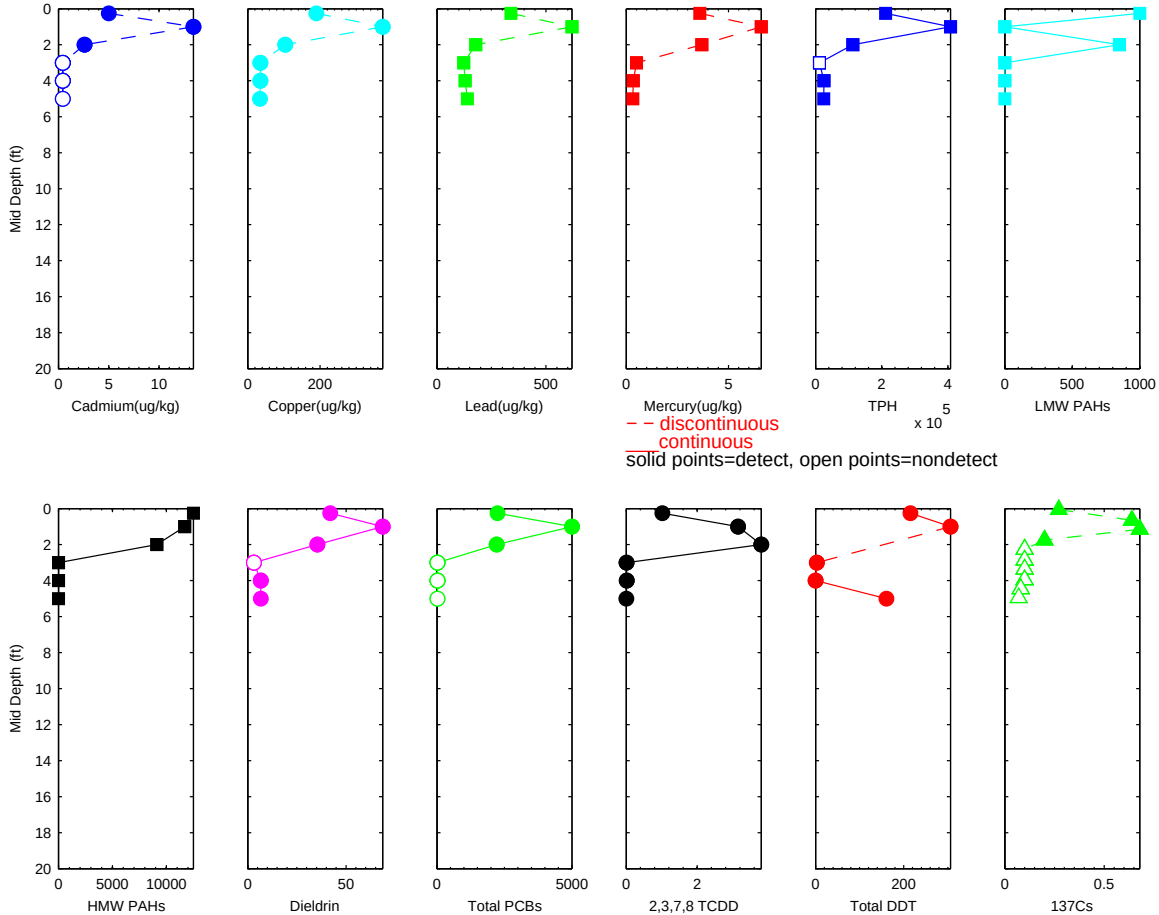
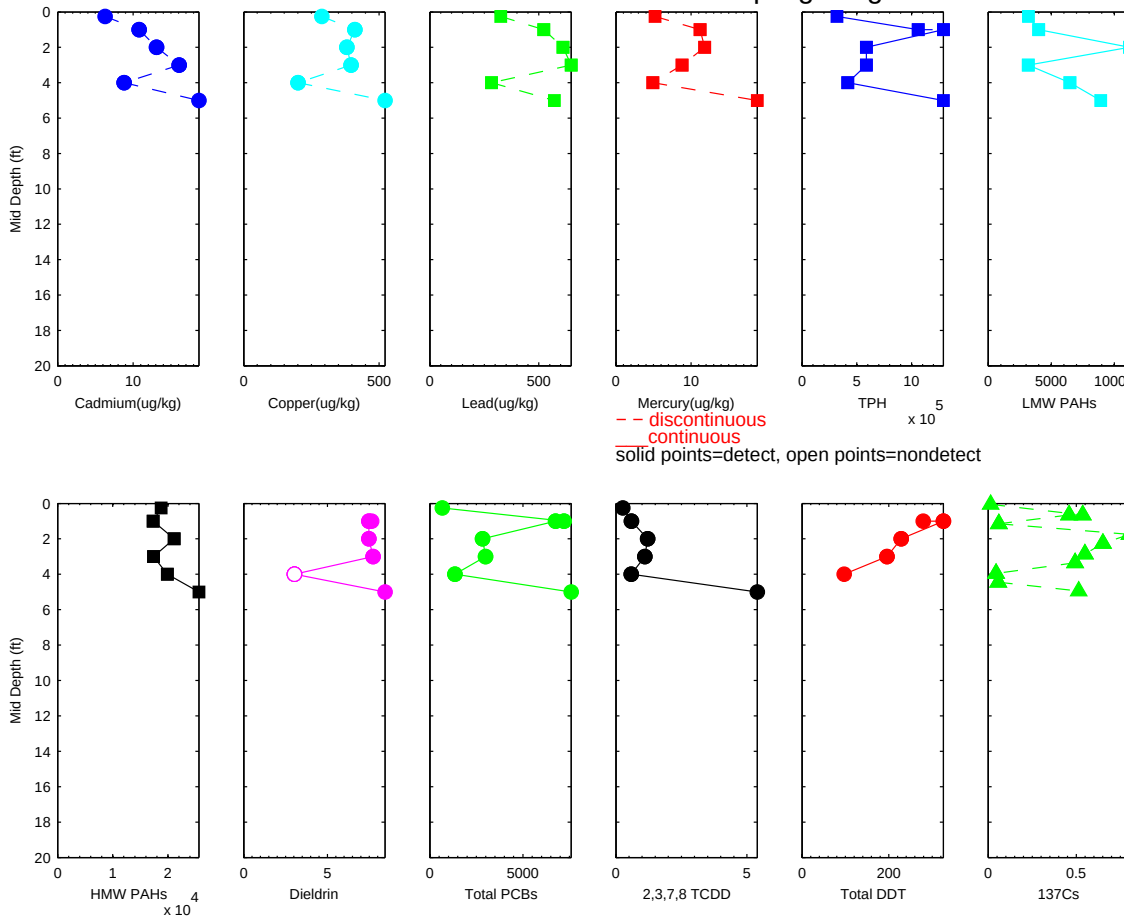


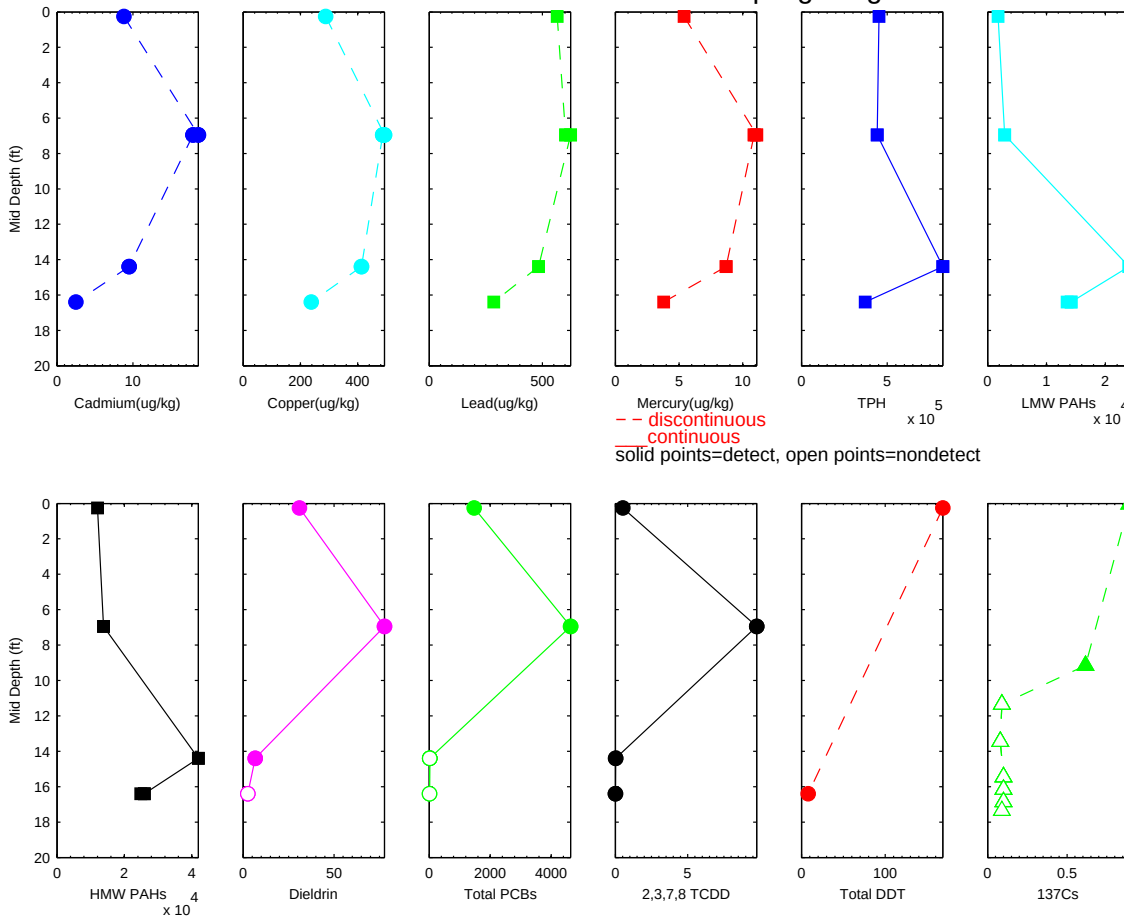
R2-0026835

Sample ID: 212 River Mile 1.7 PASSAIC 1995 RI Sampling Program



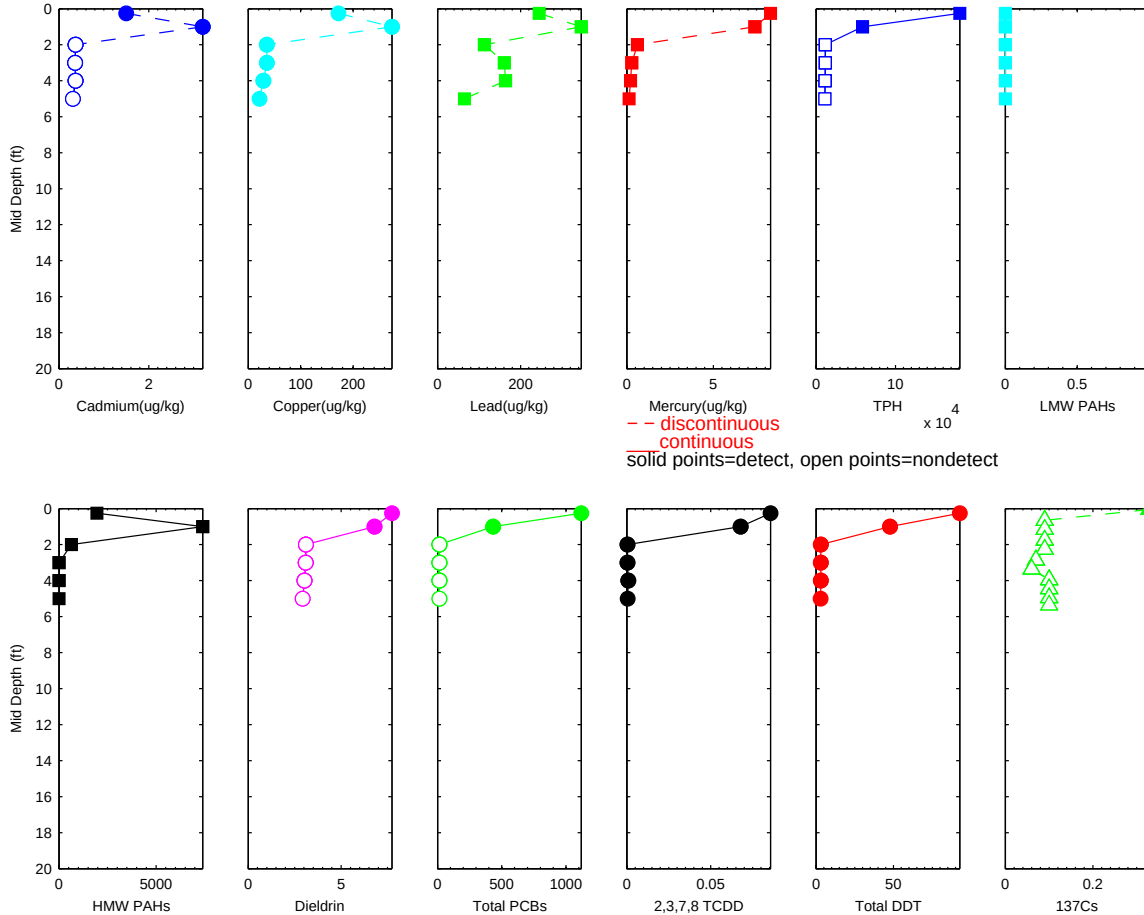
R2-0026836

Sample ID: 211 River Mile 1.7 PASSAIC 1995 RI Sampling Program



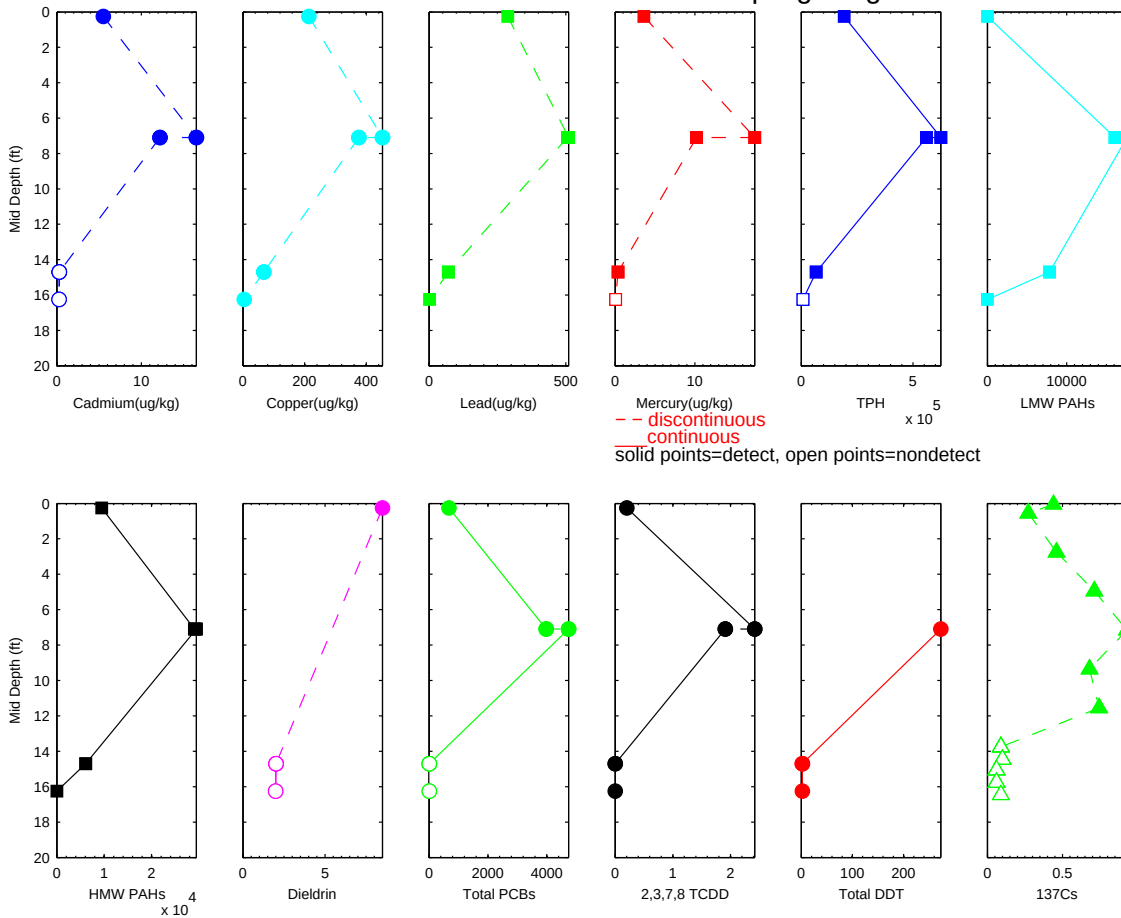
R2-0026837

Sample ID: 210 River Mile 1.7 PASSAIC 1995 RI Sampling Program



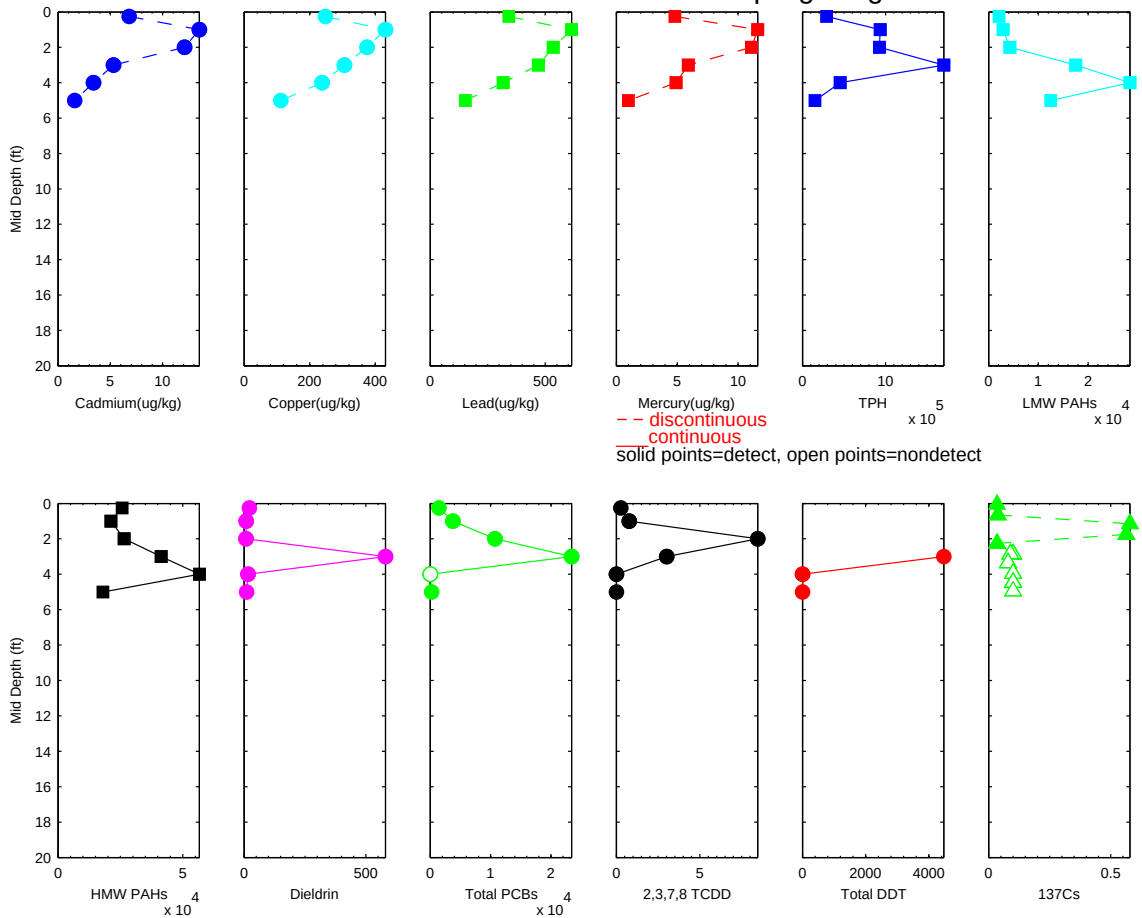
R2-0026838

Sample ID: 208 River Mile 1.47 PASSAIC 1995 RI Sampling Program



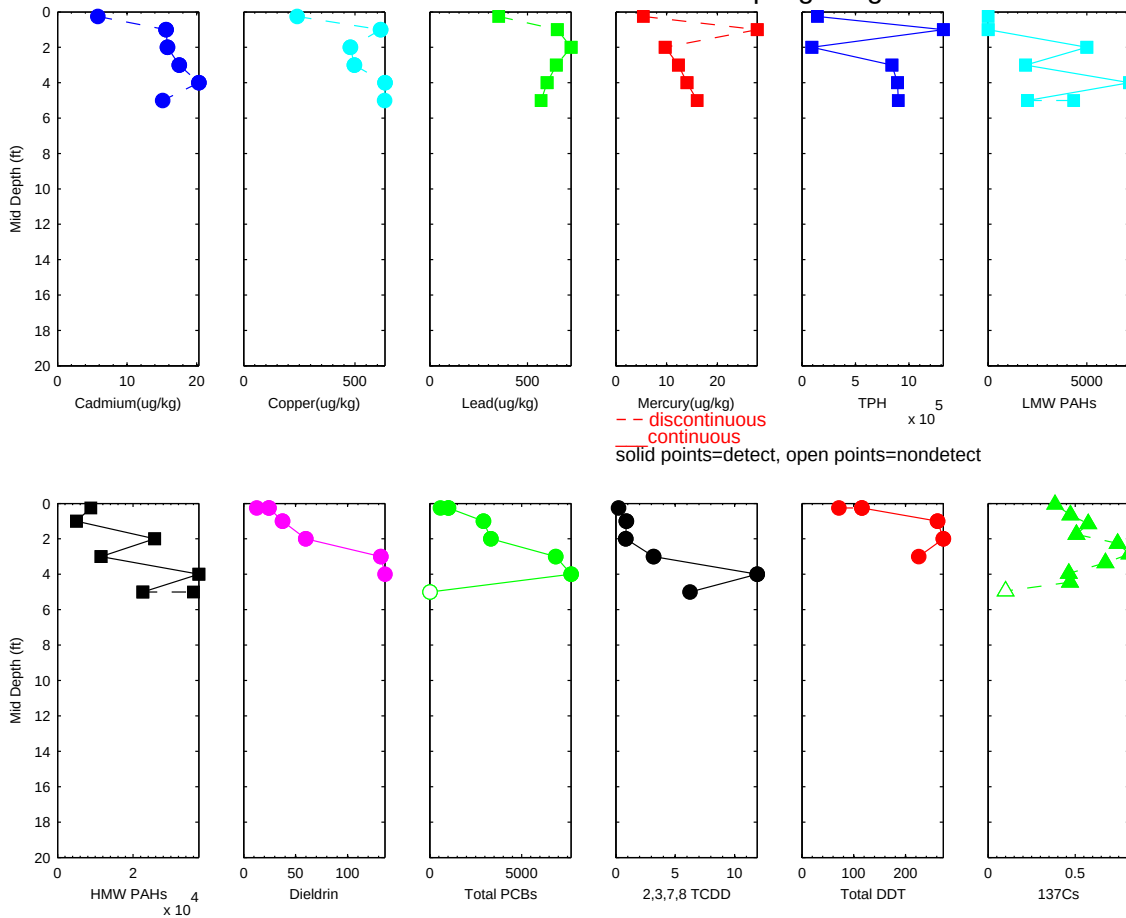
R2-0026839

Sample ID: 207 River Mile 1.47 PASSAIC 1995 RI Sampling Program



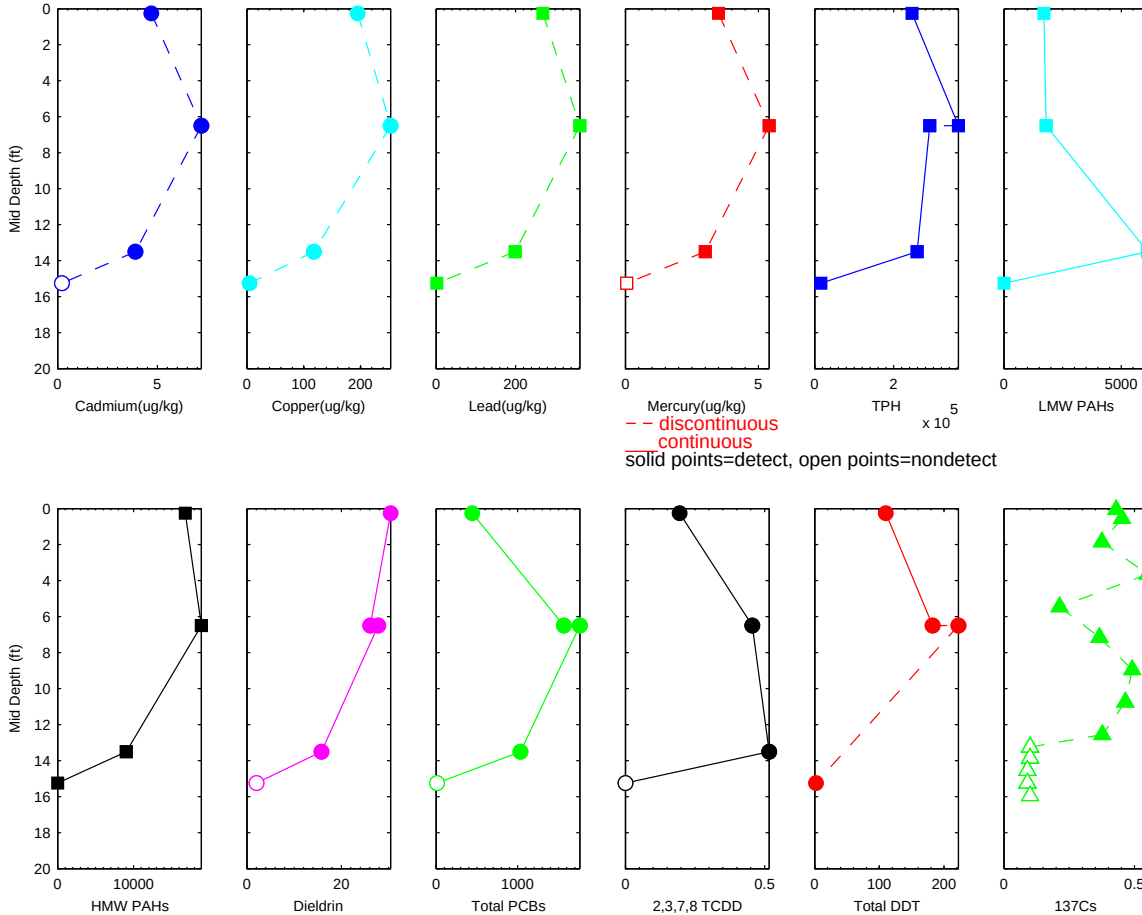
R2-0026840

Sample ID: 206 River Mile 1.25 PASSAIC 1995 RI Sampling Program



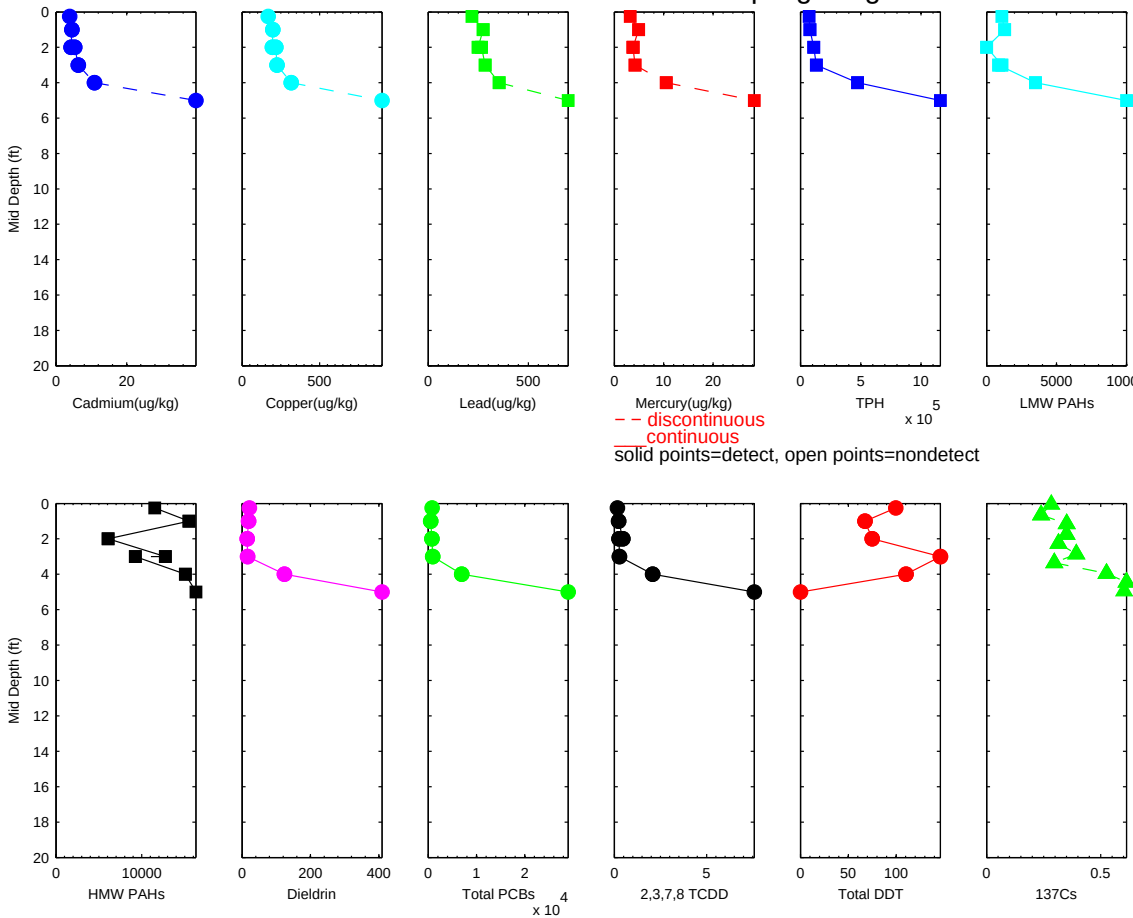
R2-0026841

Sample ID: 205 River Mile 1.24 PASSAIC 1995 RI Sampling Program



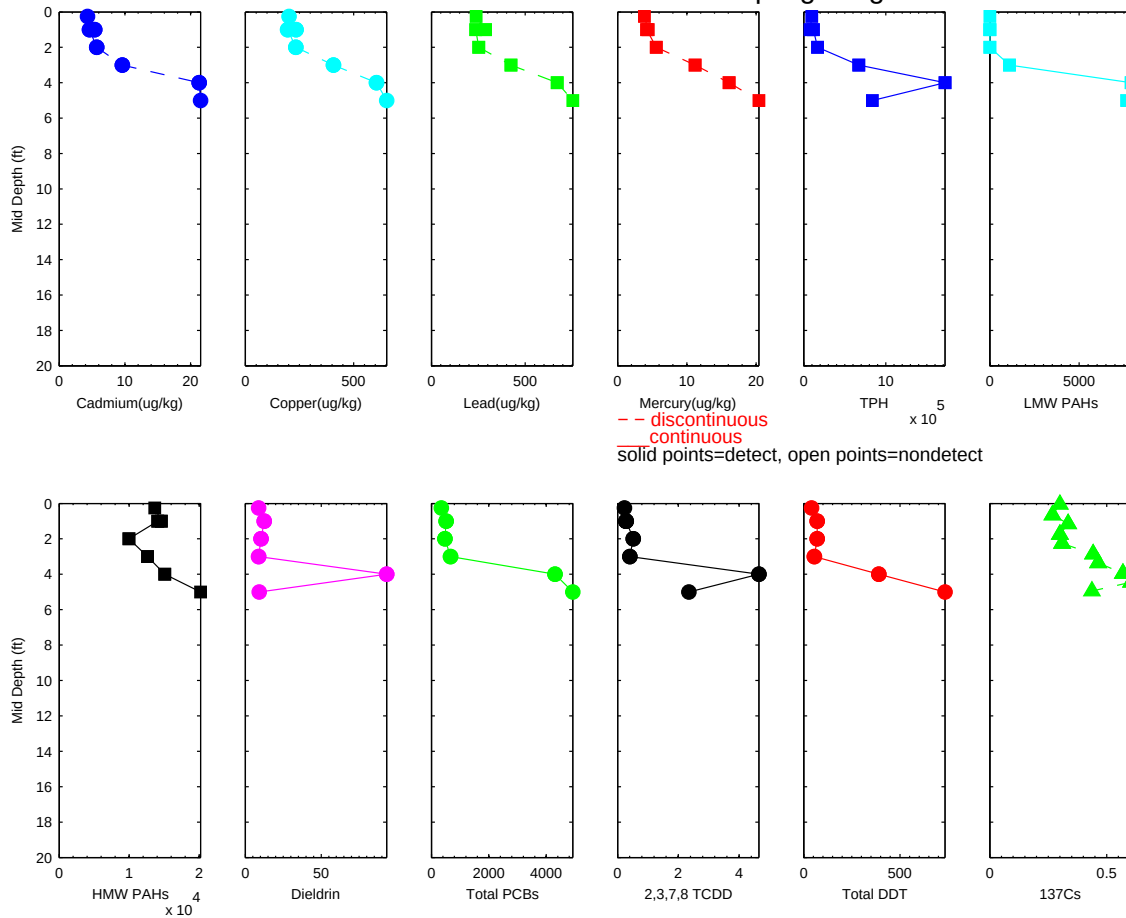
R2-0026842

Sample ID: 204 River Mile 1.25 PASSAIC 1995 RI Sampling Program



R2-0026843

Sample ID: 203 River Mile 1.02 PASSAIC 1995 RI Sampling Program



R2-0026844

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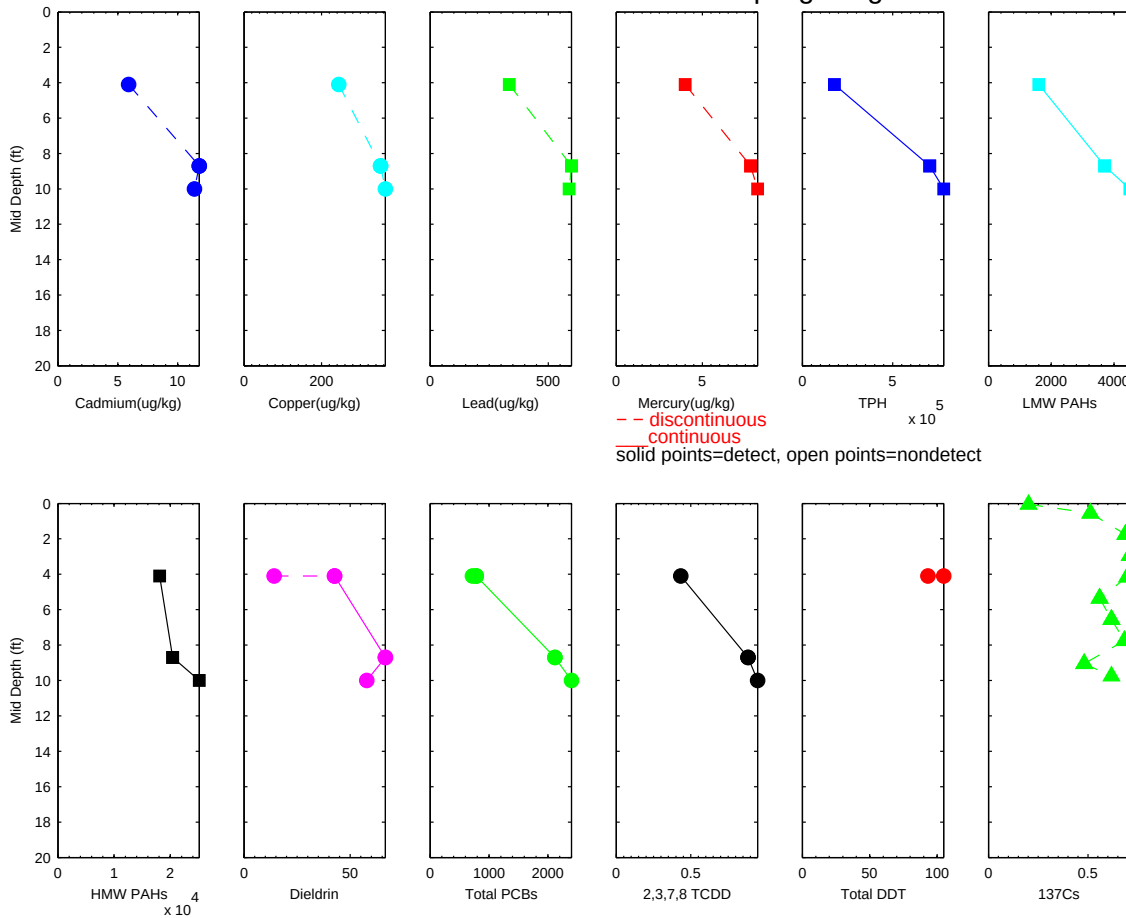
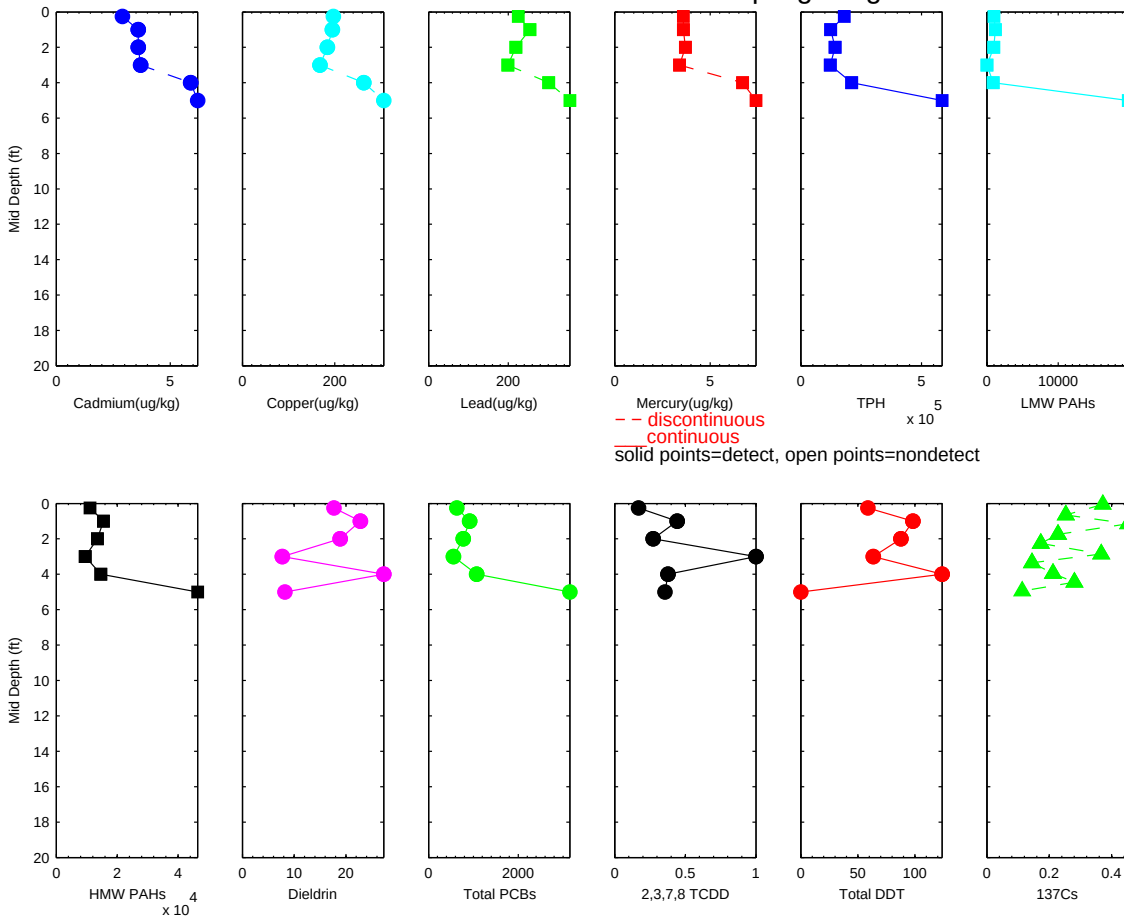


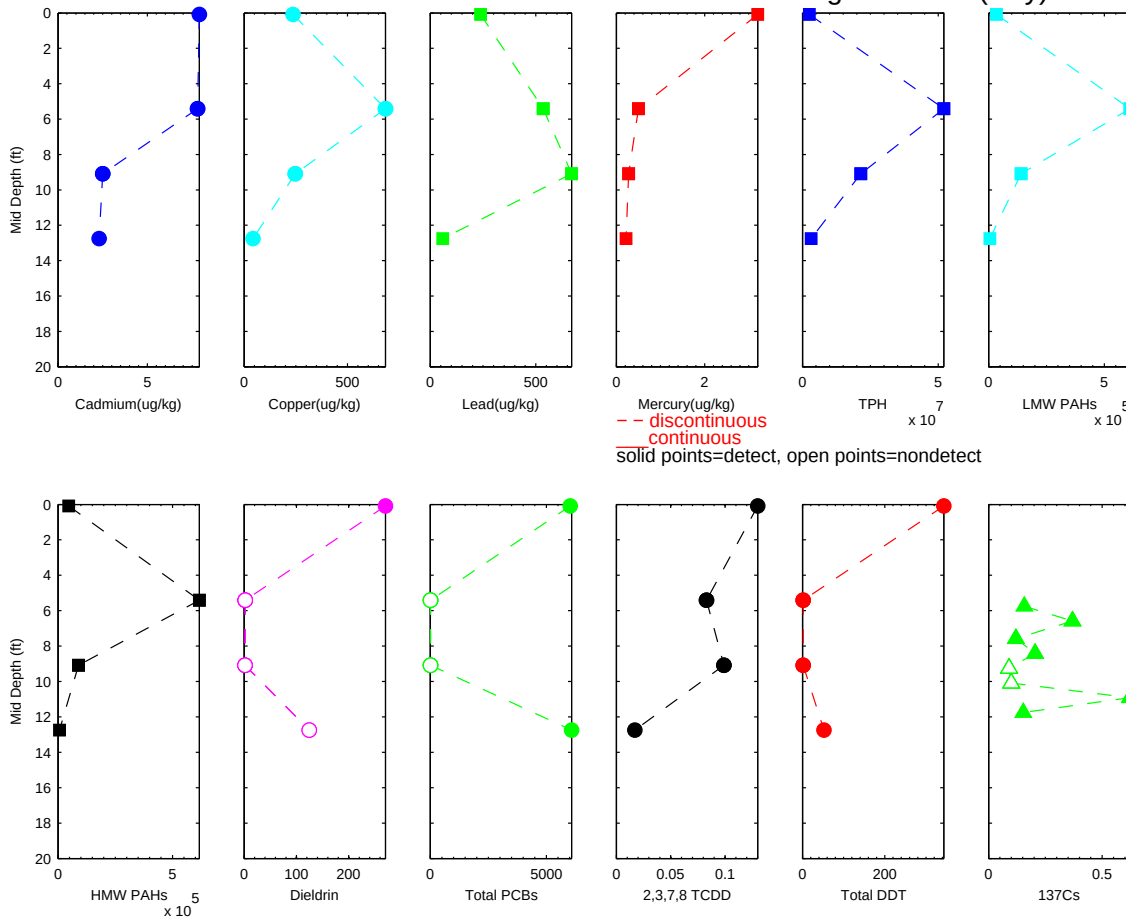
R2-0026845

Sample ID: 201 River Mile 1.02 PASSAIC 1995 RI Sampling Program



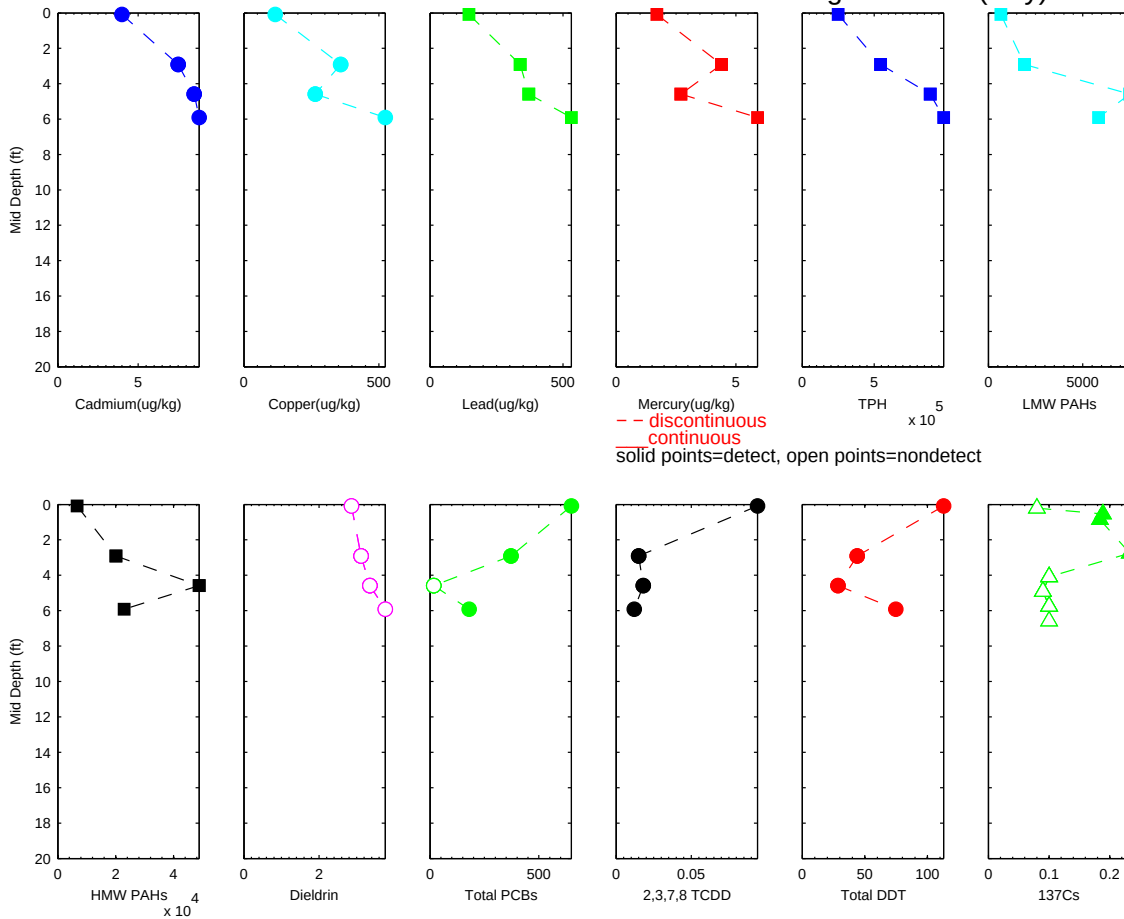
R2-0026846

Sample ID: 100 River Mile 1.13PASSAIC 1993 Core Sediment Investigation − 02 (July)



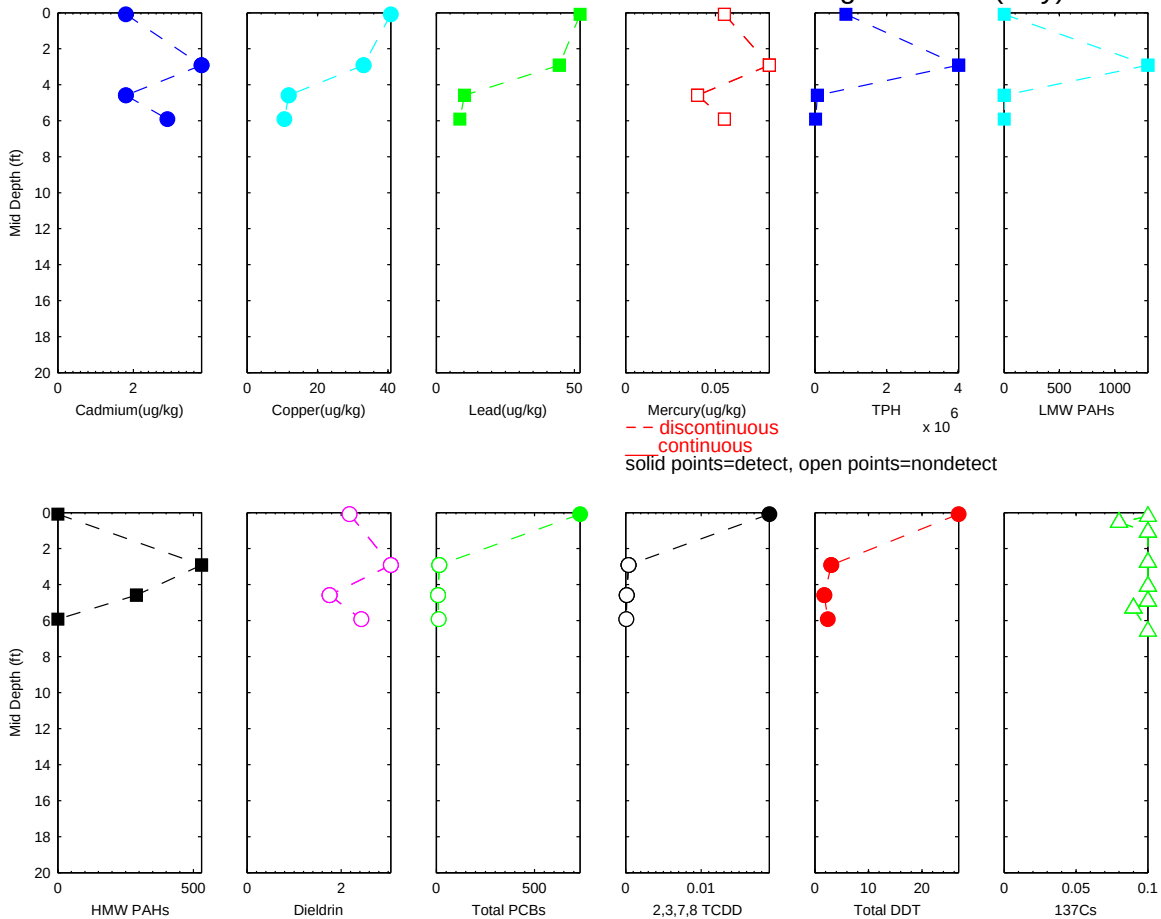
R2-0026847

Sample ID: 99A River Mile 0.64PASSAIC 1993 Core Sediment Investigation − 02 (July)



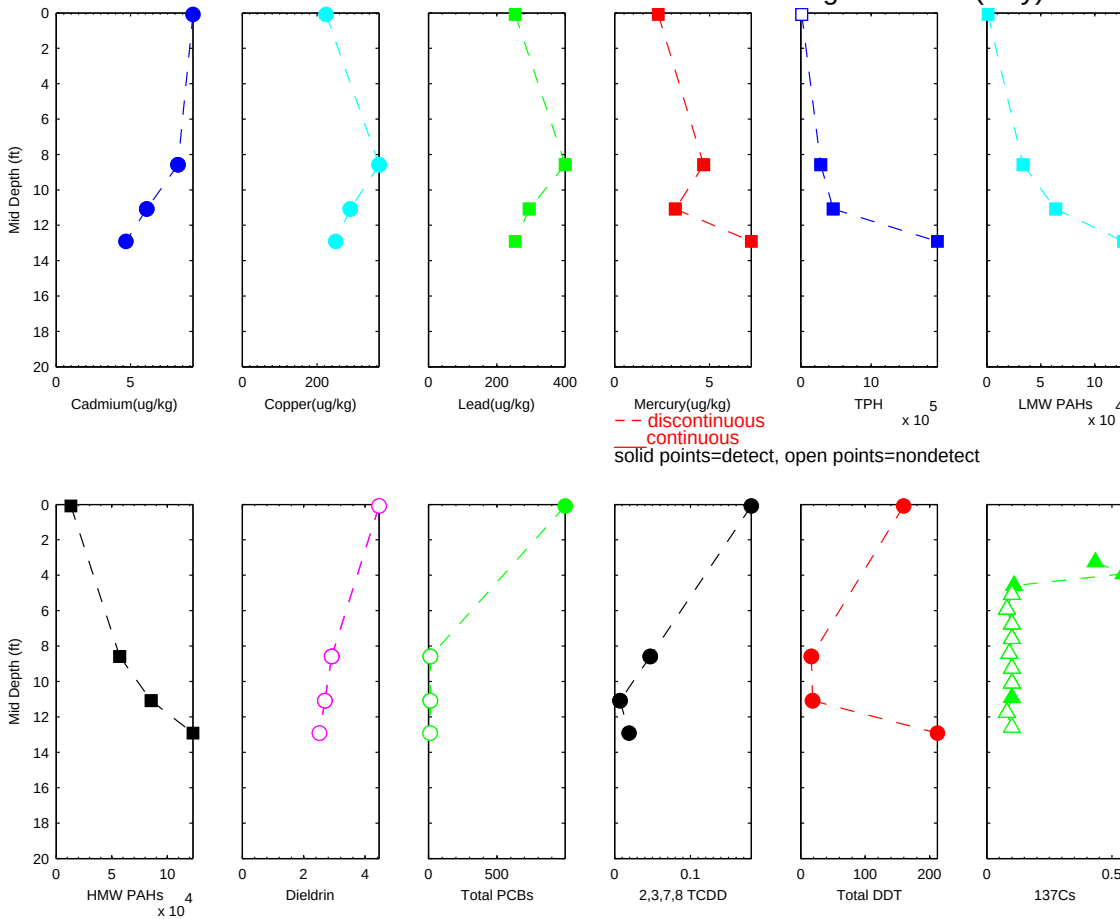
R2-0026848

Sample ID: 98A River Mile 0.54PASSAIC 1993 Core Sediment Investigation − 02 (July)



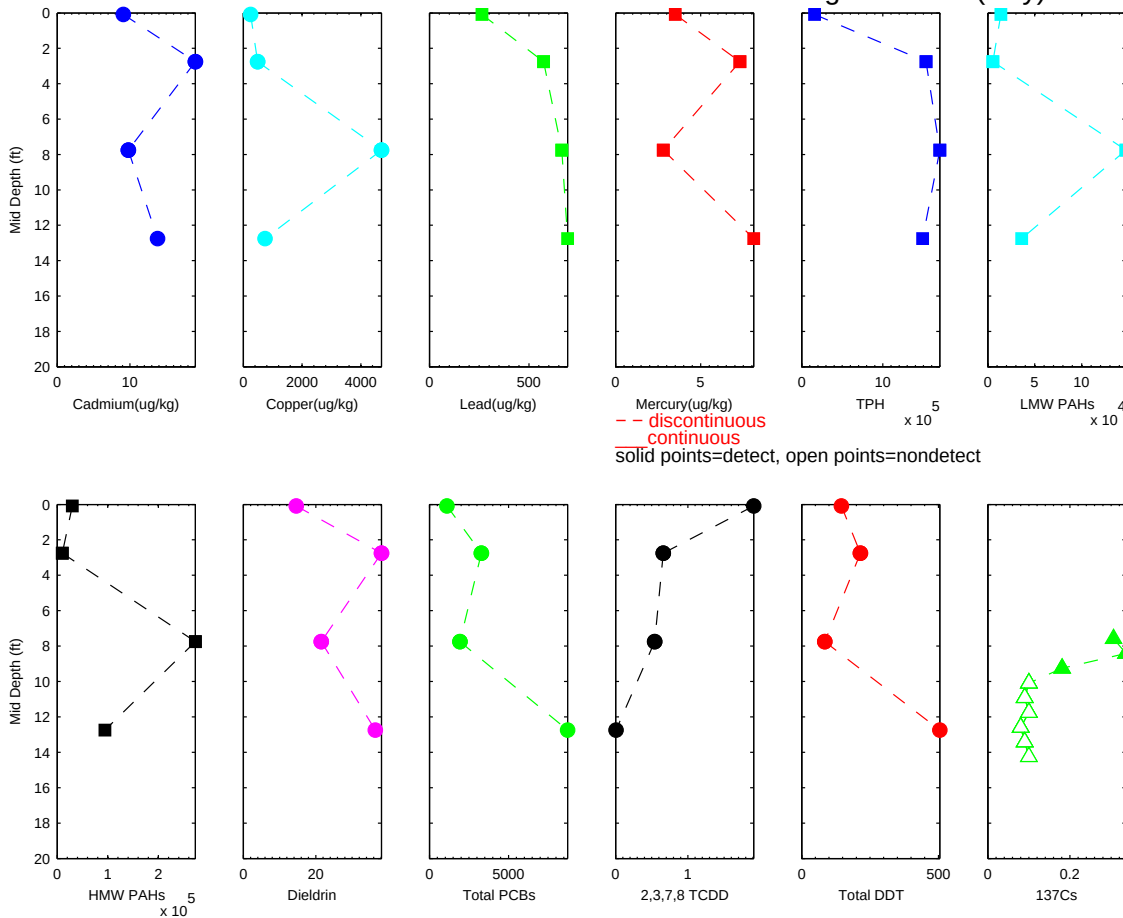
R2-0026849

Sample ID: 97B River Mile 1.51PASSAIC 1993 Core Sediment Investigation − 02 (July)



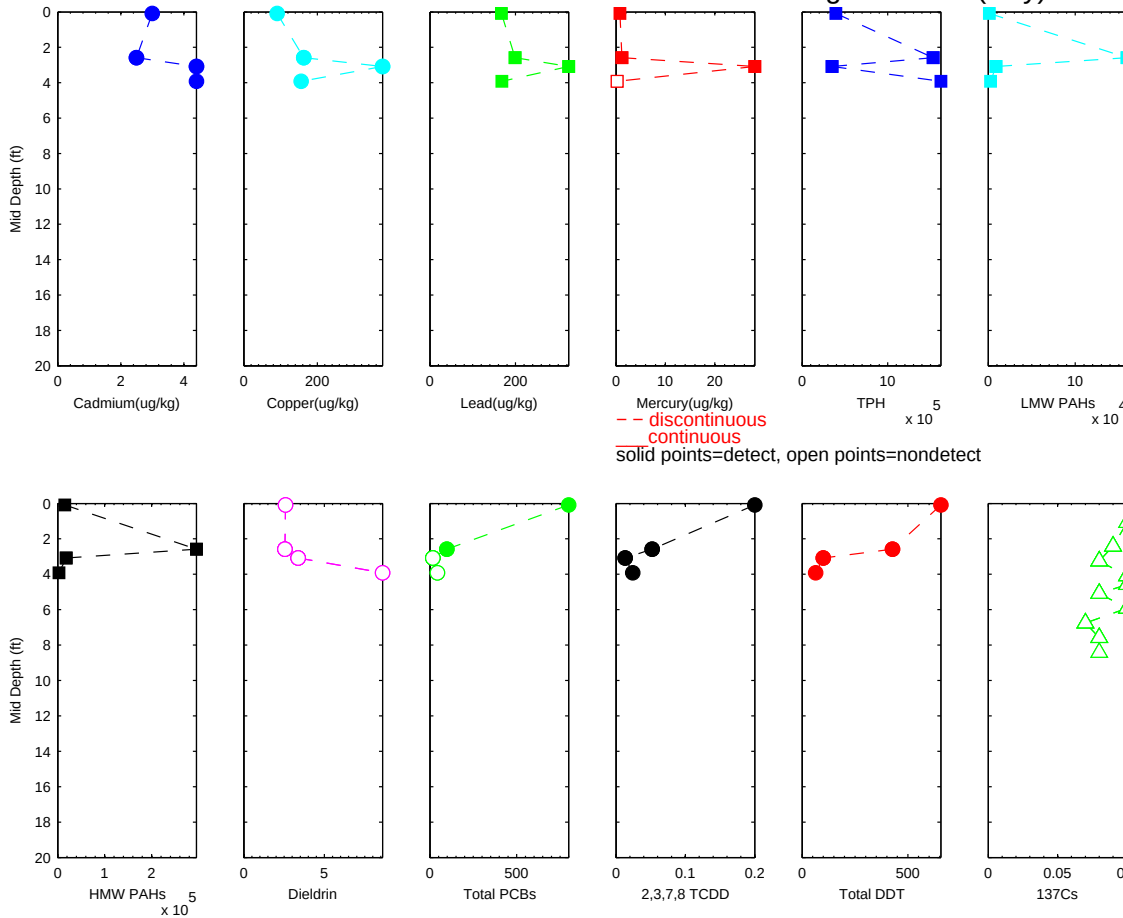
R2-0026850

Sample ID: 96A River Mile 1.1 PASSAIC 1993 Core Sediment Investigation − 02 (July)



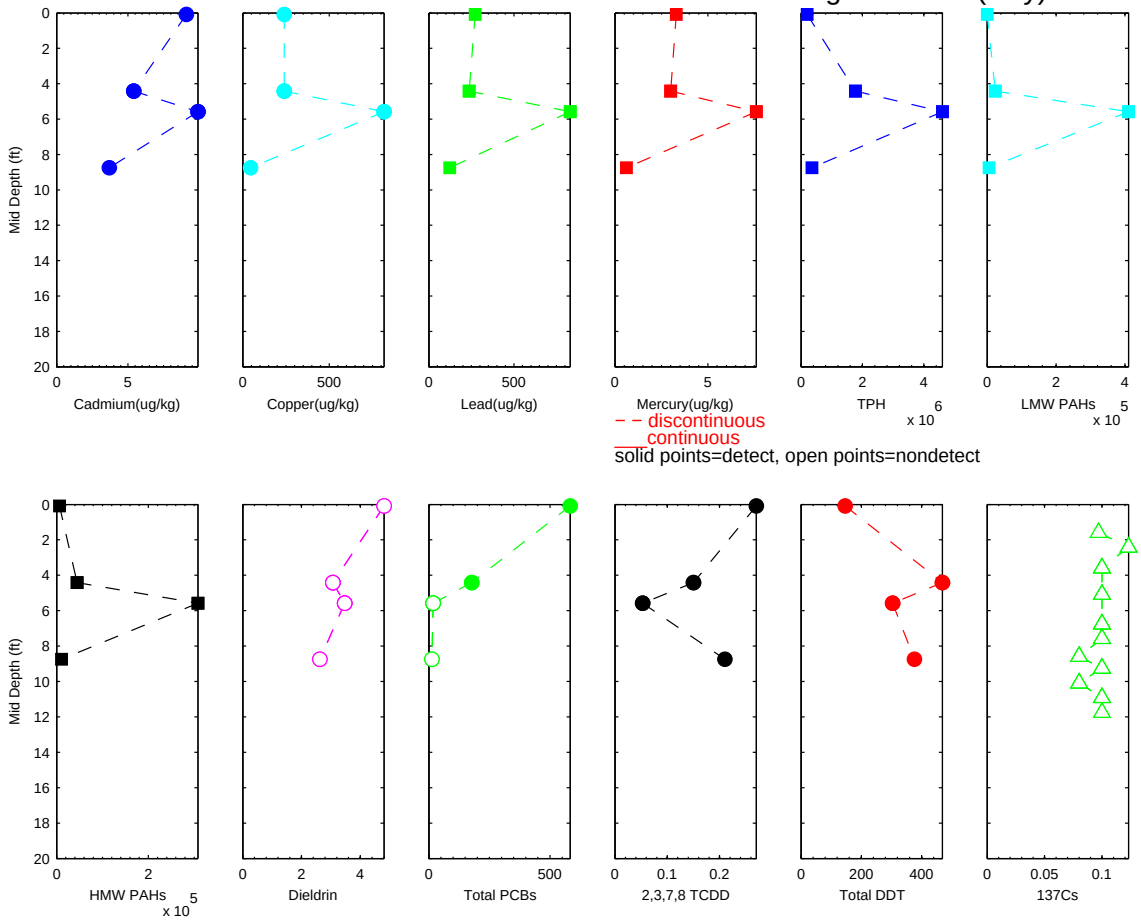
R2-0026851

Sample ID: 95A River Mile 2.3 PASSAIC 1993 Core Sediment Investigation − 02 (July)



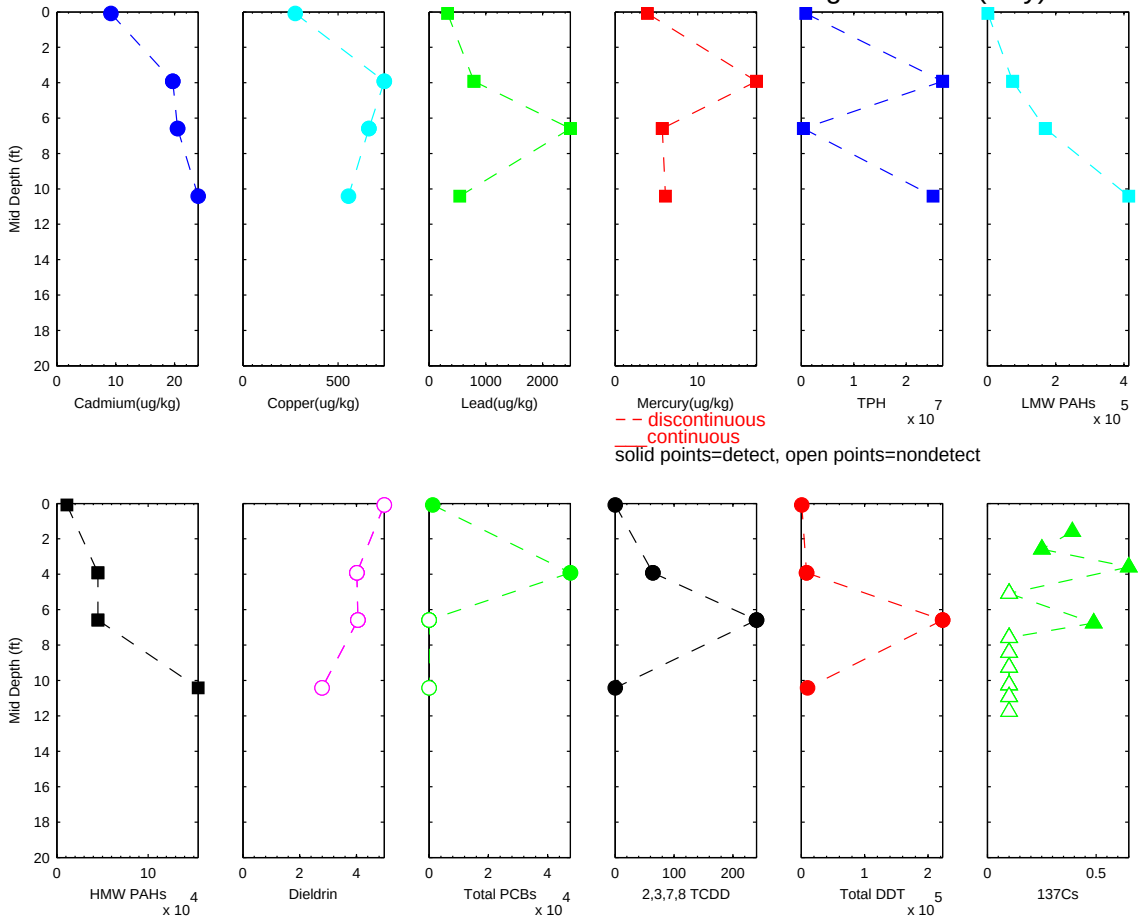
R2-0026852

Sample ID: 94A River Mile 2.91PASSAIC 1993 Core Sediment Investigation − 02 (July)



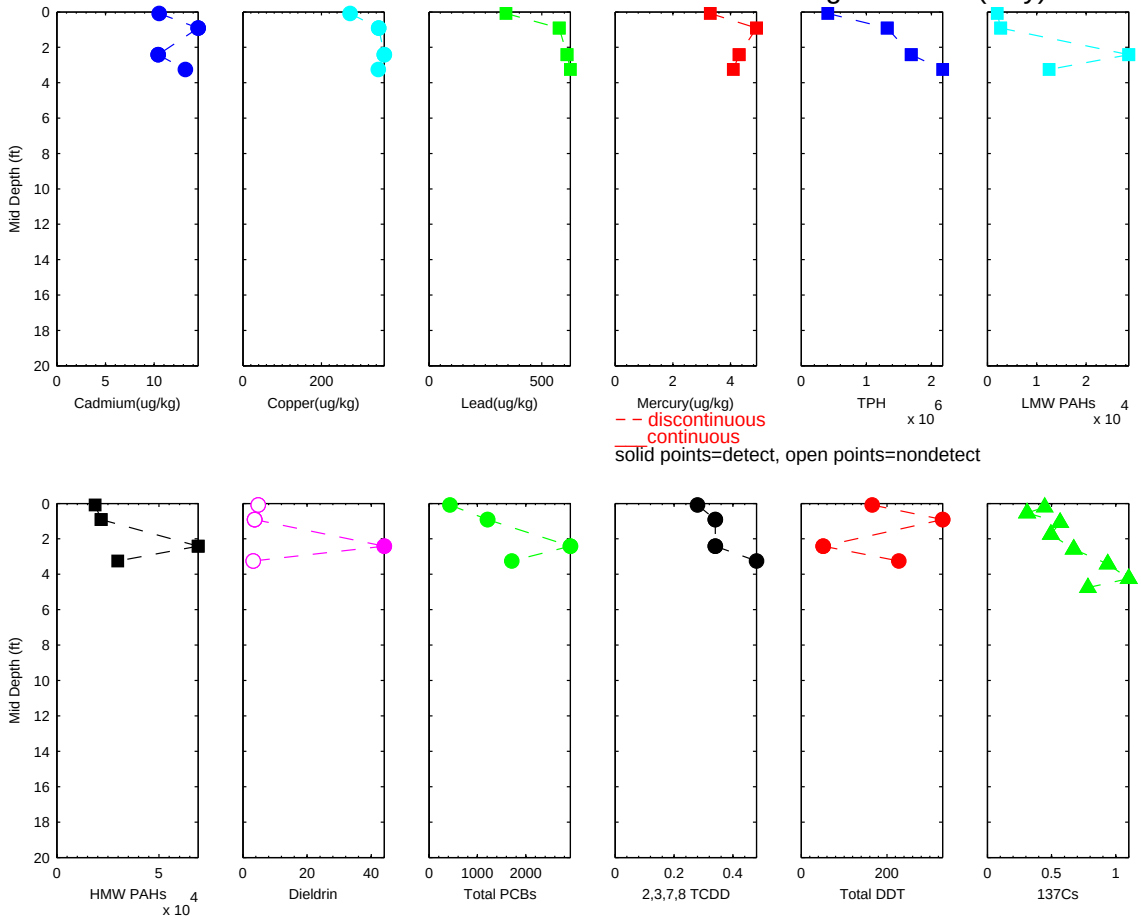
R2-0026853

Sample ID: 93A River Mile 2.86PASSAIC 1993 Core Sediment Investigation − 02 (July)



R2-0026854

Sample ID: 92A River Mile 1.66PASSAIC 1993 Core Sediment Investigation − 02 (July)



R2-0026855

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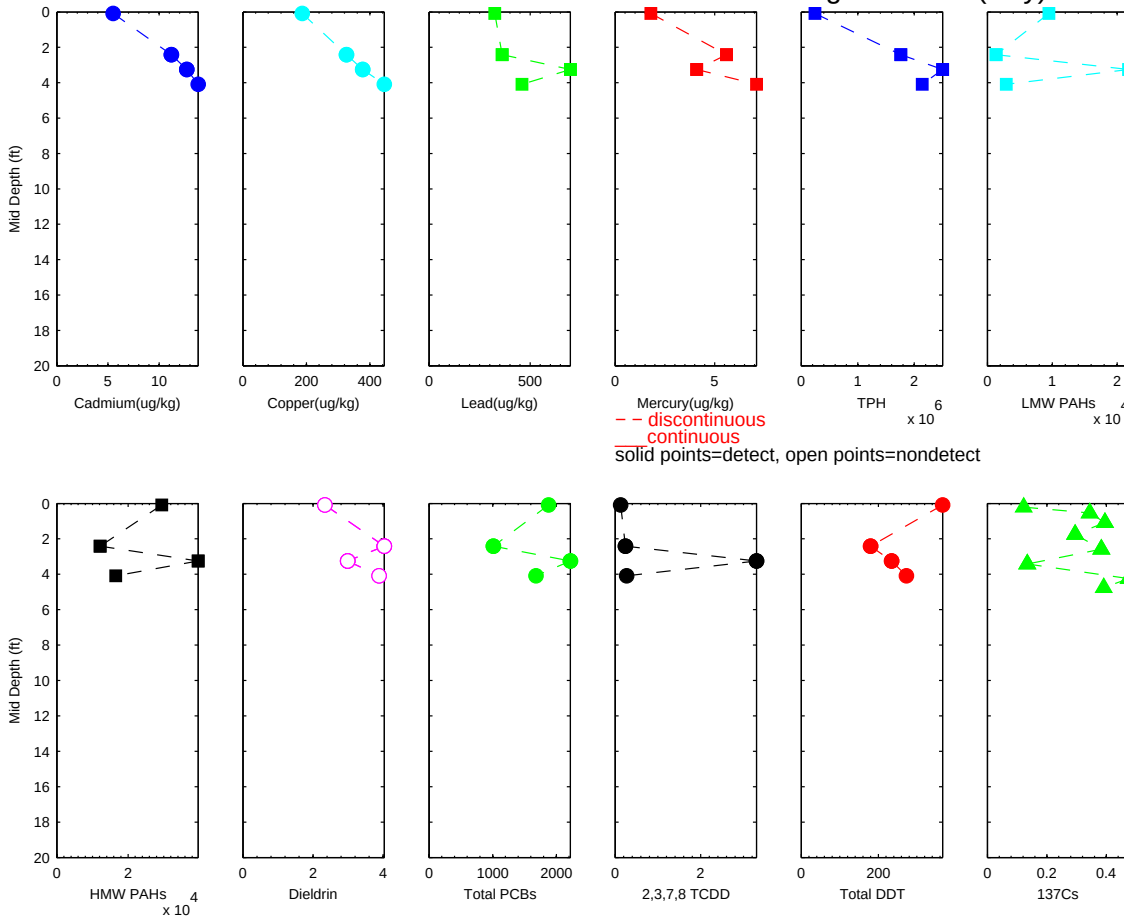
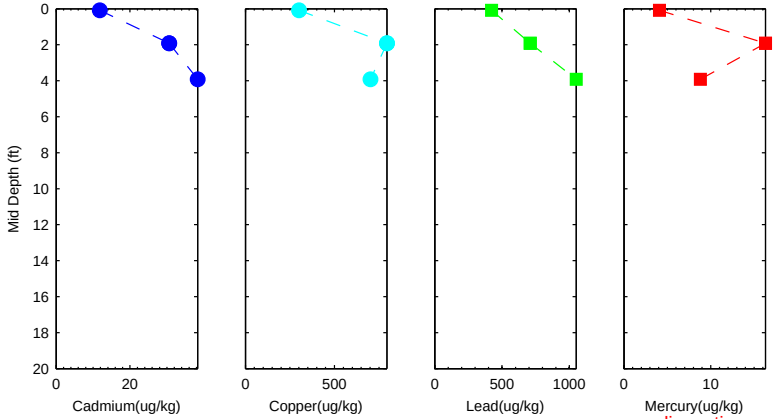
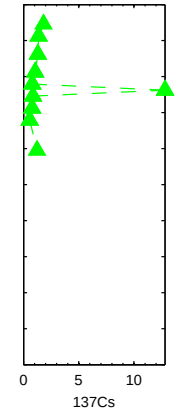


R2-0026856

Sample ID: 90A River Mile 6.94PASSAIC 1993 Core Sediment Investigation − 02 (July)

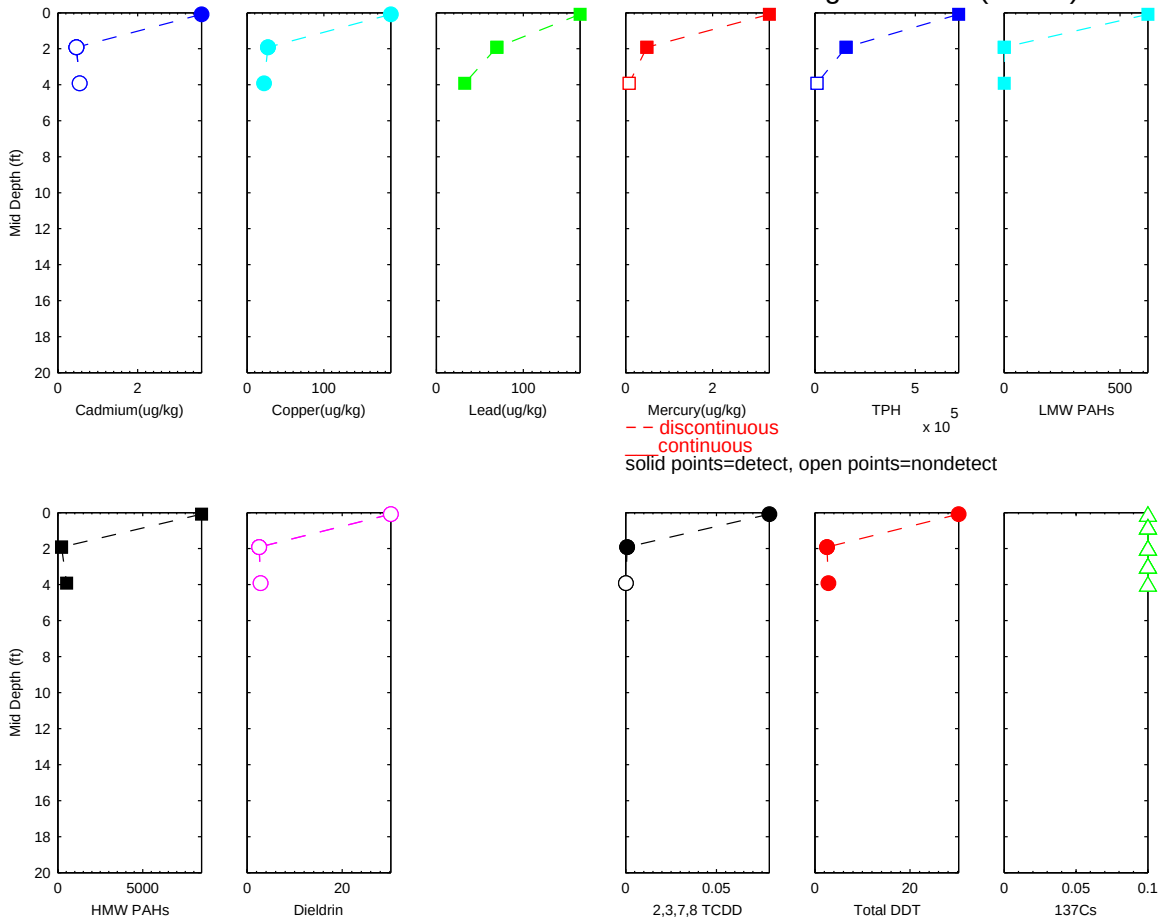


− − discontinuous
___ continuous
solid points=detect, open points=nondetect



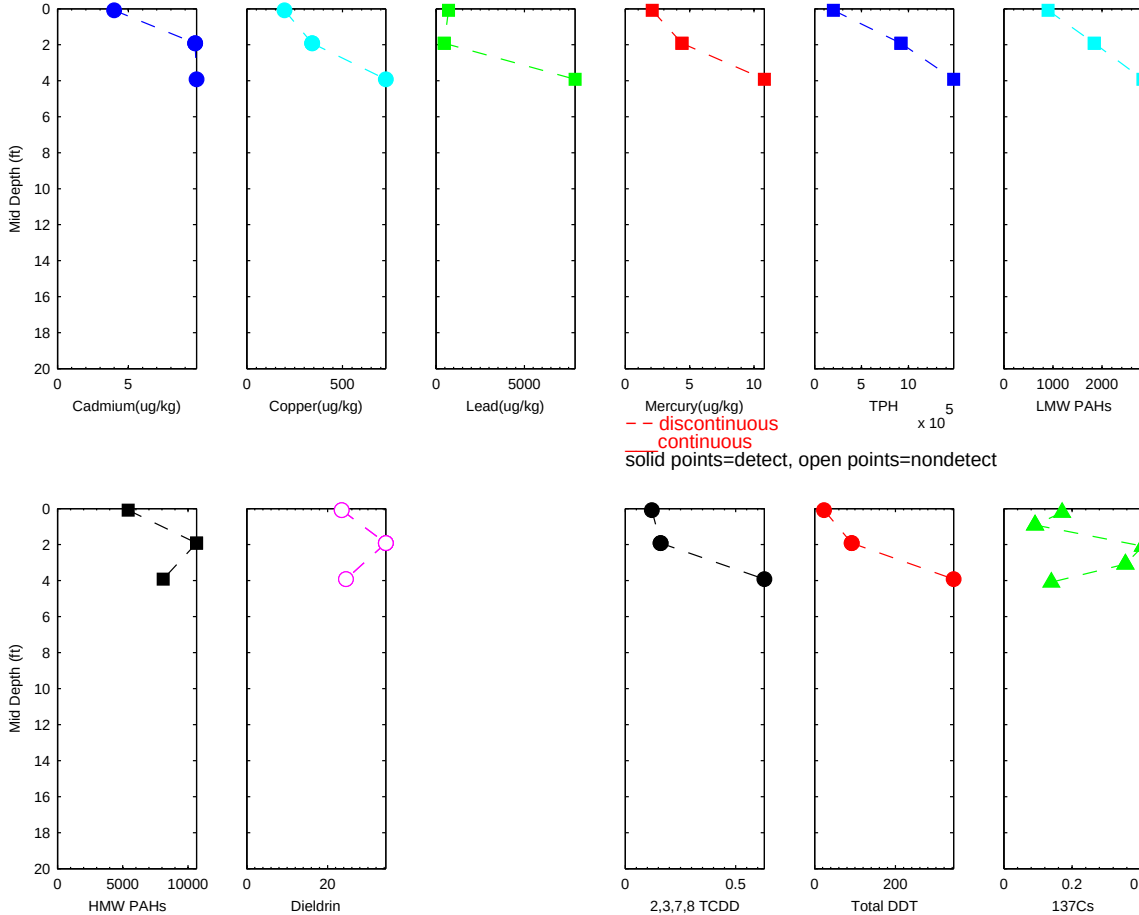
R2-0026857

Sample ID: 82A River Mile 0.34 PASSAIC 1993 Core Sediment Investigation − 01 (March)



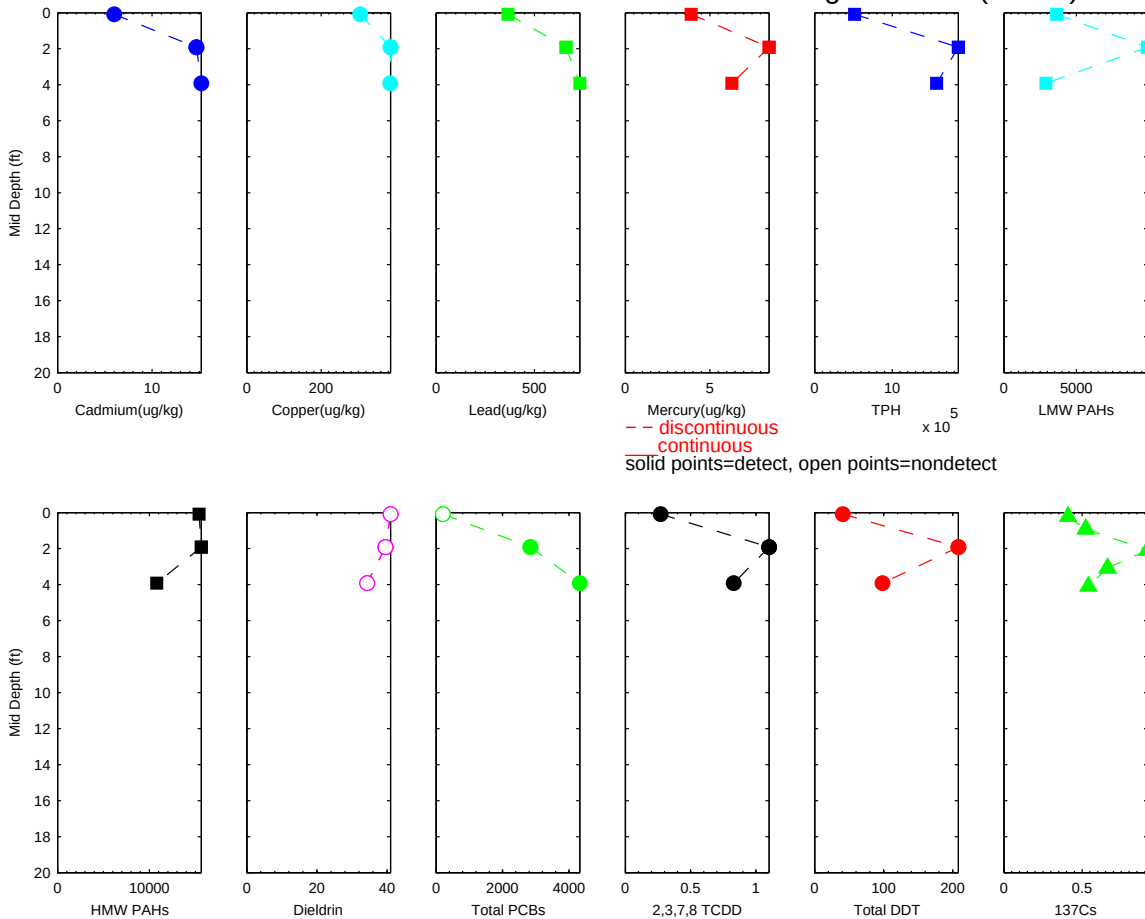
R2-0026858

Sample ID: 81A River Mile 0.3 PASSAIC 1993 Core Sediment Investigation − 01 (March)



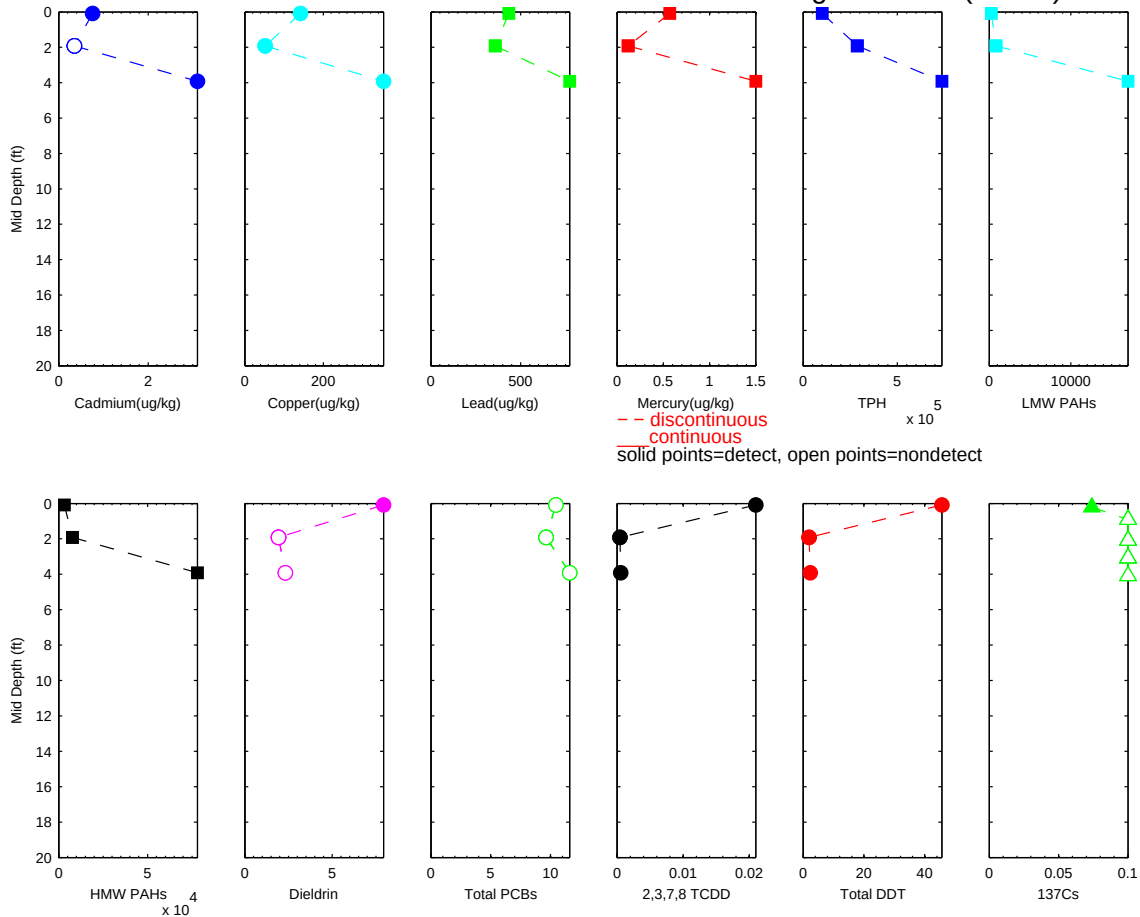
R2-0026859

Sample ID: 77A River Mile 2.14 PASSAIC 1993 Core Sediment Investigation − 01 (March)



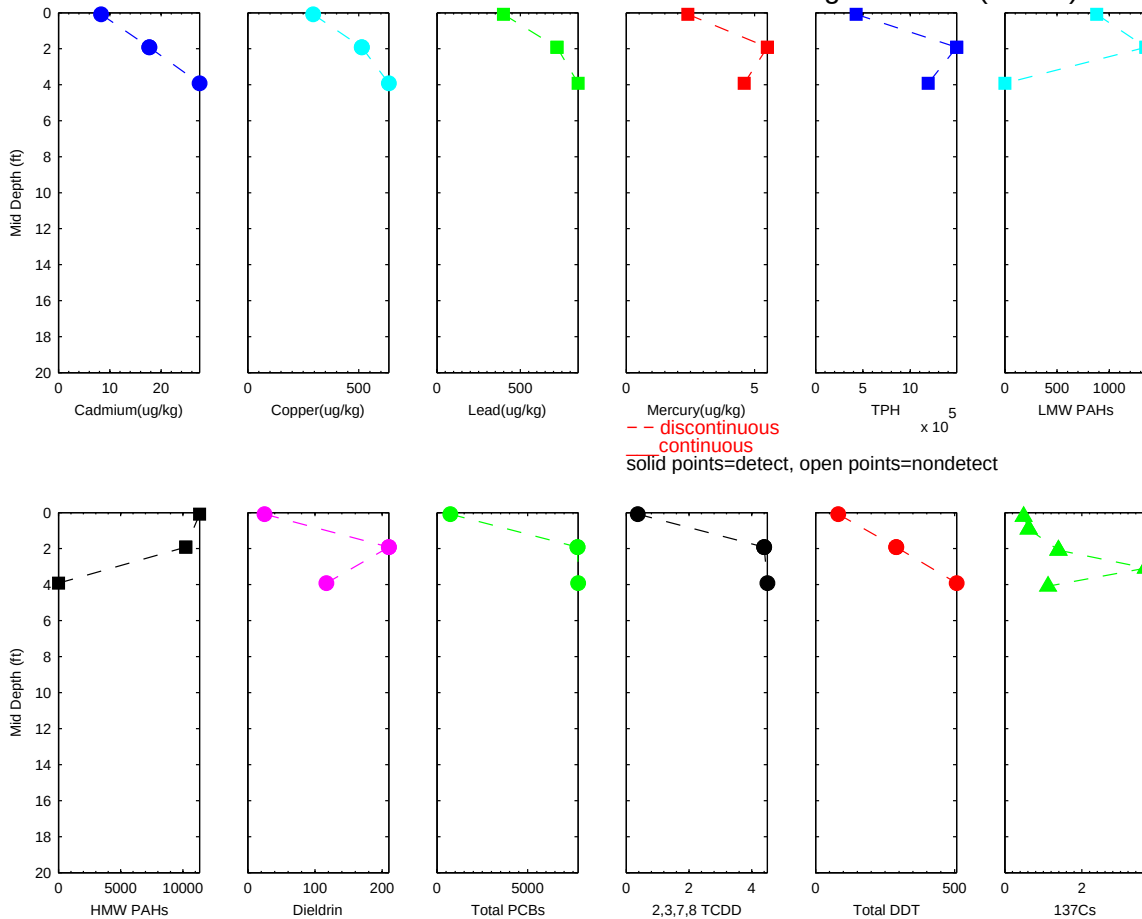
R2-0026860

Sample ID: 76A River Mile 6.92 PASSAIC 1993 Core Sediment Investigation − 01 (March)



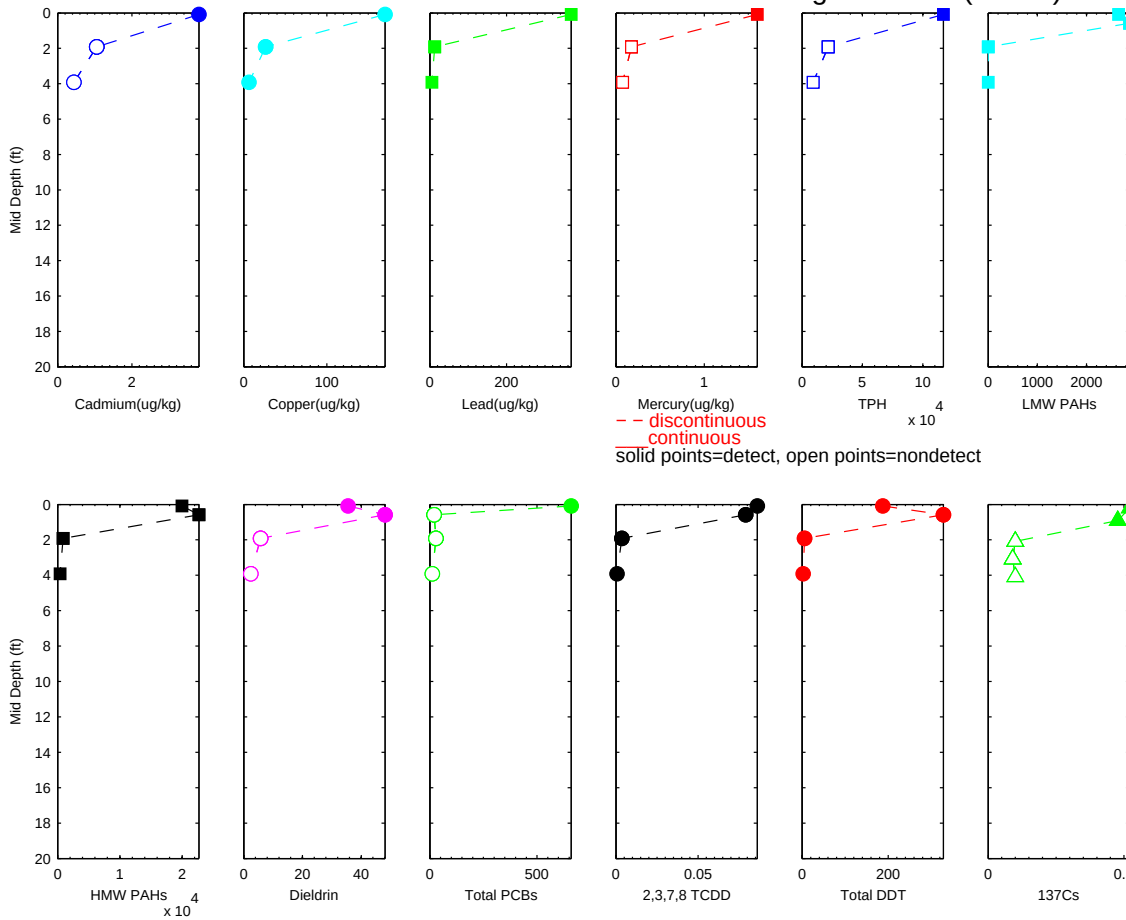
R2-0026861

Sample ID: 75A River Mile 6.94 PASSAIC 1993 Core Sediment Investigation − 01 (March)



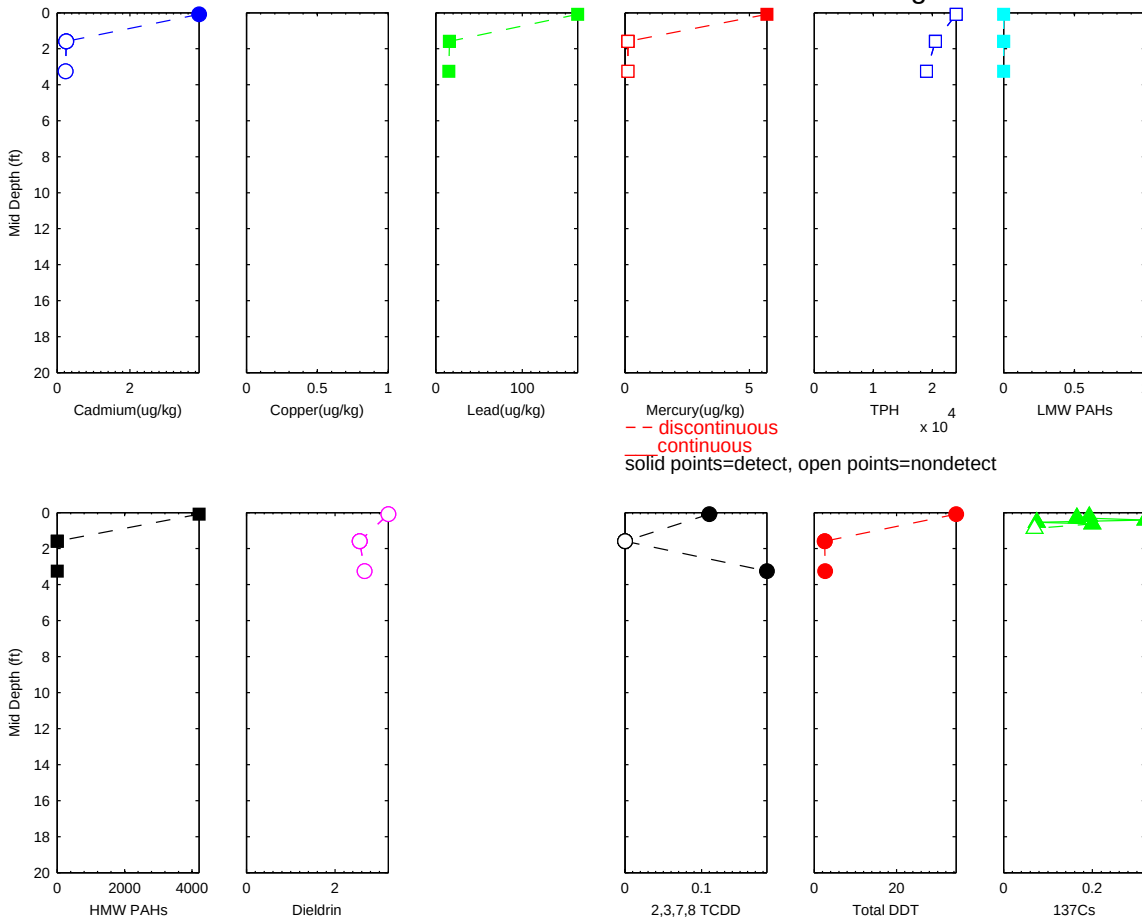
R2-0026862

Sample ID: 74A River Mile 11.16 PASSAIC 1993 Core Sediment Investigation − 01 (March)



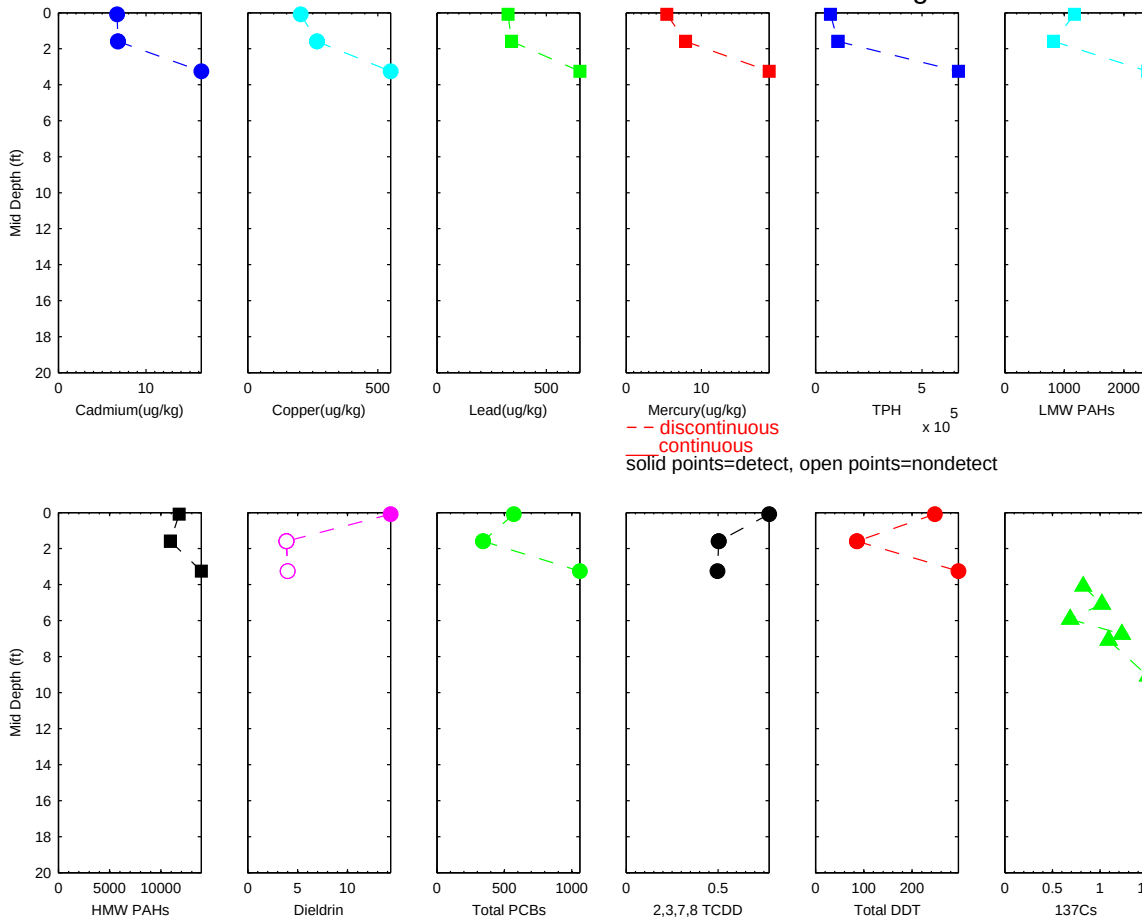
R2-0026863

Sample ID: 26A River Mile 0.21 PASSAIC 1991 Core Sediment Investigation



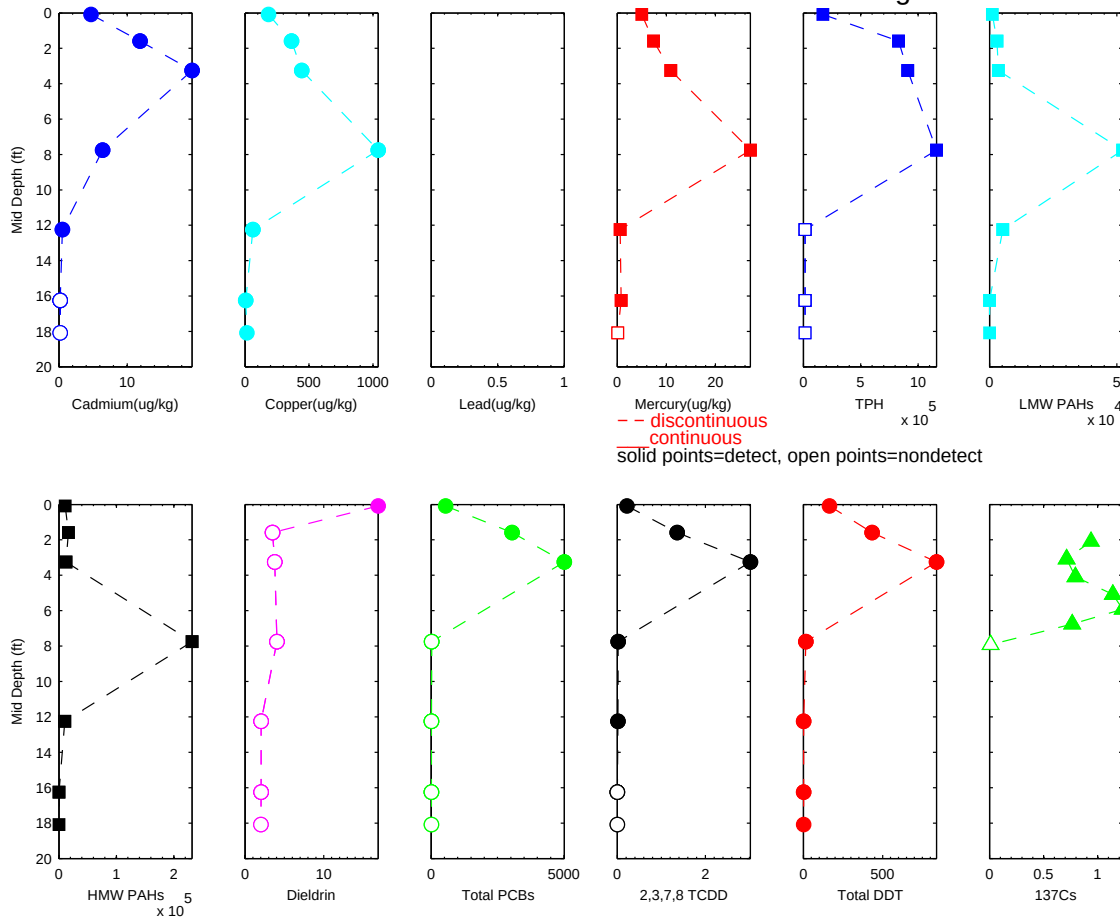
R2-0026864

Sample ID: 23A River Mile 2.02 PASSAIC 1991 Core Sediment Investigation



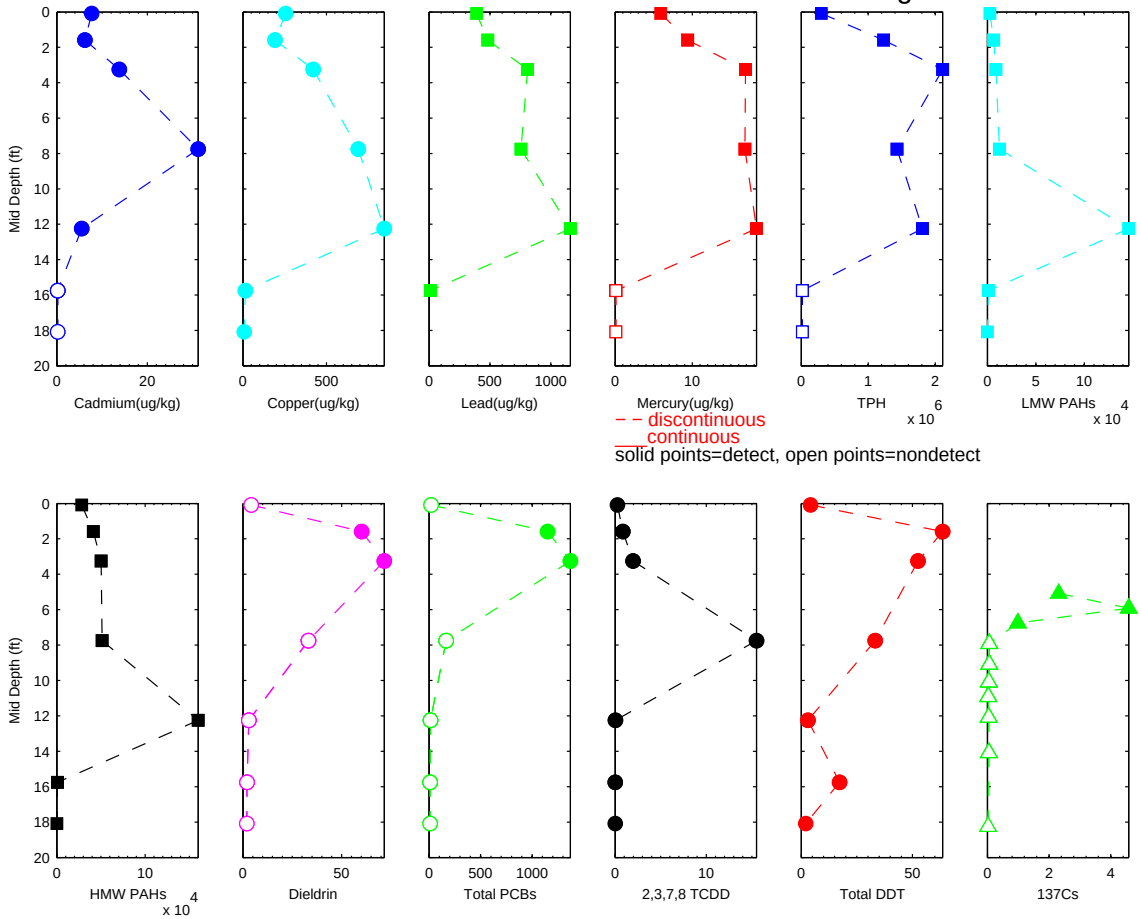
R2-0026865

Sample ID: 22A River Mile 2.39 PASSAIC 1991 Core Sediment Investigation



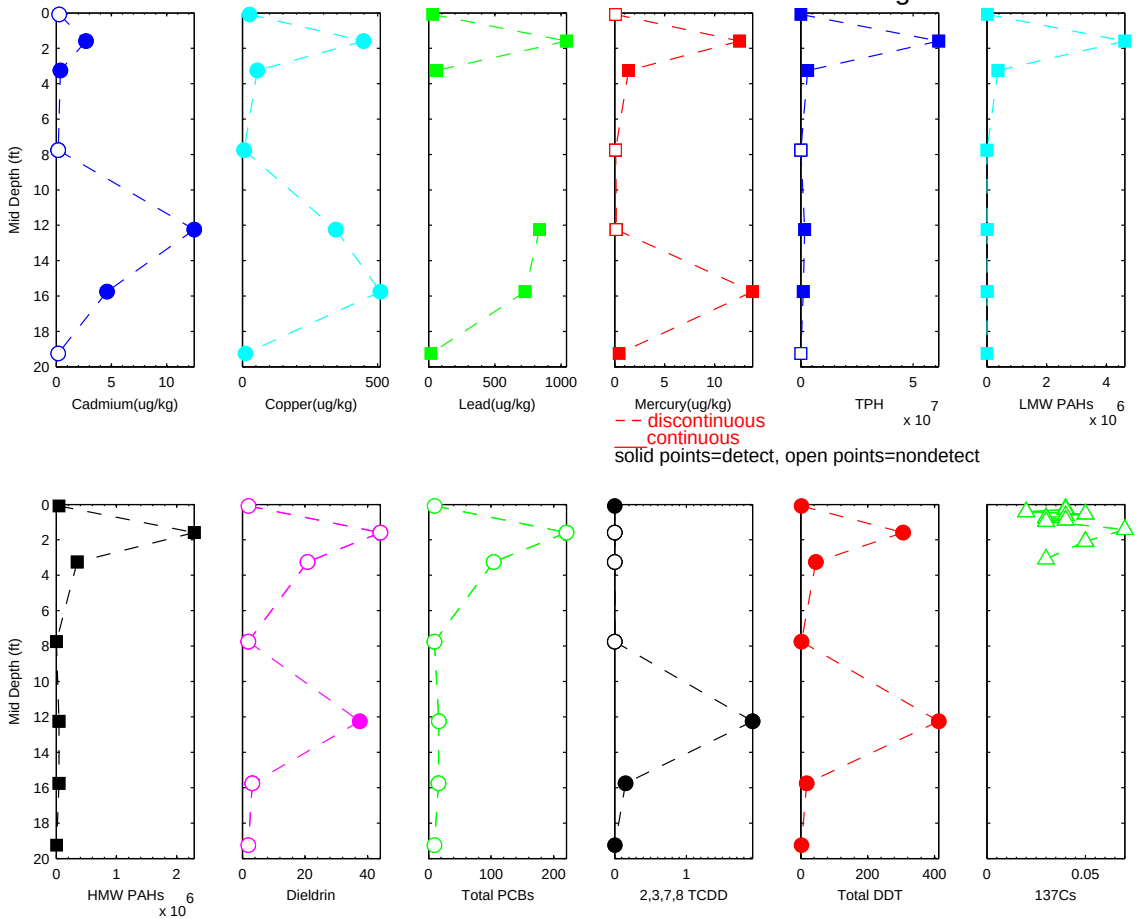
R2-0026866

Sample ID: 21A River Mile 3.01 PASSAIC 1991 Core Sediment Investigation



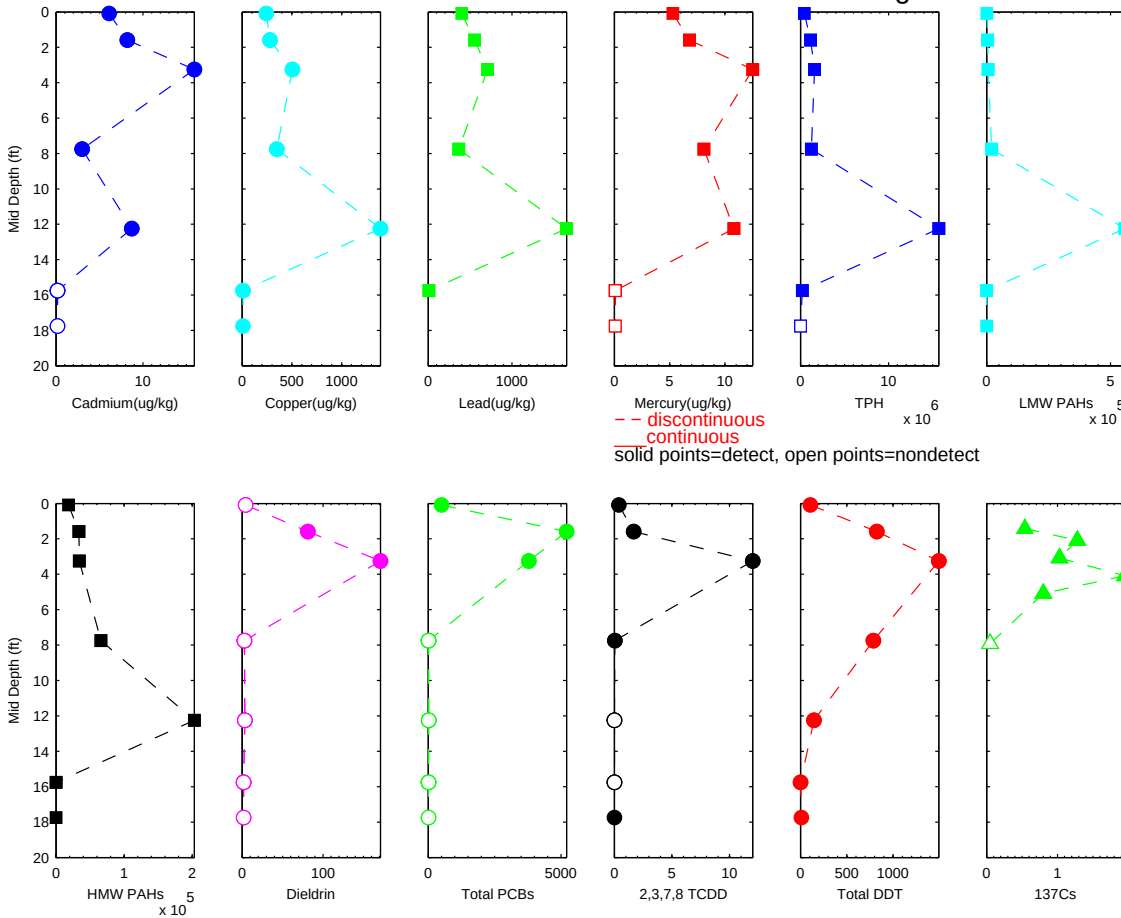
R2-0026867

Sample ID: 20A River Mile 3.05 PASSAIC 1991 Core Sediment Investigation



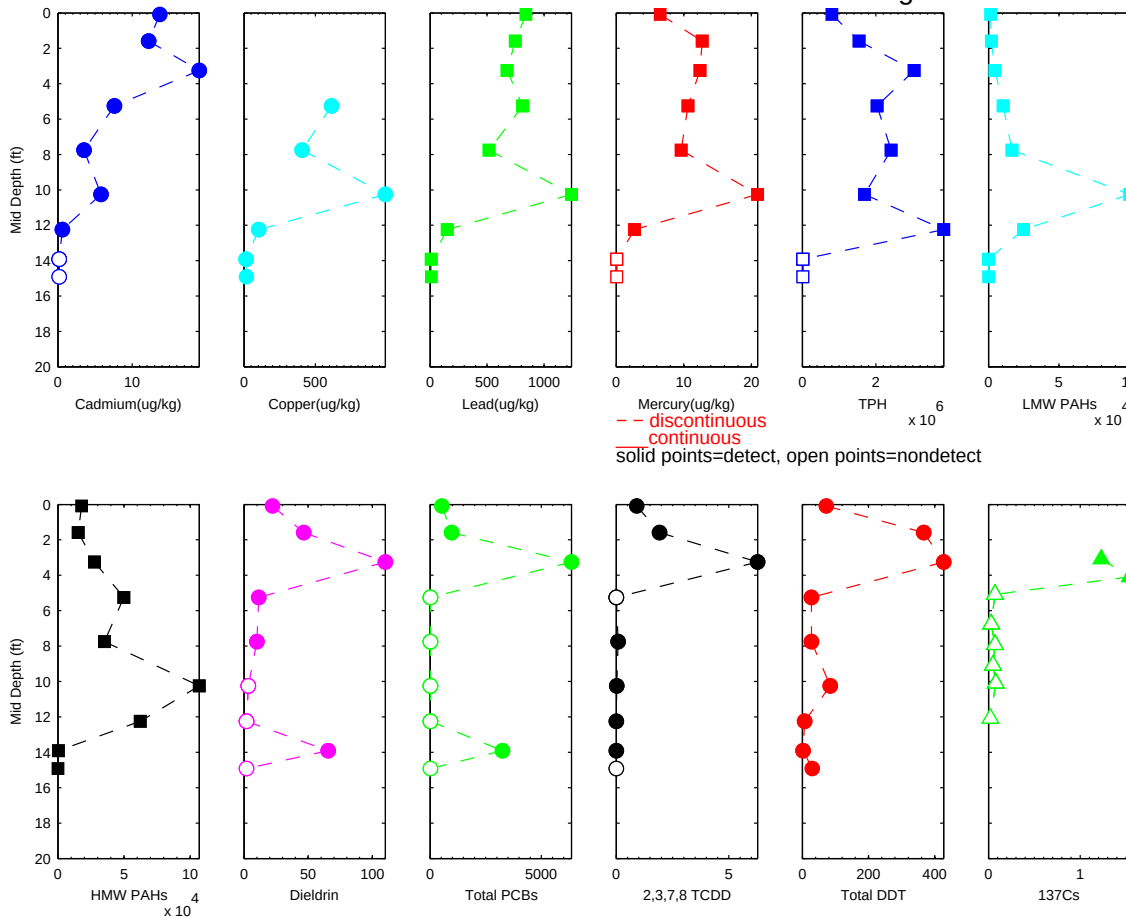
R2-0026868

Sample ID: 19A River Mile 3.09 PASSAIC 1991 Core Sediment Investigation



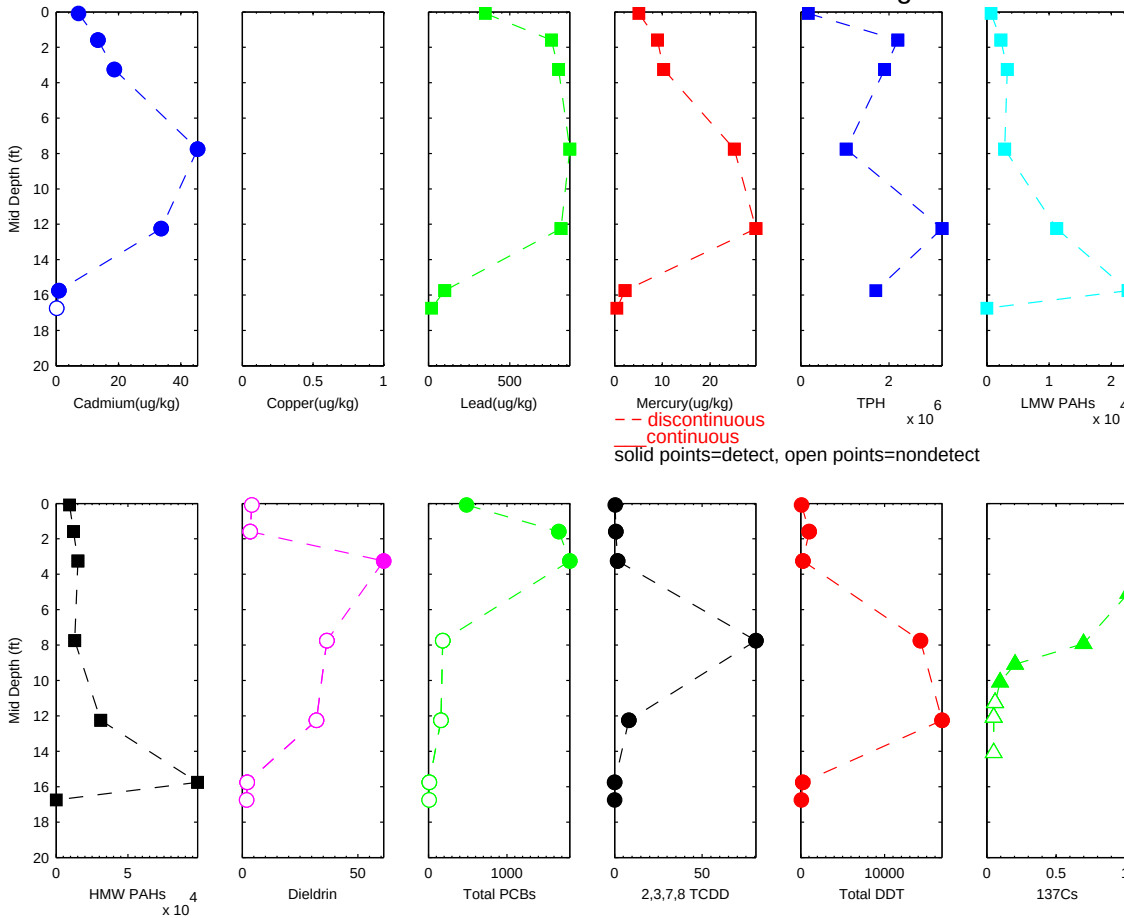
R2-0026869

Sample ID: 18A River Mile 3.14 PASSAIC 1991 Core Sediment Investigation



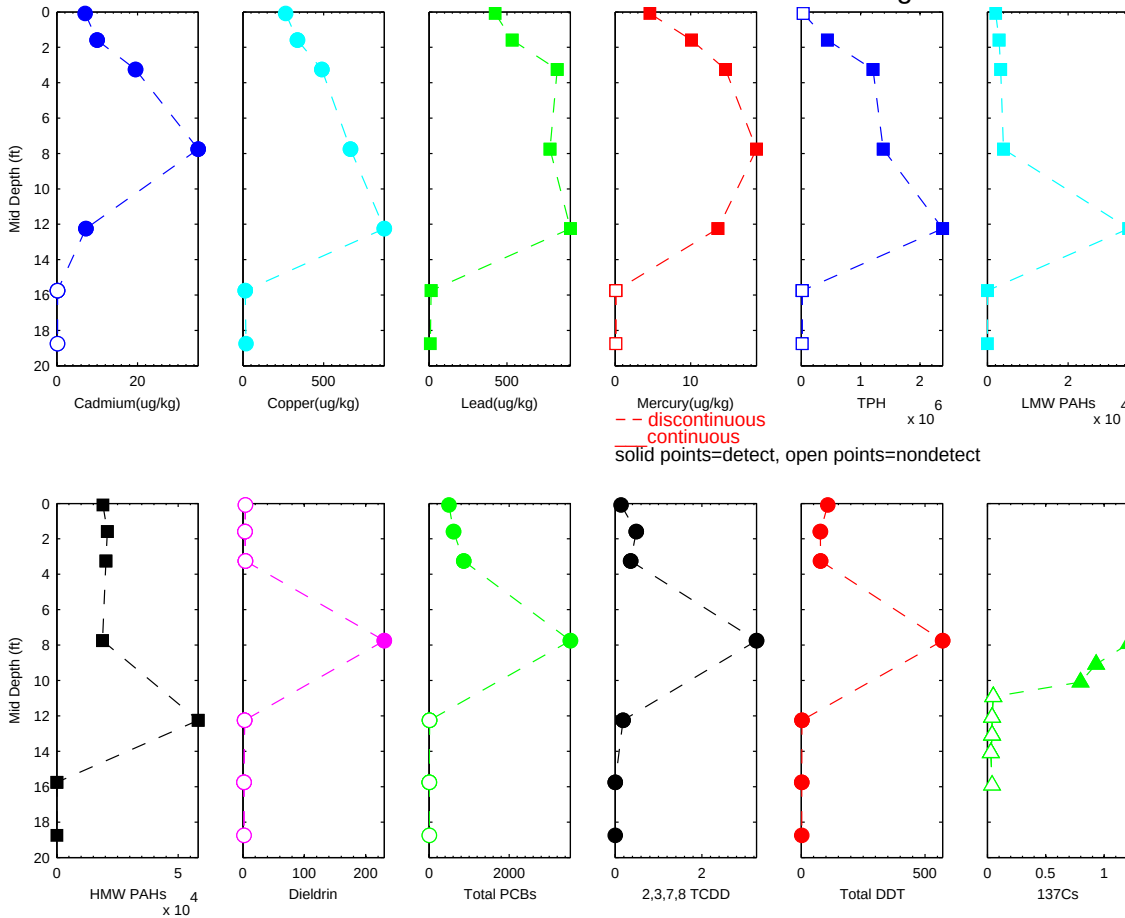
R2-0026870

Sample ID: 17A River Mile 3.25 PASSAIC 1991 Core Sediment Investigation



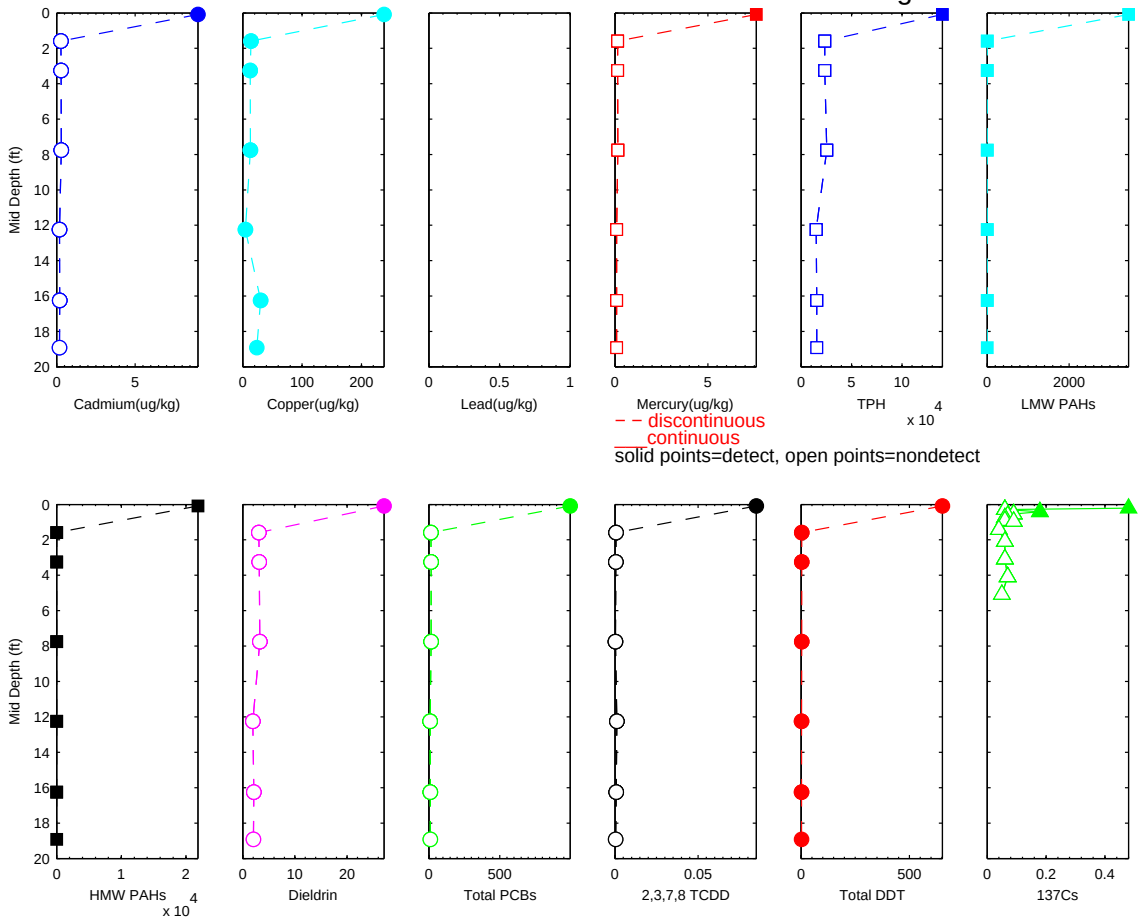
R2-0026871

Sample ID: 16A River Mile 3.36 PASSAIC 1991 Core Sediment Investigation



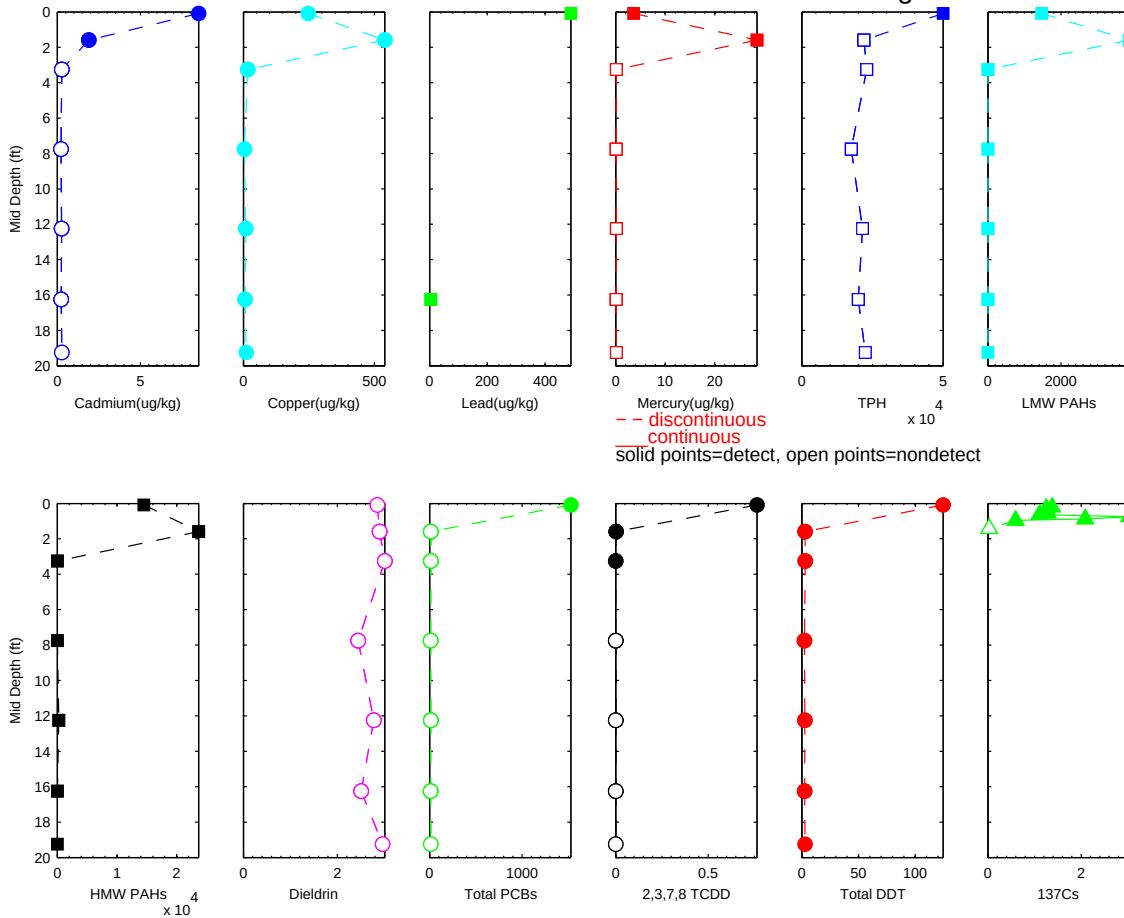
R2-0026872

Sample ID: 15A River Mile 3.55 PASSAIC 1991 Core Sediment Investigation



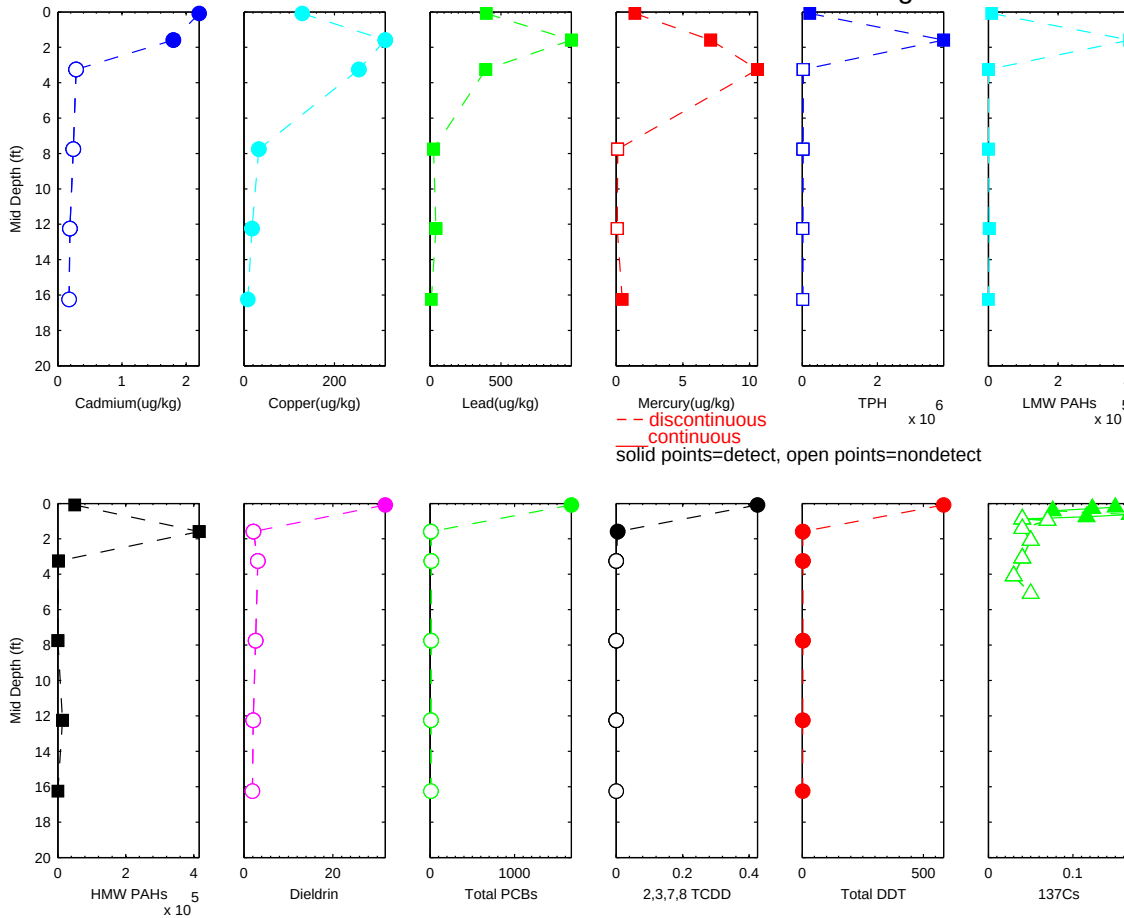
R2-0026873

Sample ID: 14A River Mile 4.2 PASSAIC 1991 Core Sediment Investigation



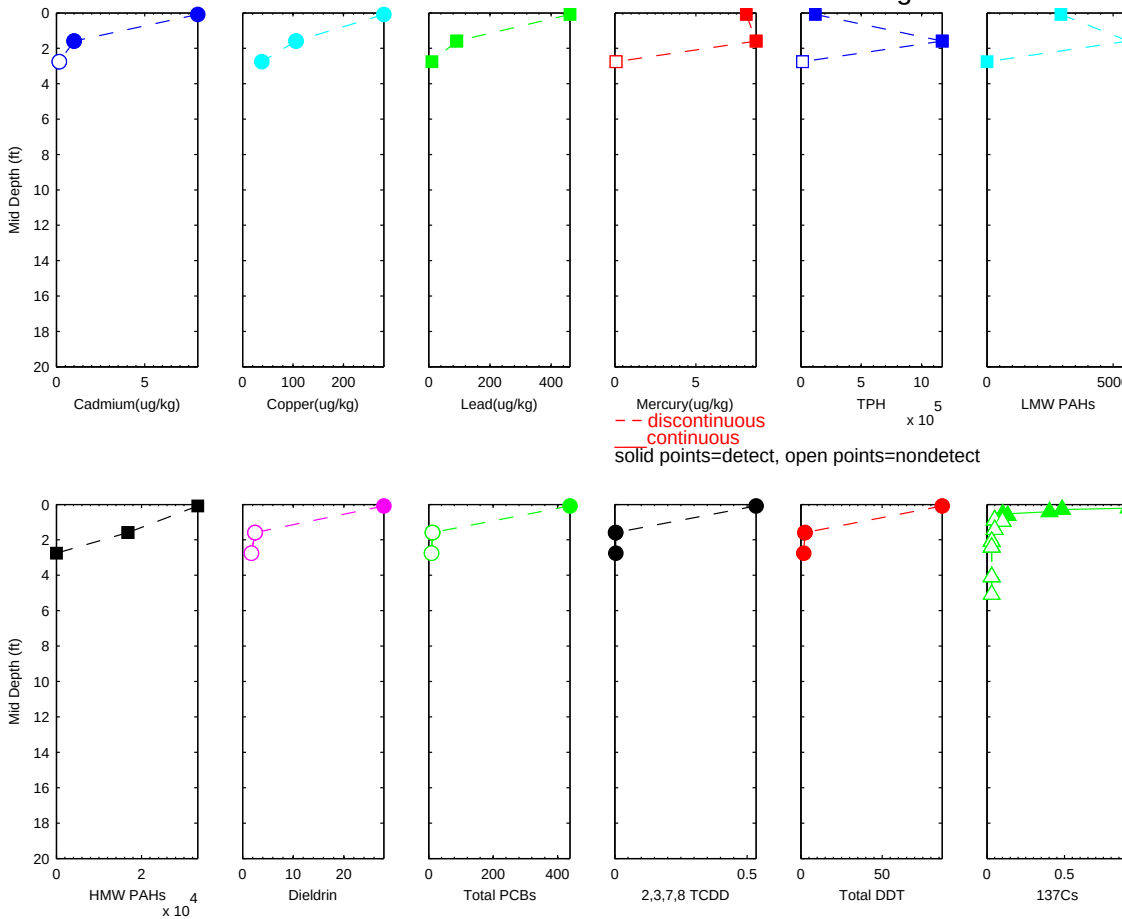
R2-0026874

Sample ID: 13A River Mile 3.97 PASSAIC 1991 Core Sediment Investigation



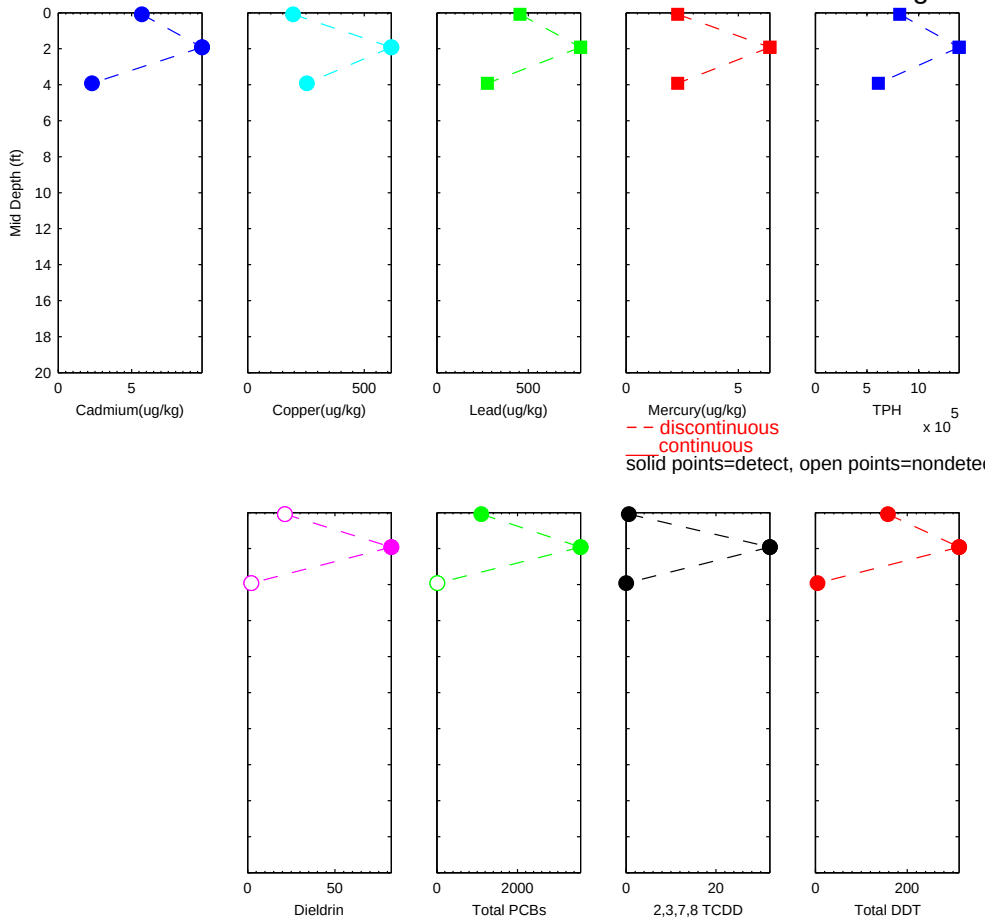
R2-0026875

Sample ID: 12A River Mile 4.87 PASSAIC 1991 Core Sediment Investigation



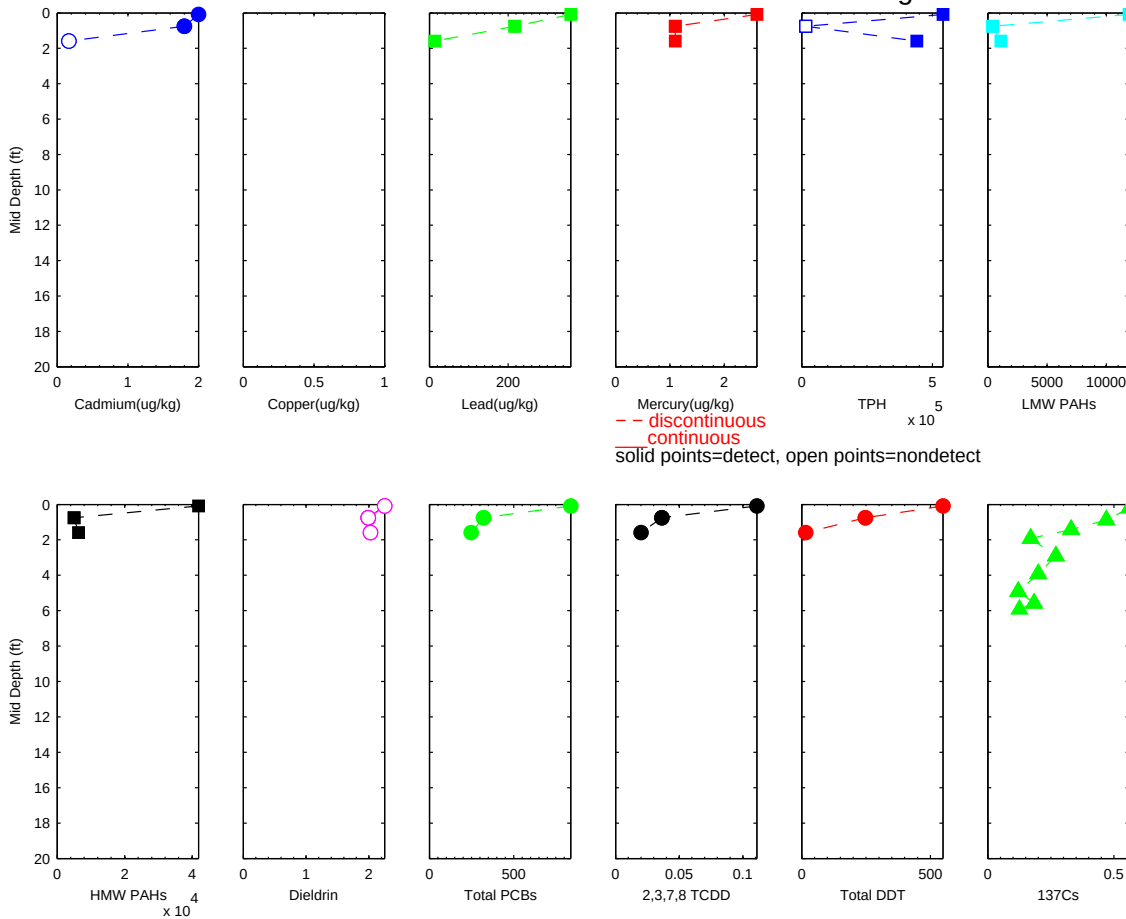
R2-0026876

Sample ID: 10A River Mile 6.91 PASSAIC 1991 Core Sediment Investigation



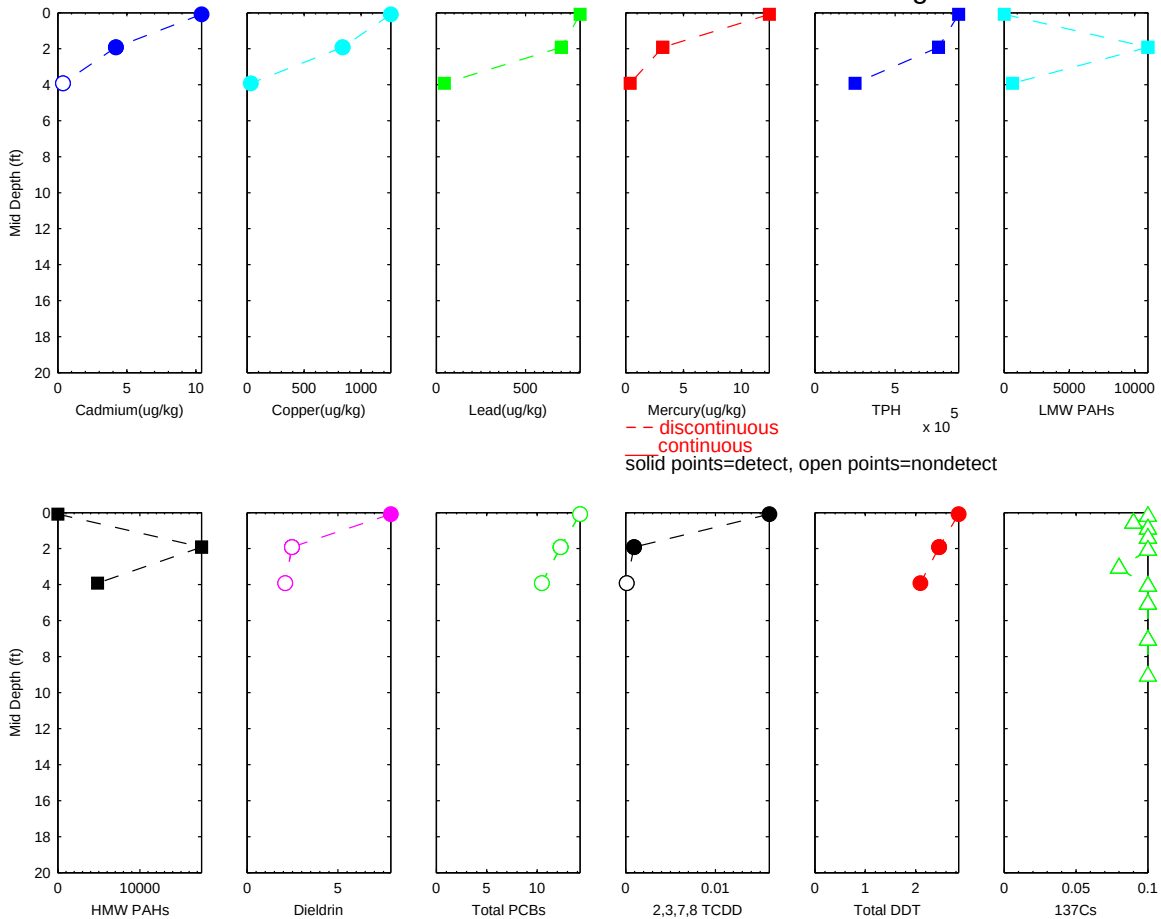
R2-0026877

Sample ID: 09A River Mile 7.98 PASSAIC 1991 Core Sediment Investigation



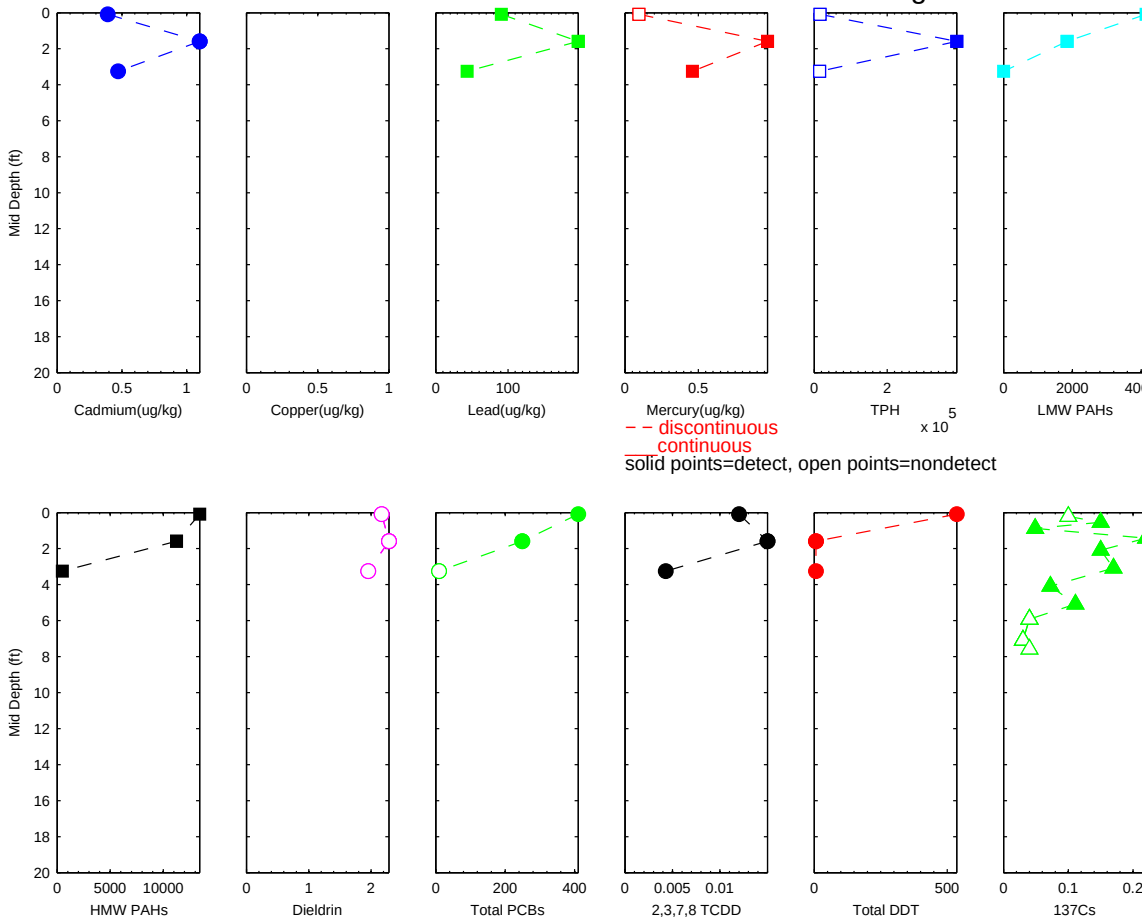
R2-0026878

Sample ID: 08A River Mile 8.91 PASSAIC 1991 Core Sediment Investigation



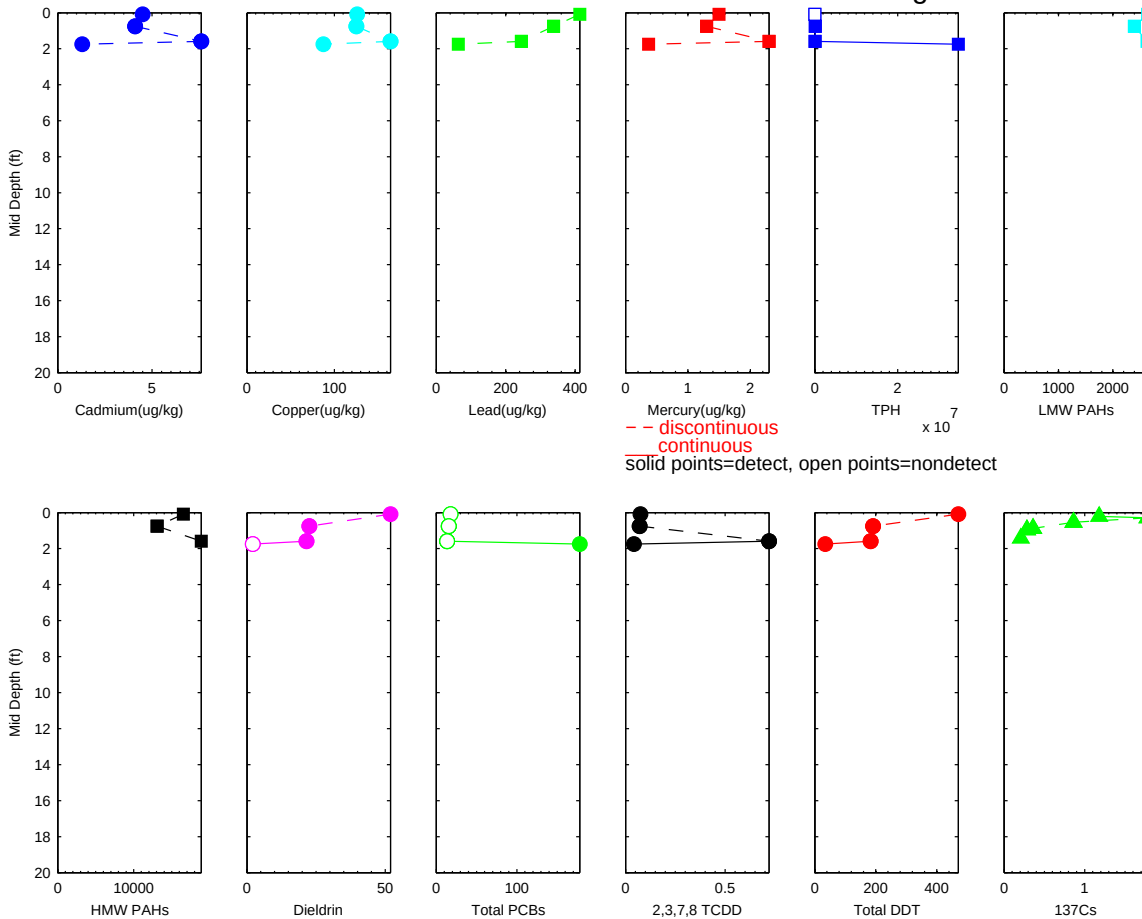
R2-0026879

Sample ID: 06A River Mile 11.21 PASSAIC 1991 Core Sediment Investigation



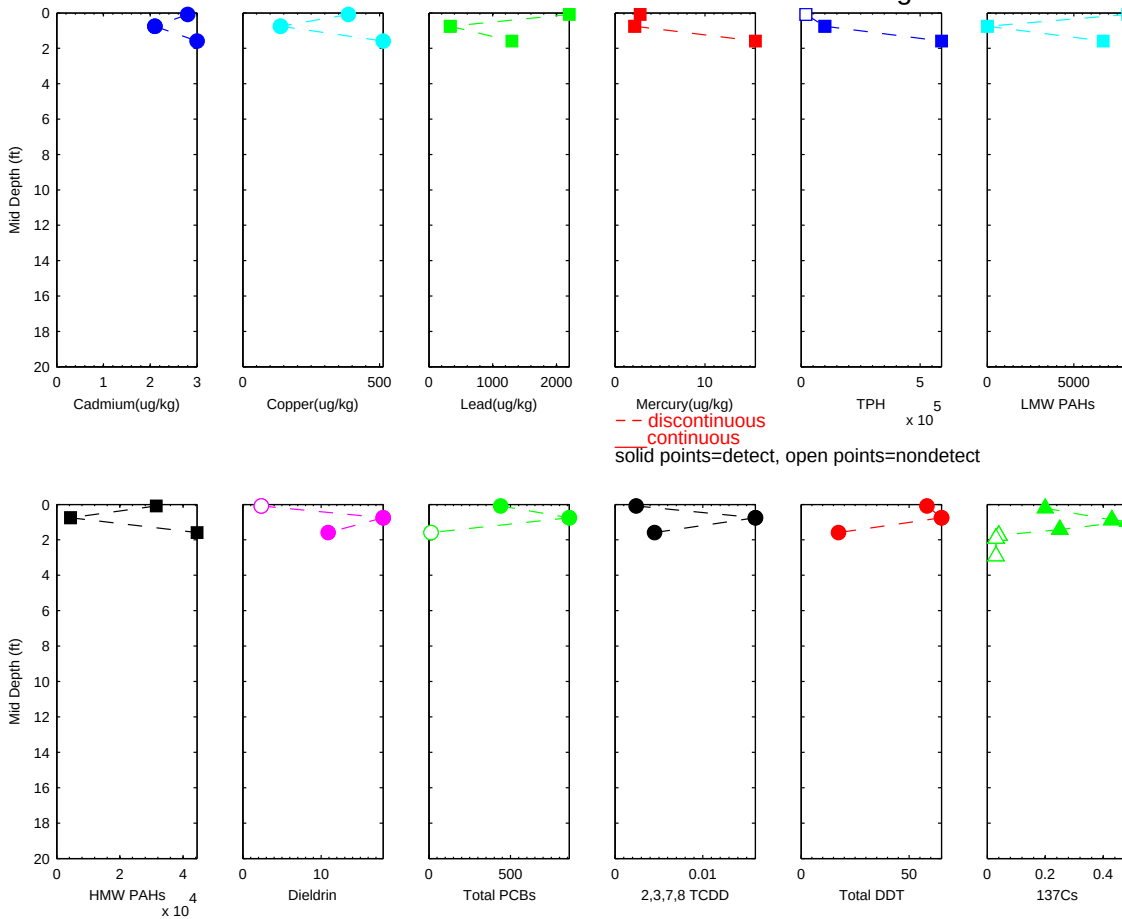
R2-0026880

Sample ID: 05B River Mile 11.19 PASSAIC 1991 Core Sediment Investigation



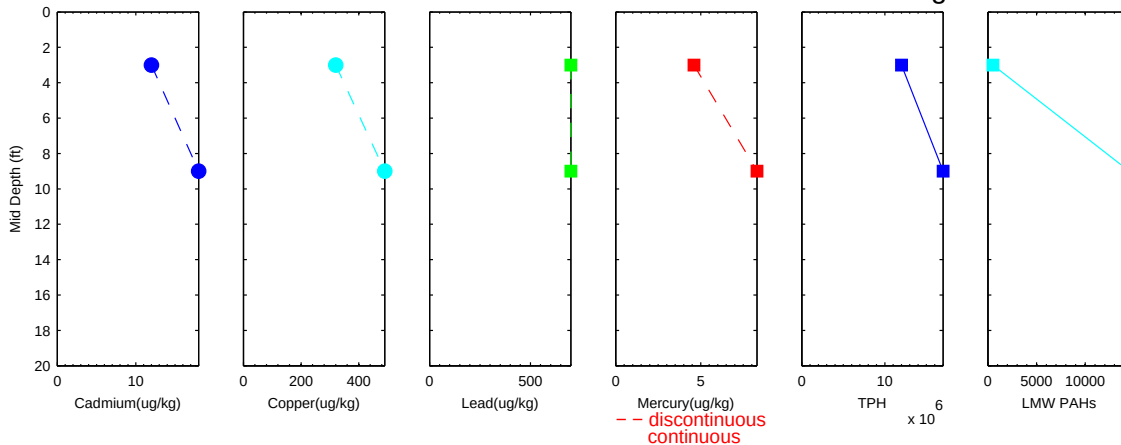
R2-0026881

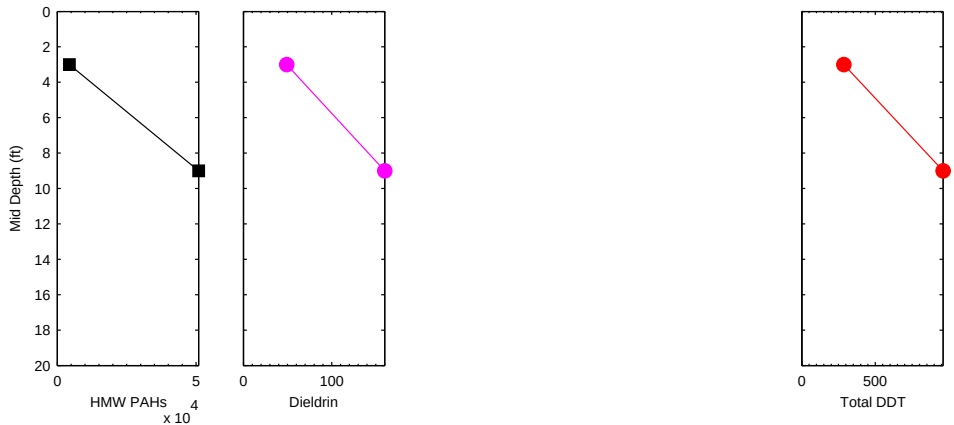
Sample ID: 02A River Mile 16.95 PASSAIC 1991 Core Sediment Investigation



R2-0026882

Sample ID: WTH−7 River Mile 5.02 PASSAIC 1995 USACE Minish Park Investigation

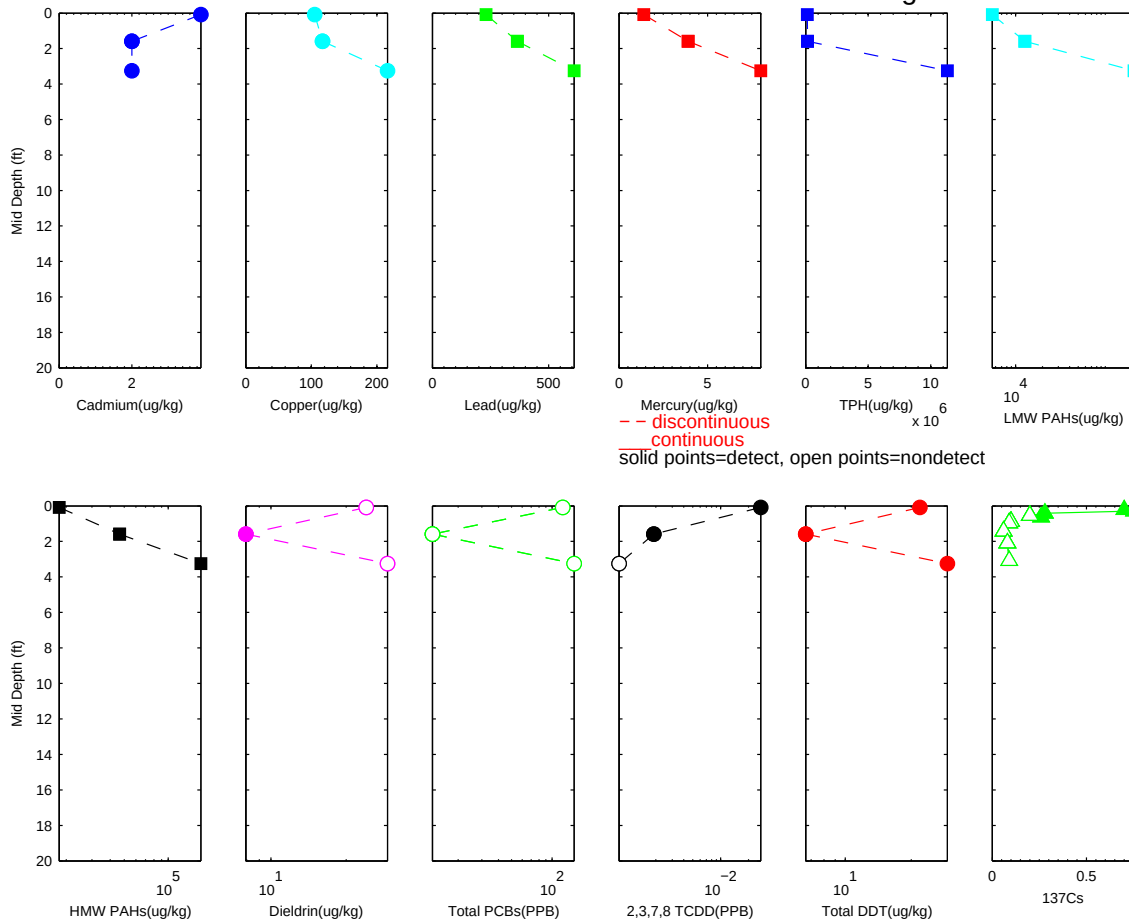




R2-0026883

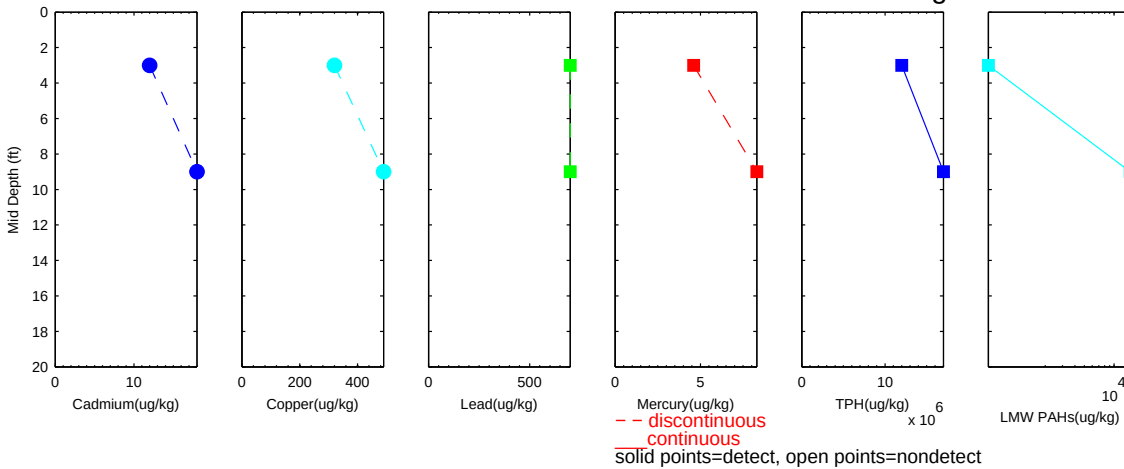
Historical Analyte Plots,
Plotted on a Logarithmic Scale

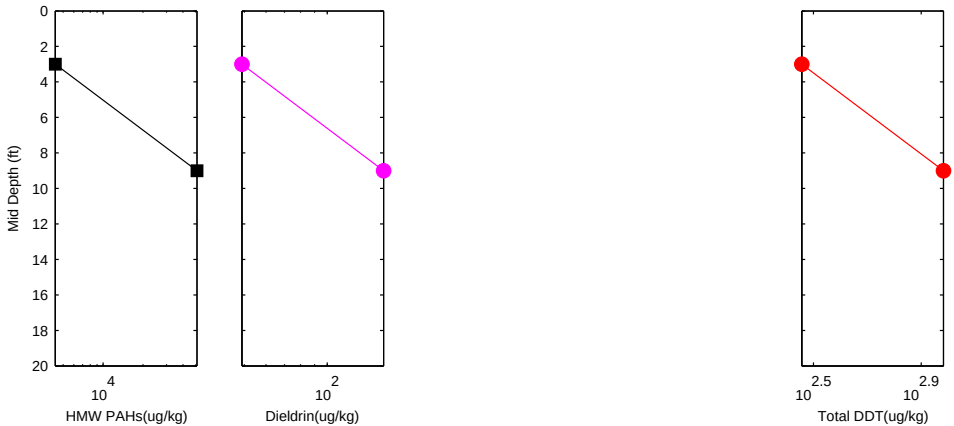
Sample ID: 01A River Mile 17.43 PASSAIC 1991 Core Sediment Investigation



R2-0026885

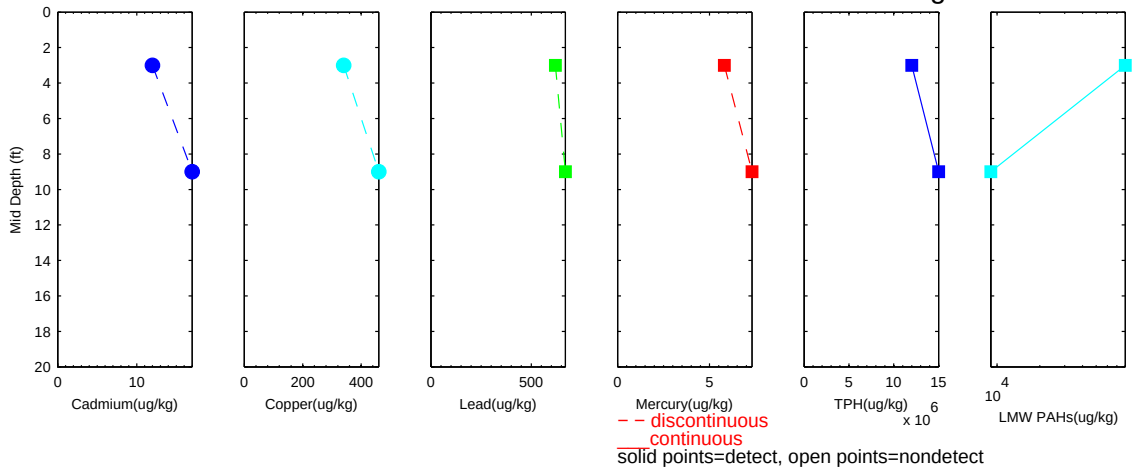
Sample ID: WTH−7 River Mile 5.02 PASSAIC 1995 USACE Minish Park Investigation

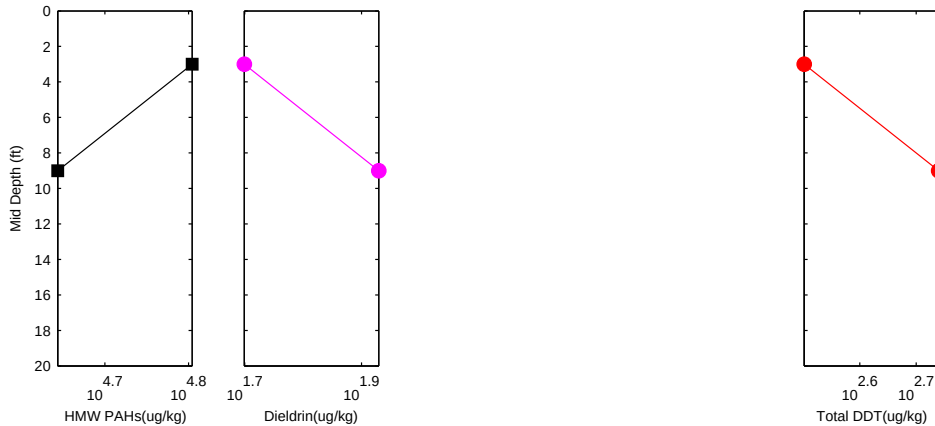




R2-0026886

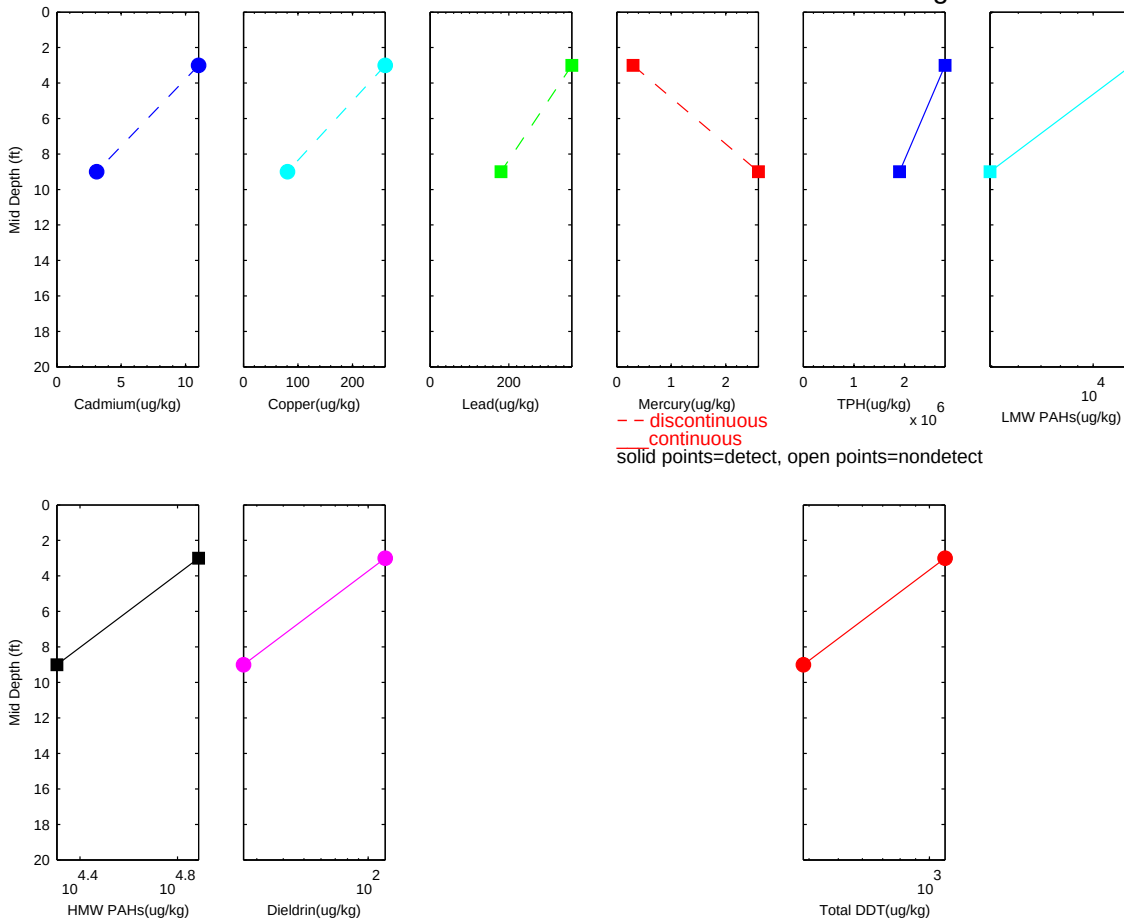
Sample ID: WTH−6 River Mile 4.98 PASSAIC 1995 USACE Minish Park Investigation





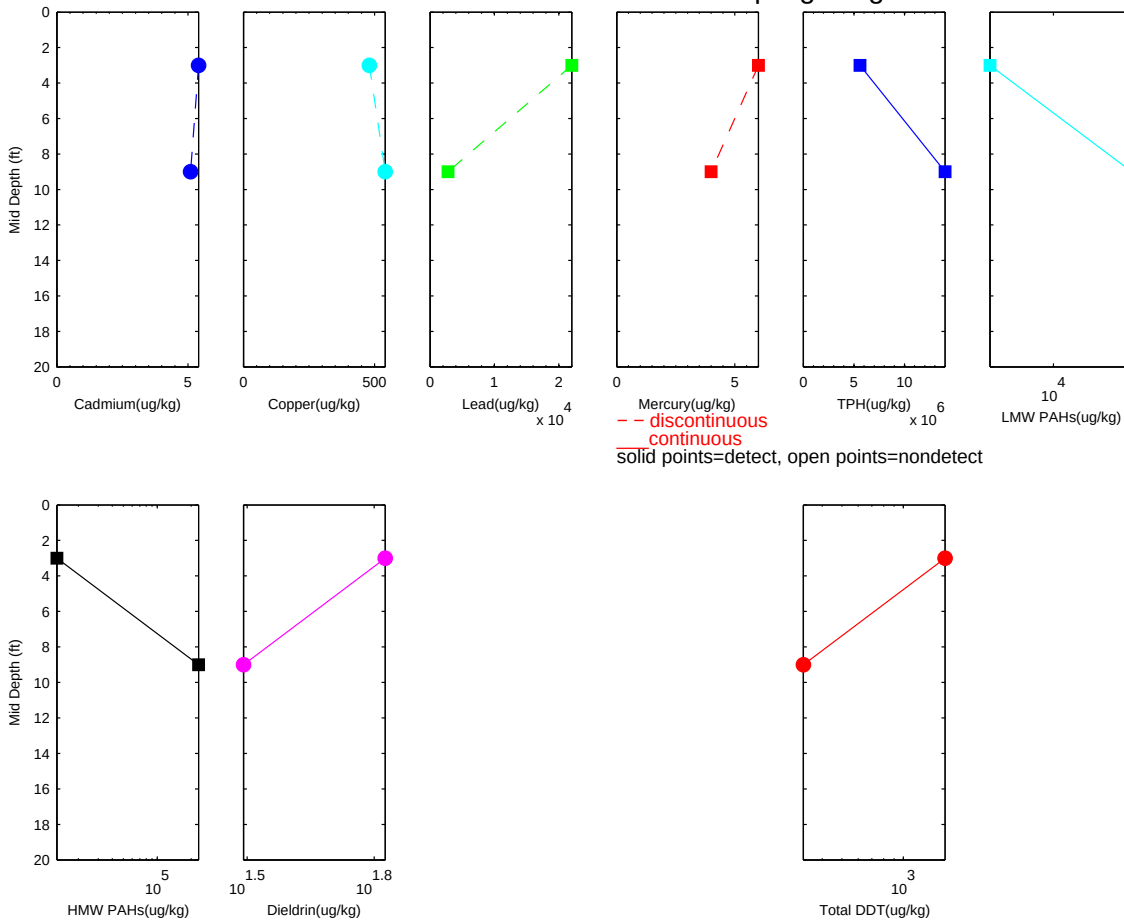
R2-0026887

Sample ID: WTH−5 River Mile 4.74 PASSAIC 1995 USACE Minish Park Investigation



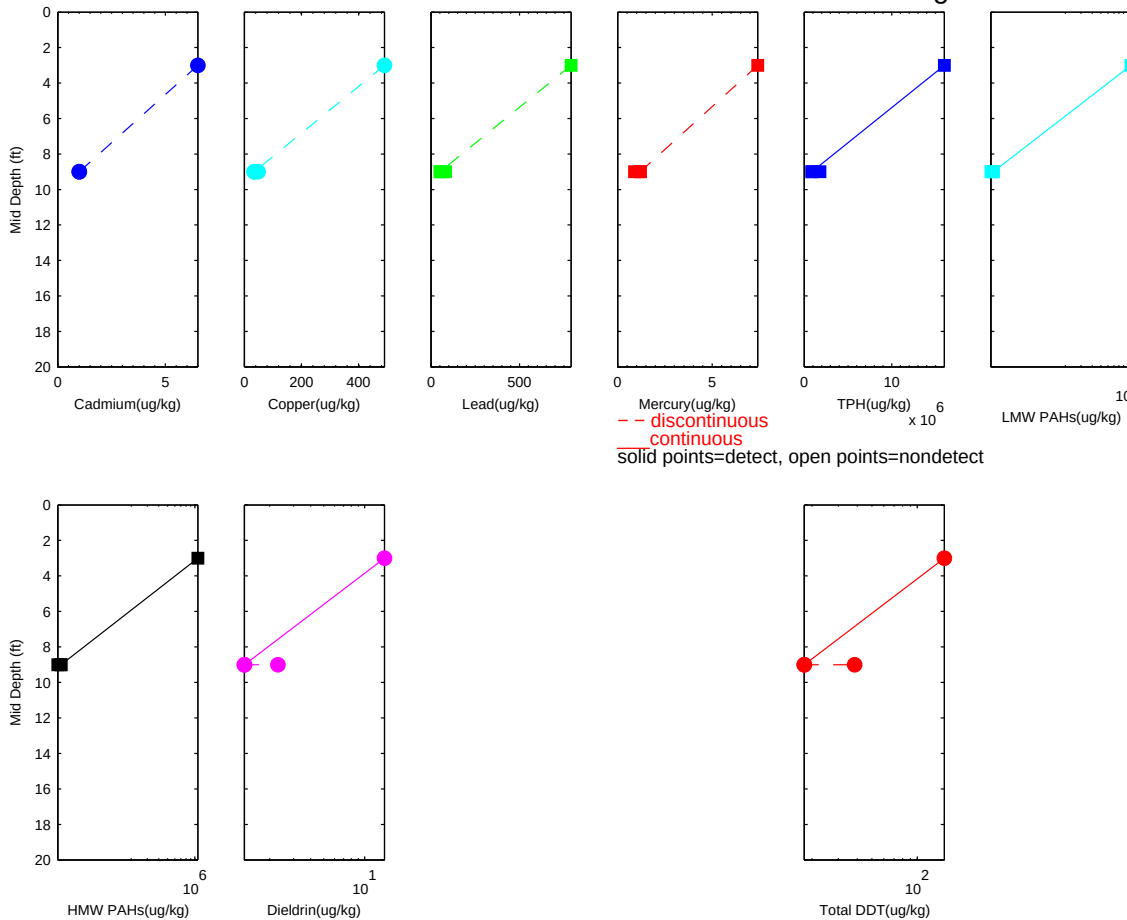
R2-0026888

Sample ID: WTH−3 River Mile 4.36 PASSAIC 1995 RI Sampling Program



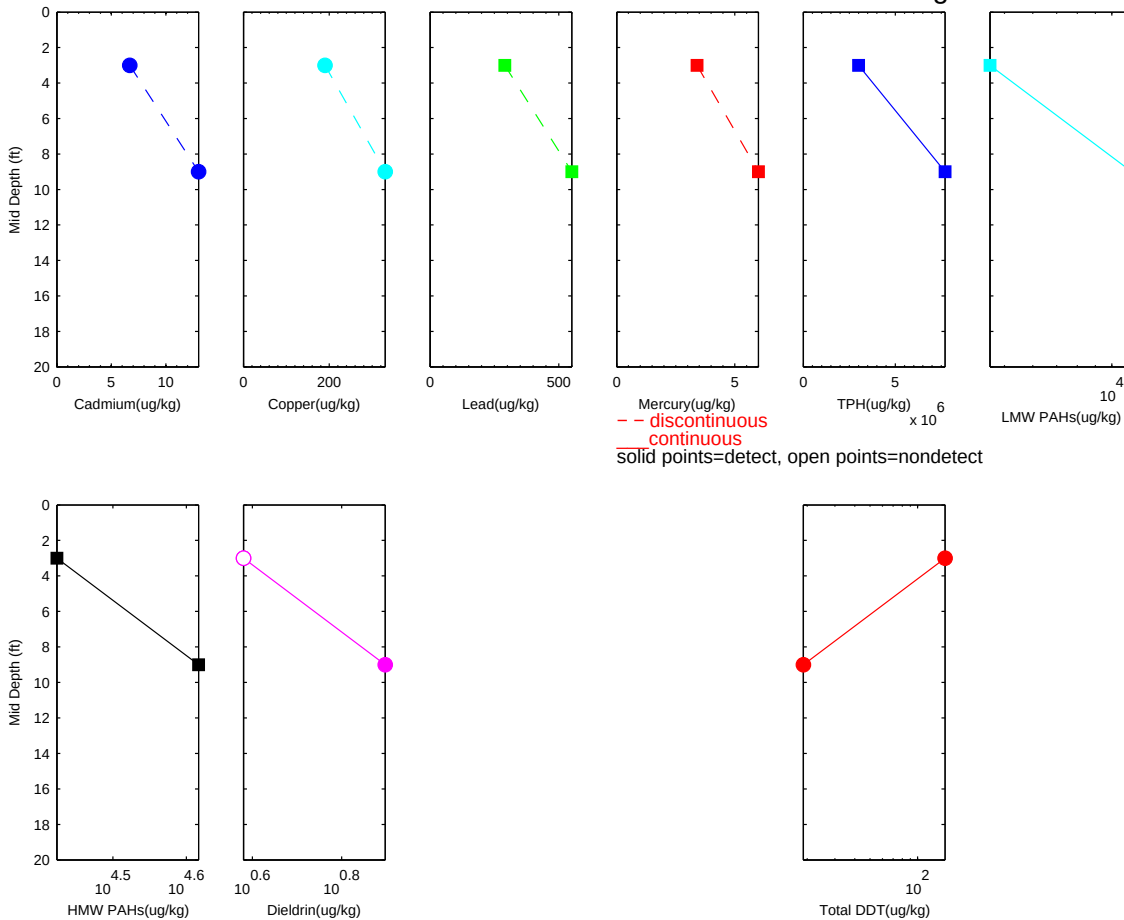
R2-0026889

Sample ID: WTH−2 River Mile 4.04 PASSAIC 1995 USACE Minish Park Investigation



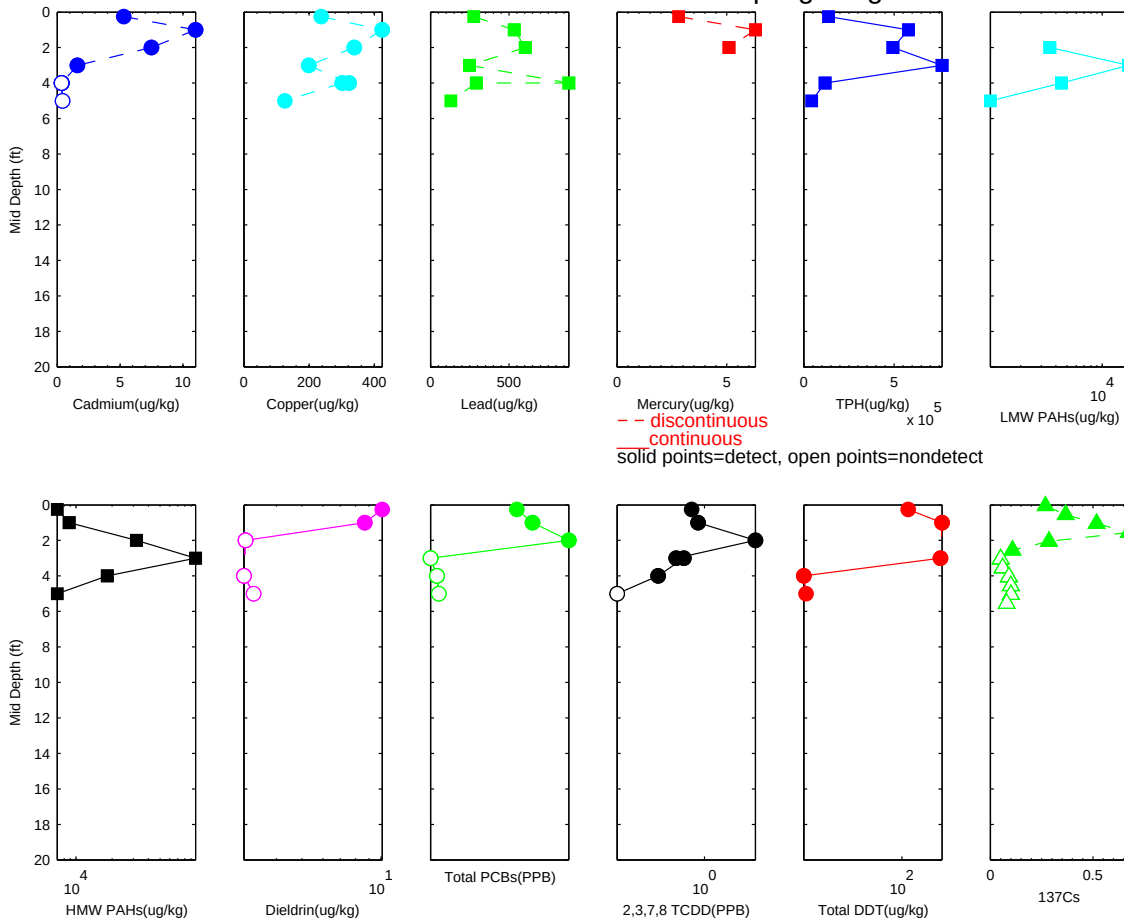
R2-0026890

Sample ID: WTH−1 River Mile 5.39 PASSAIC 1995 USACE Minish Park Investigation



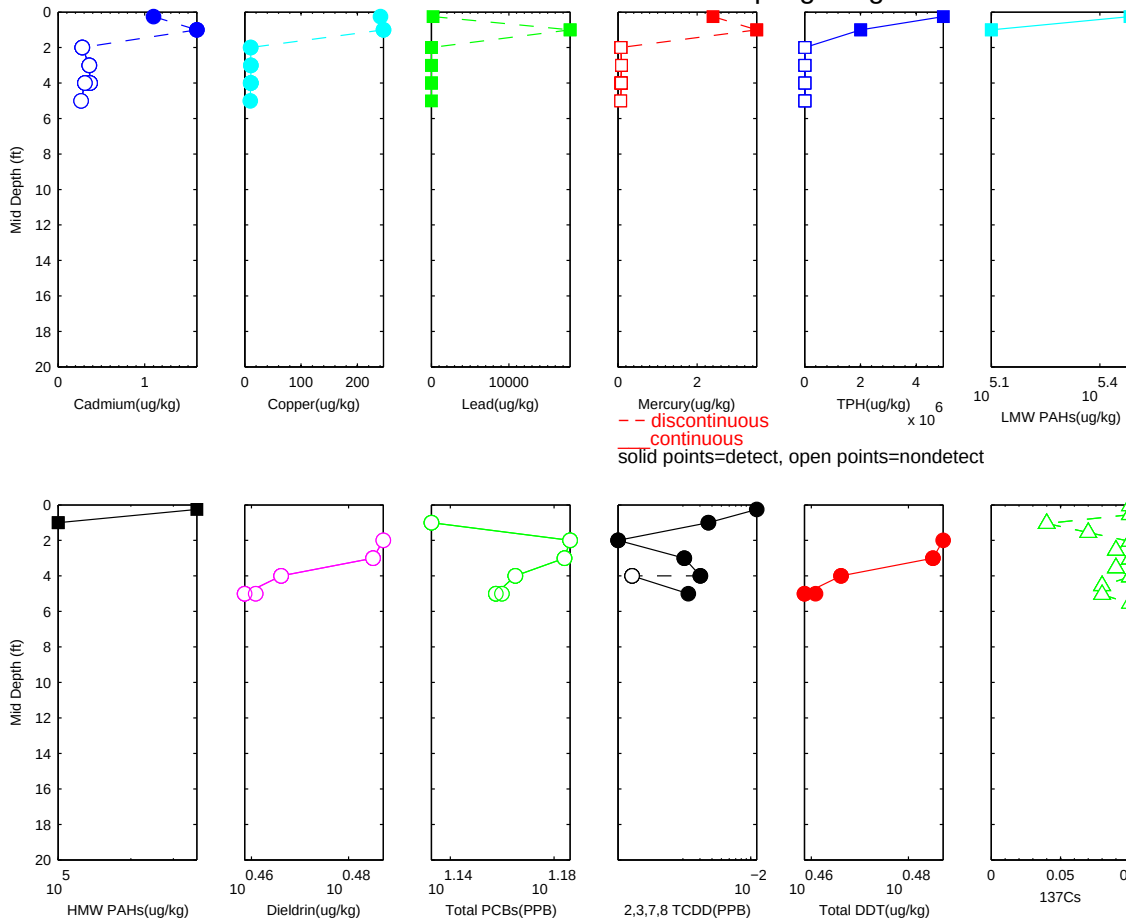
R2-0026891

Sample ID: D03 River Mile 2.65 PASSAIC 1995 RI Sampling Program



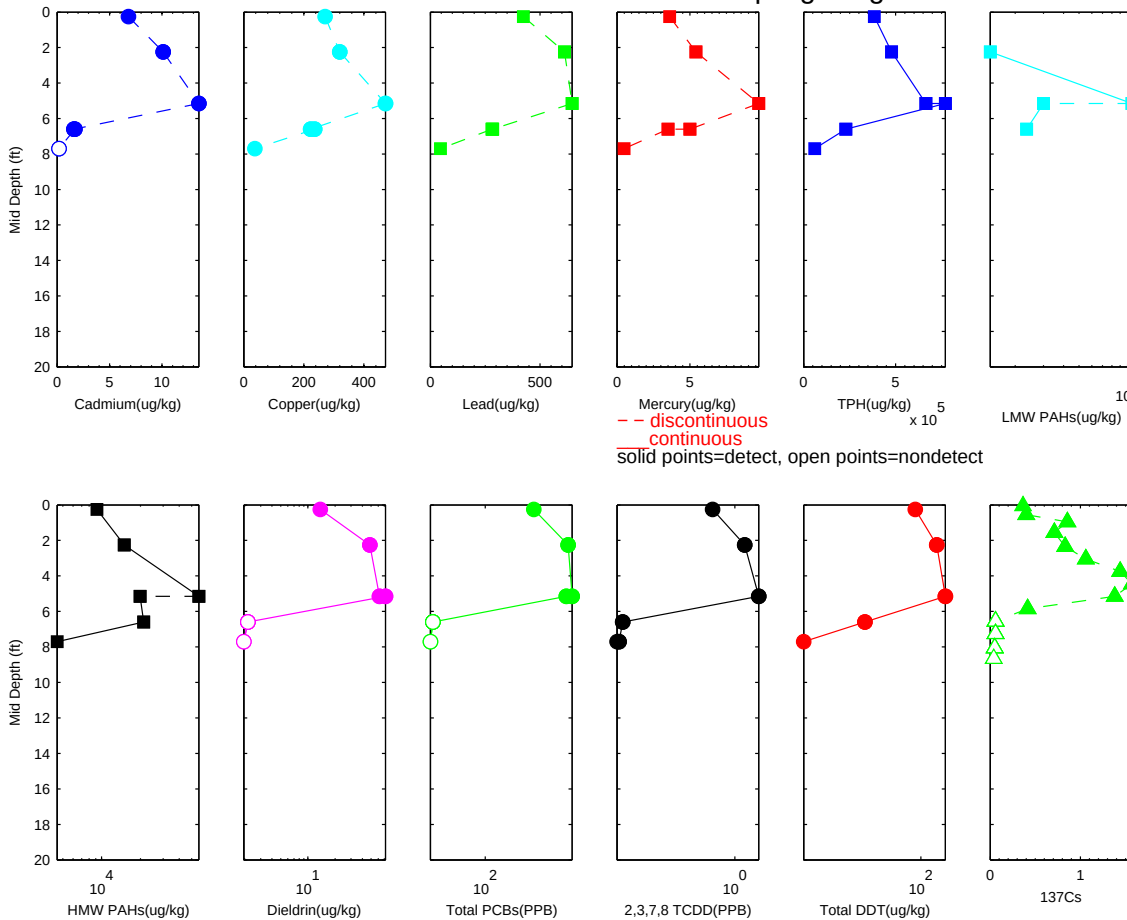
R2-0026892

Sample ID: D02 River Mile 3.64 PASSAIC 1995 RI Sampling Program



R2-0026893

Sample ID: D01 River Mile 5.16 PASSAIC 1995 RI Sampling Program



R2-0026894

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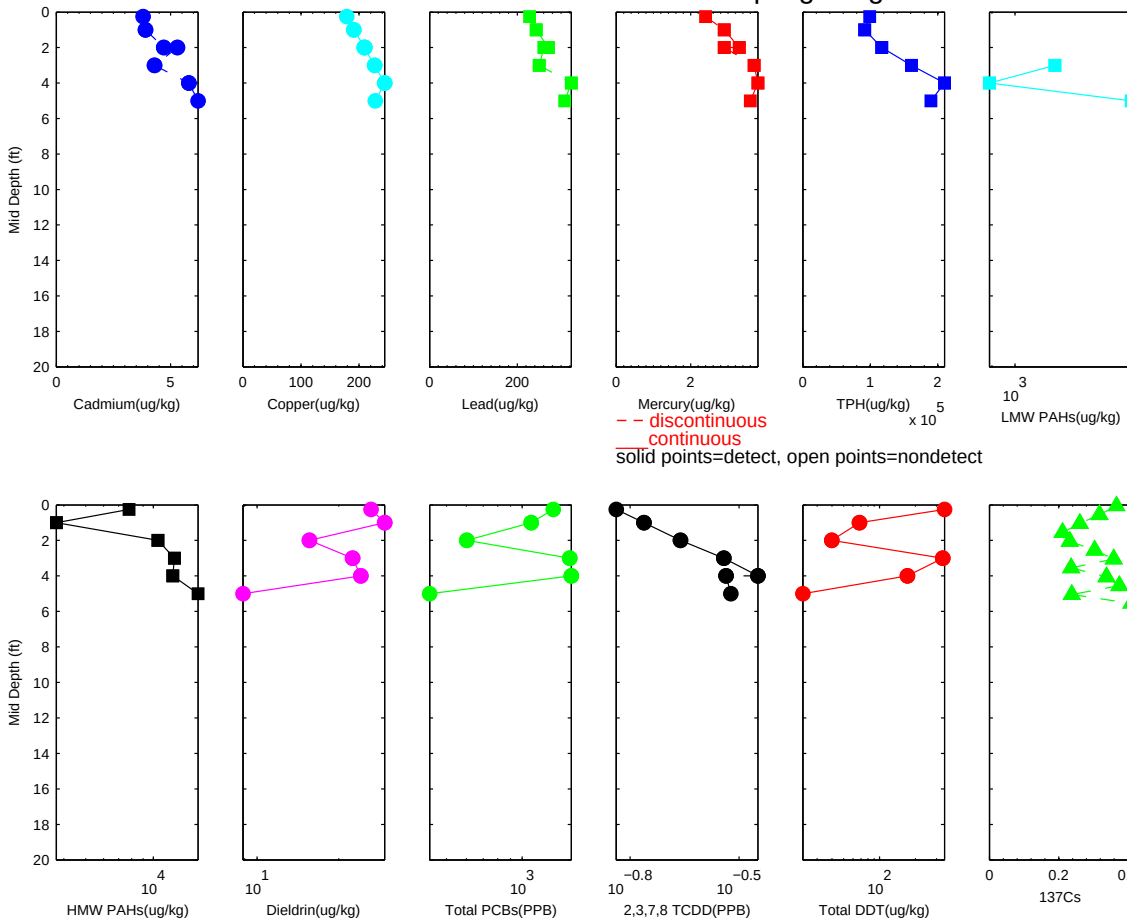
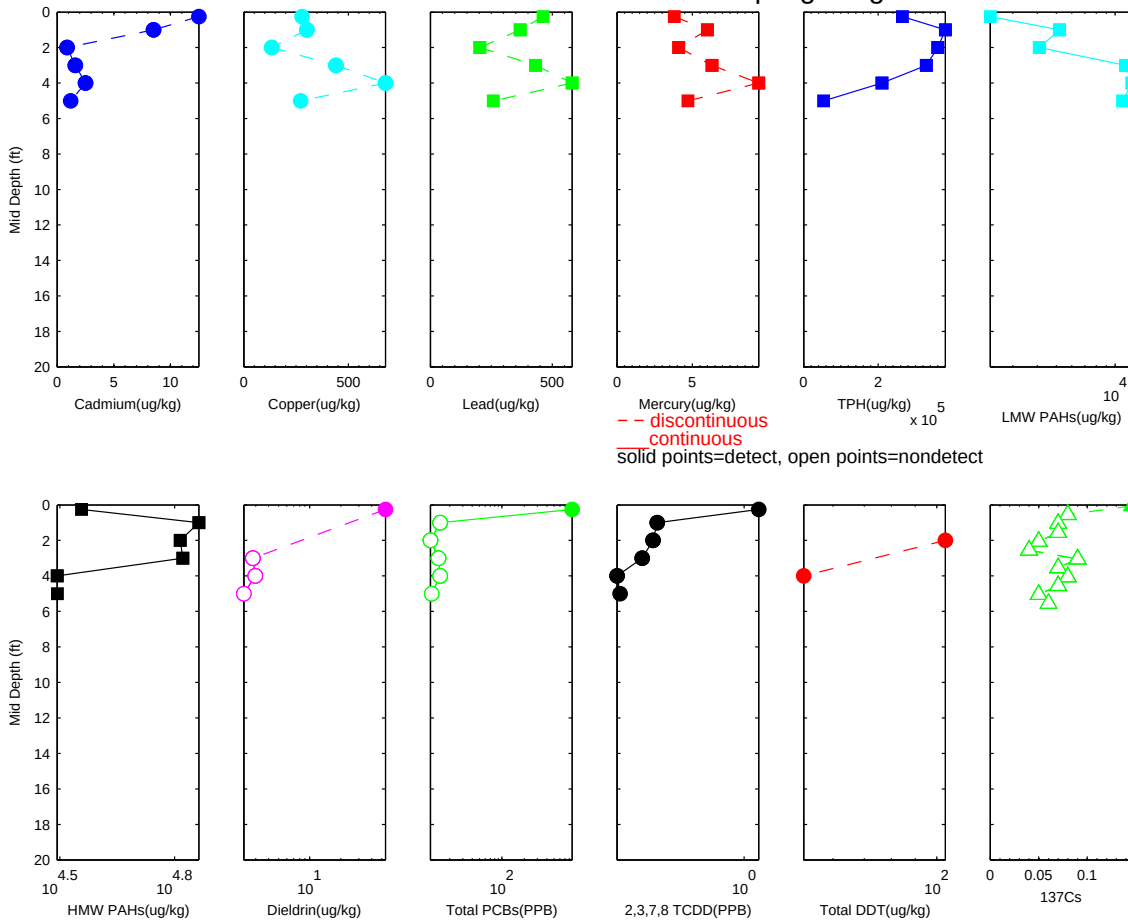


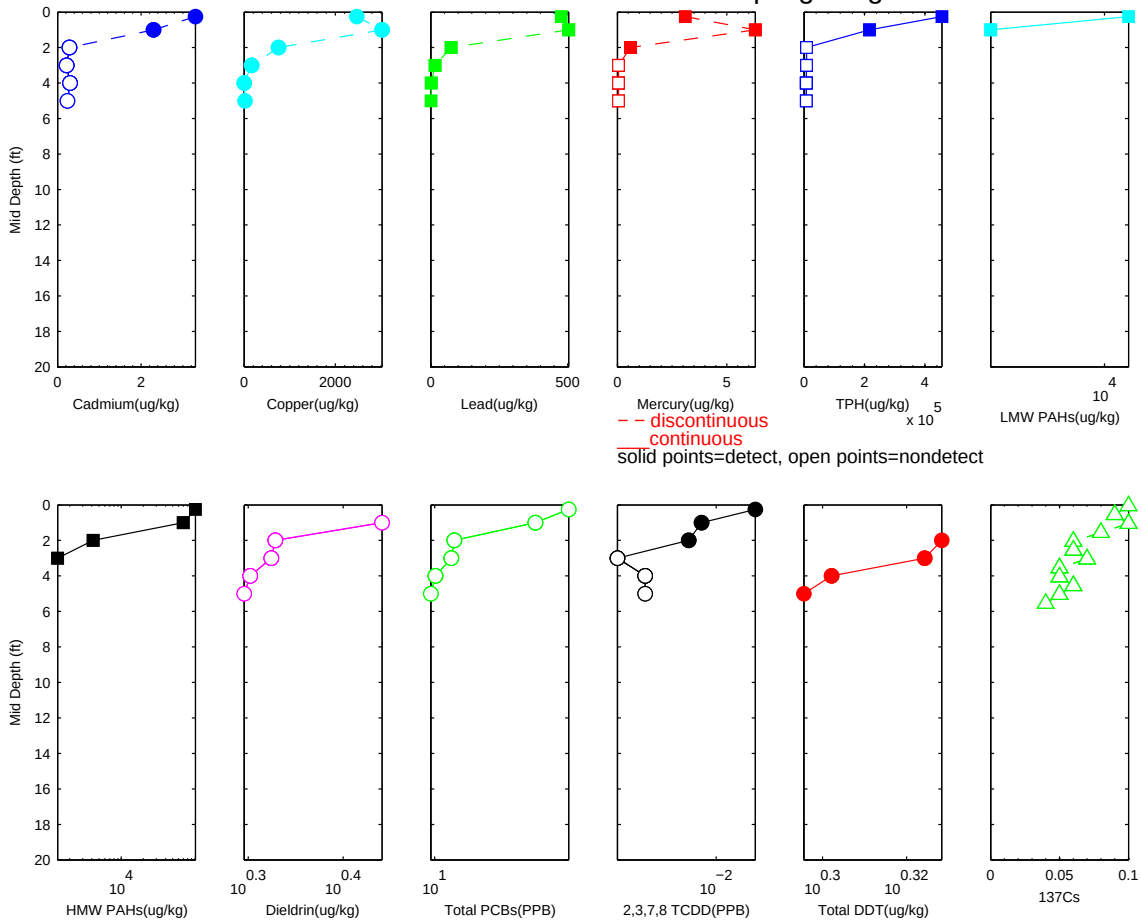
R2-0026895

Sample ID: 294 River Mile 3.13 PASSAIC 1995 RI Sampling Program



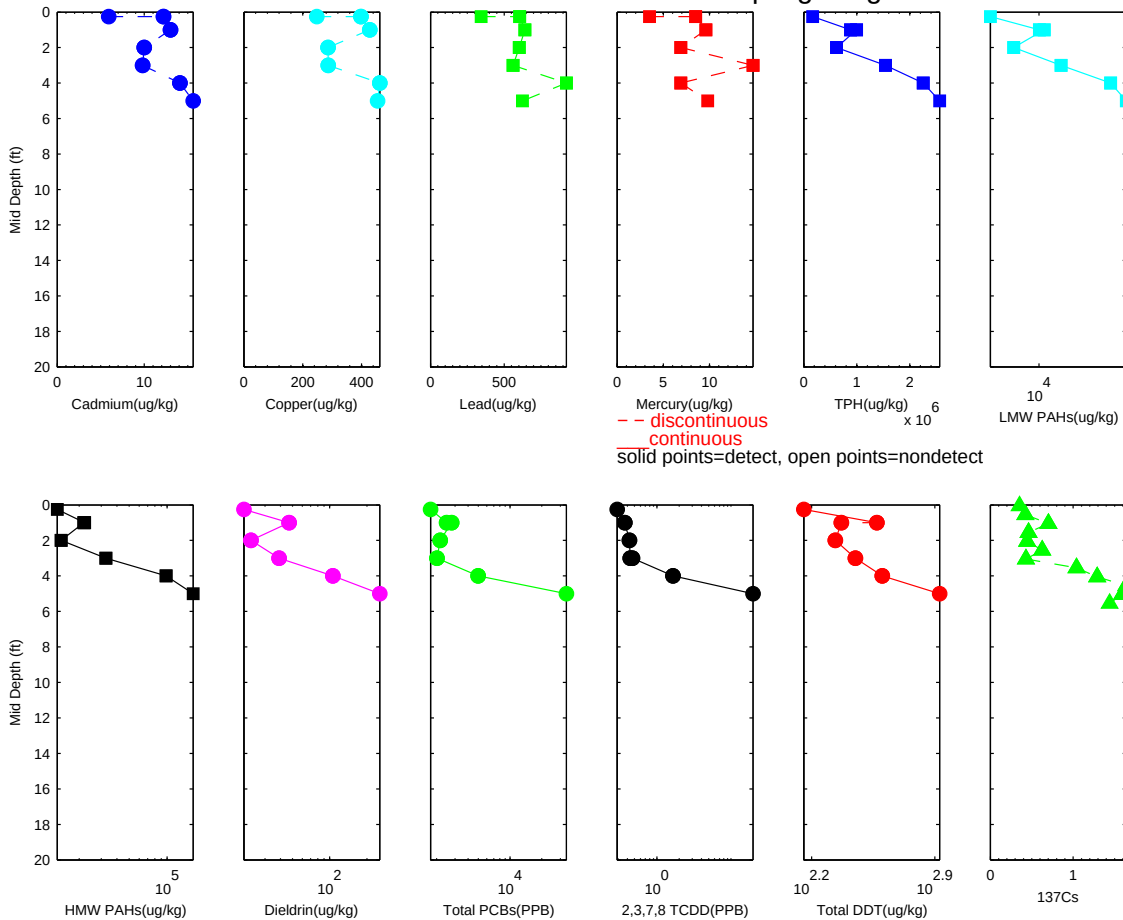
R2-0026896

Sample ID: 293 River Mile 5.08 PASSAIC 1995 RI Sampling Program



R2-0026897

Sample ID: 292 River Mile 4.37 PASSAIC 1995 RI Sampling Program



R2-0026898

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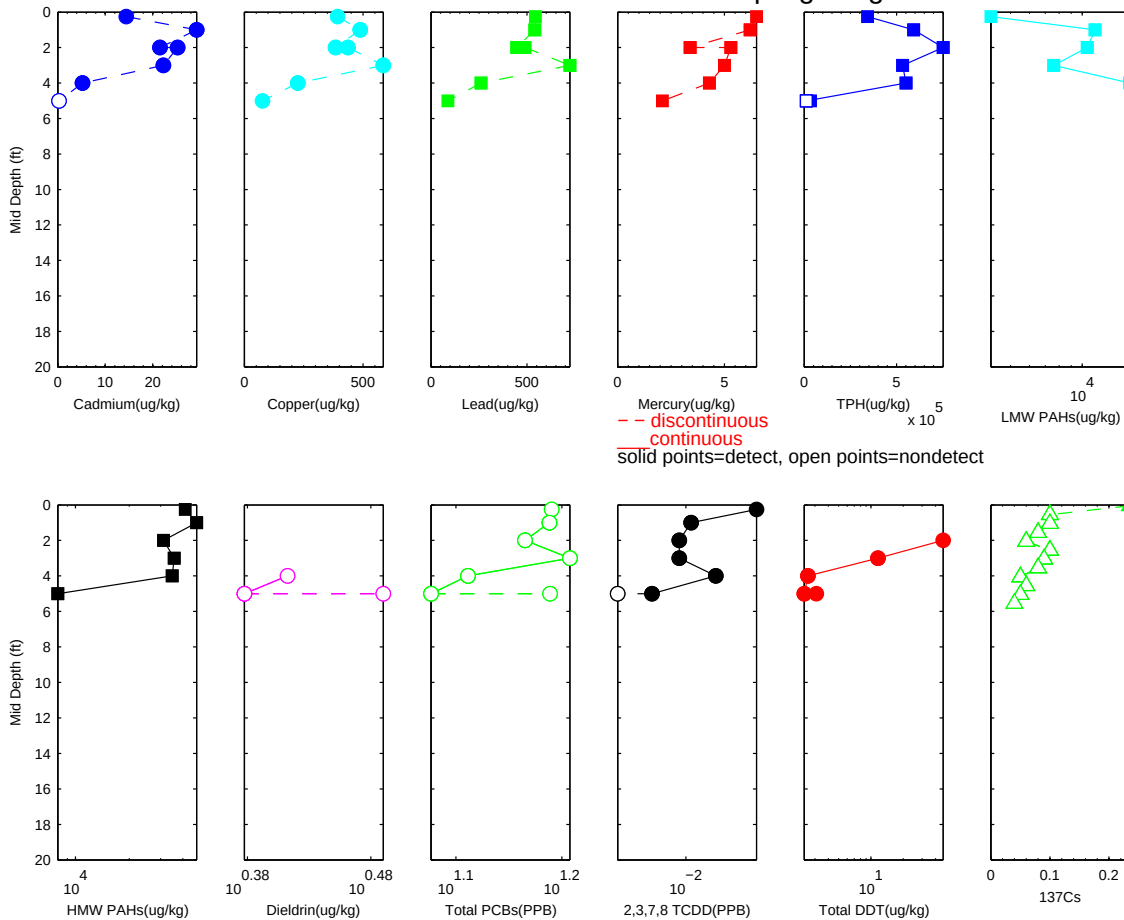
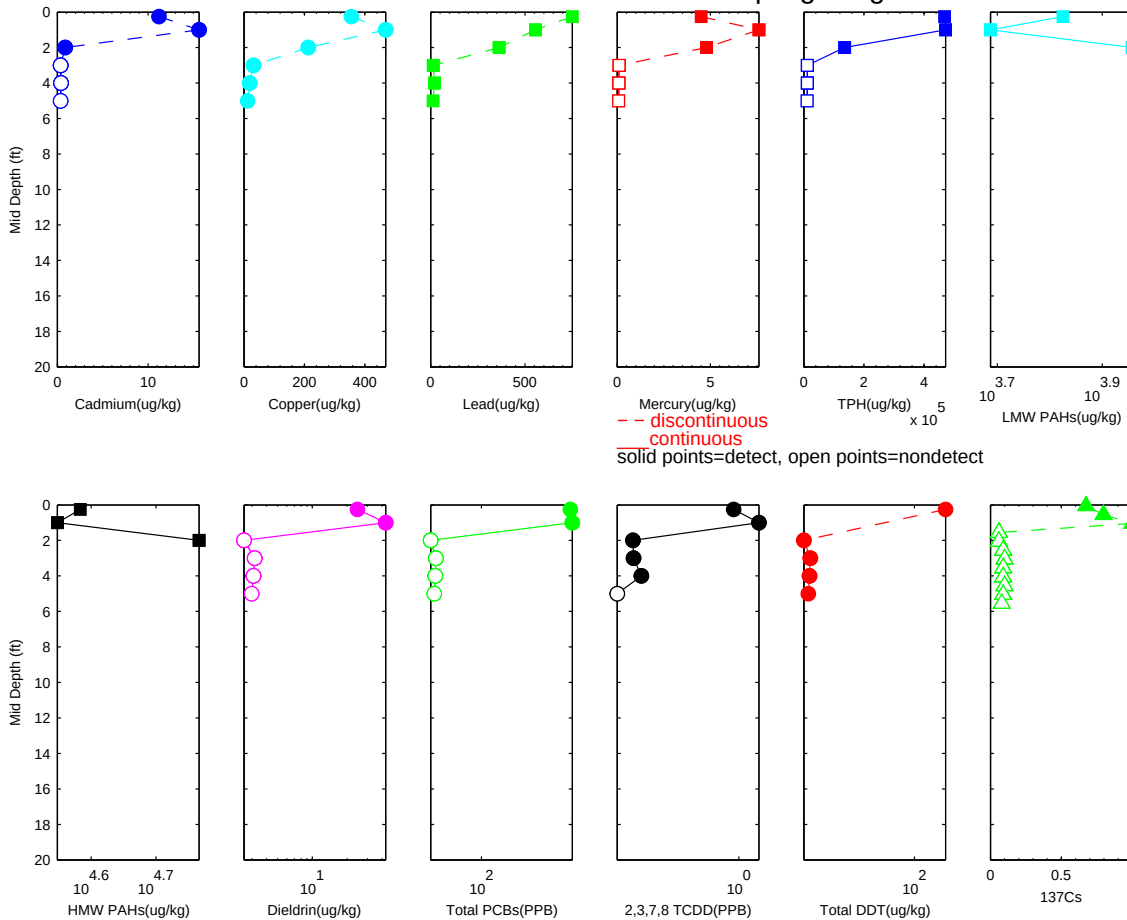


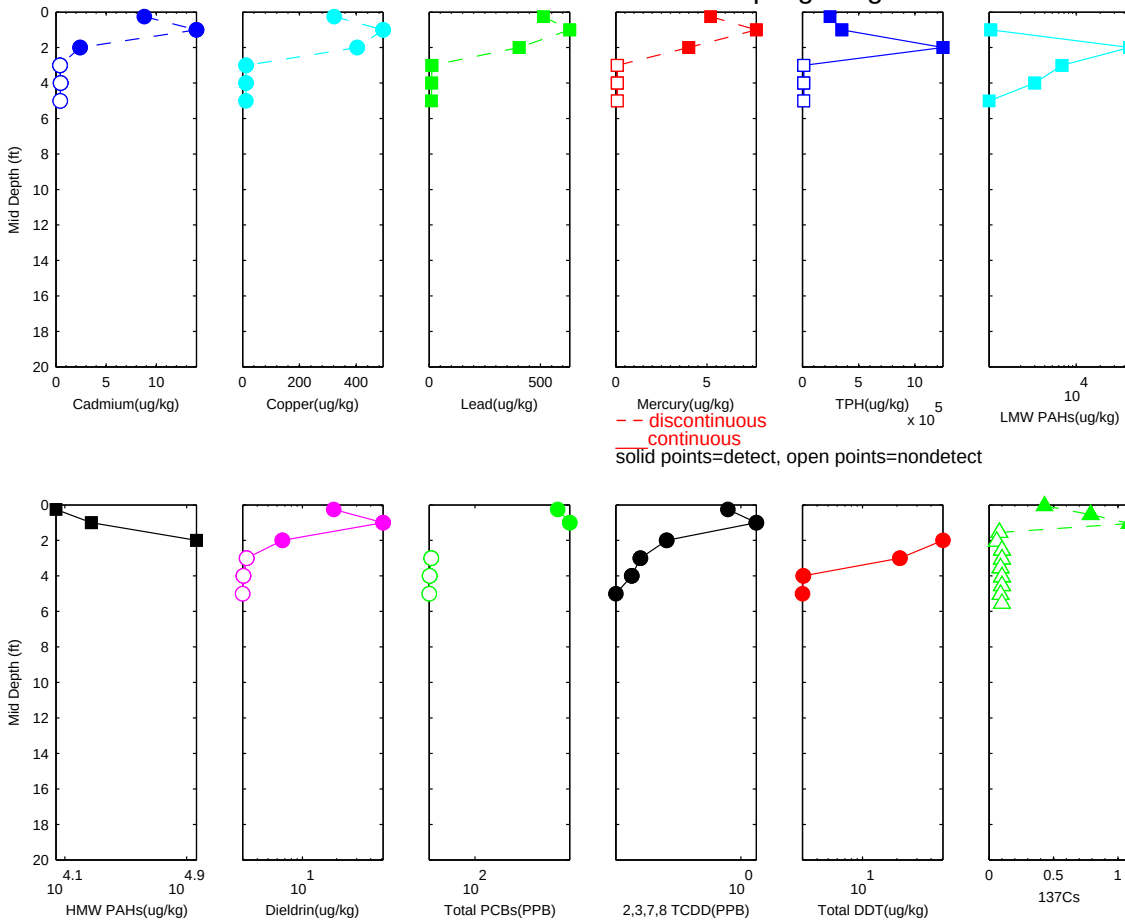
R2-0026899

Sample ID: 290 River Mile 4.24 PASSAIC 1995 RI Sampling Program



R2-0026900

Sample ID: 289 River Mile 4.17 PASSAIC 1995 RI Sampling Program



R2-0026901

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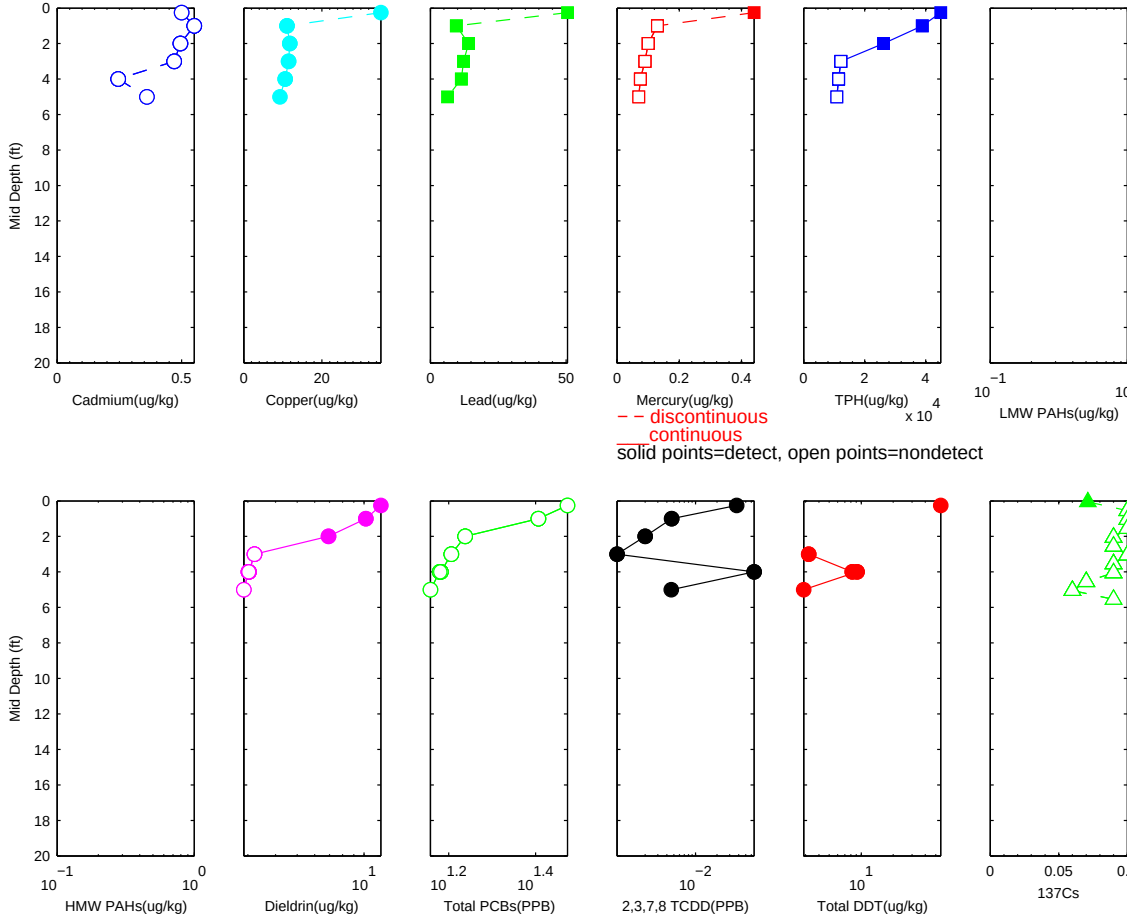
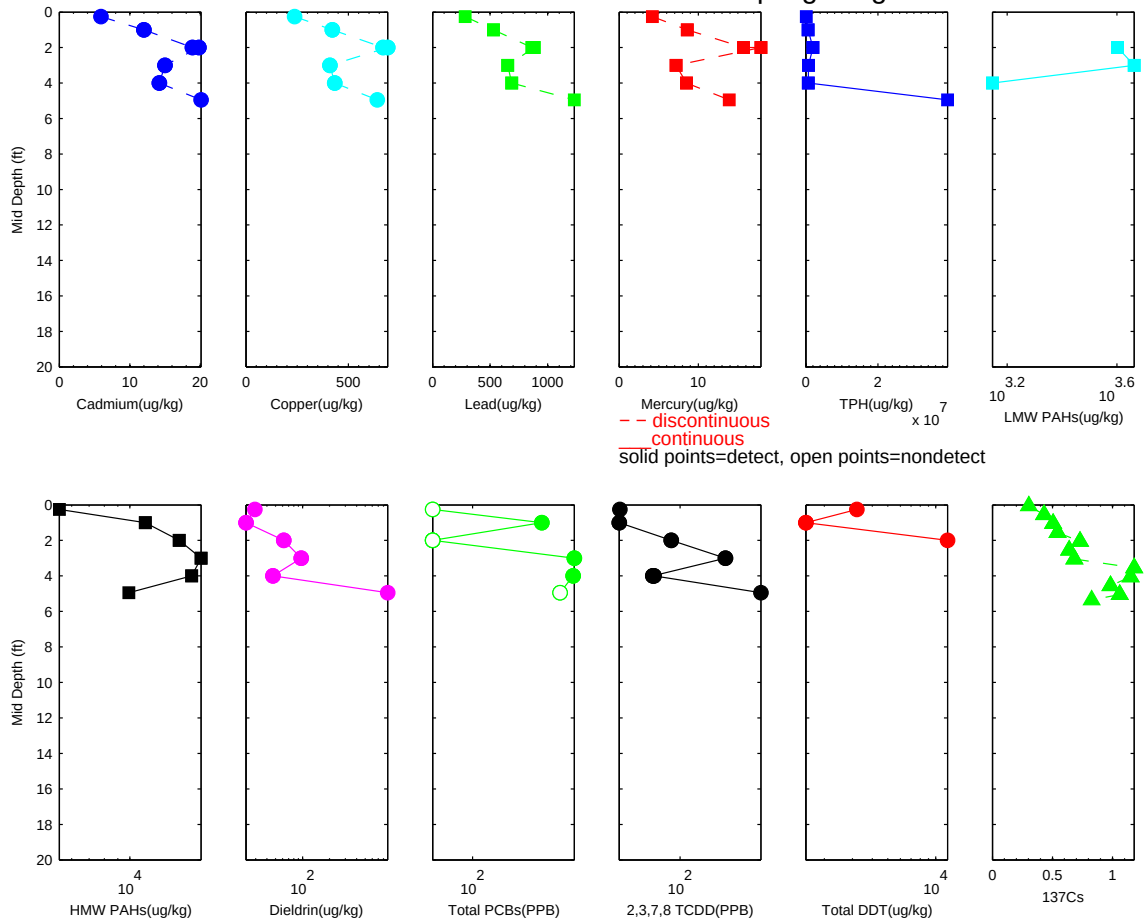


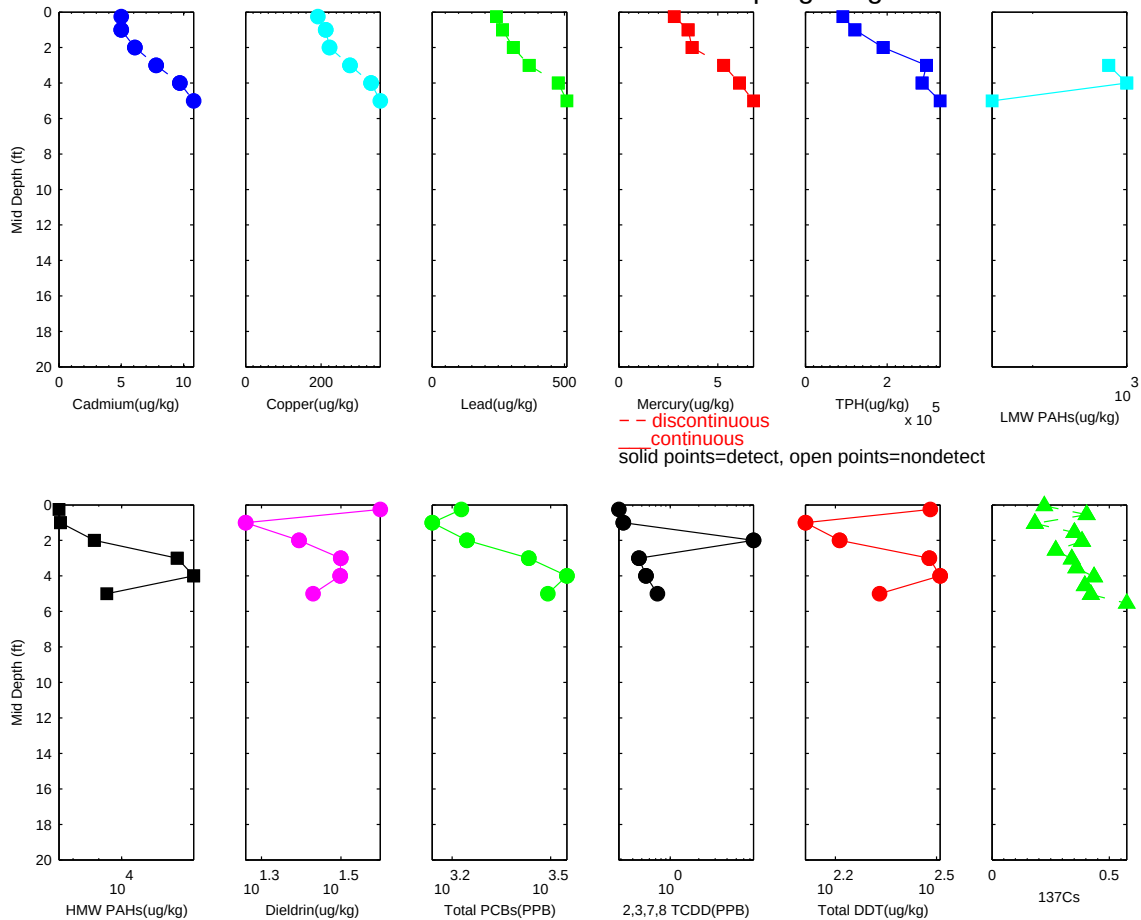
R2-0026902

Sample ID: 285 River Mile 3.14 PASSAIC 1995 RI Sampling Program



R2-0026903

Sample ID: 283 River Mile 2.24 PASSAIC 1995 RI Sampling Program



R2-0026904

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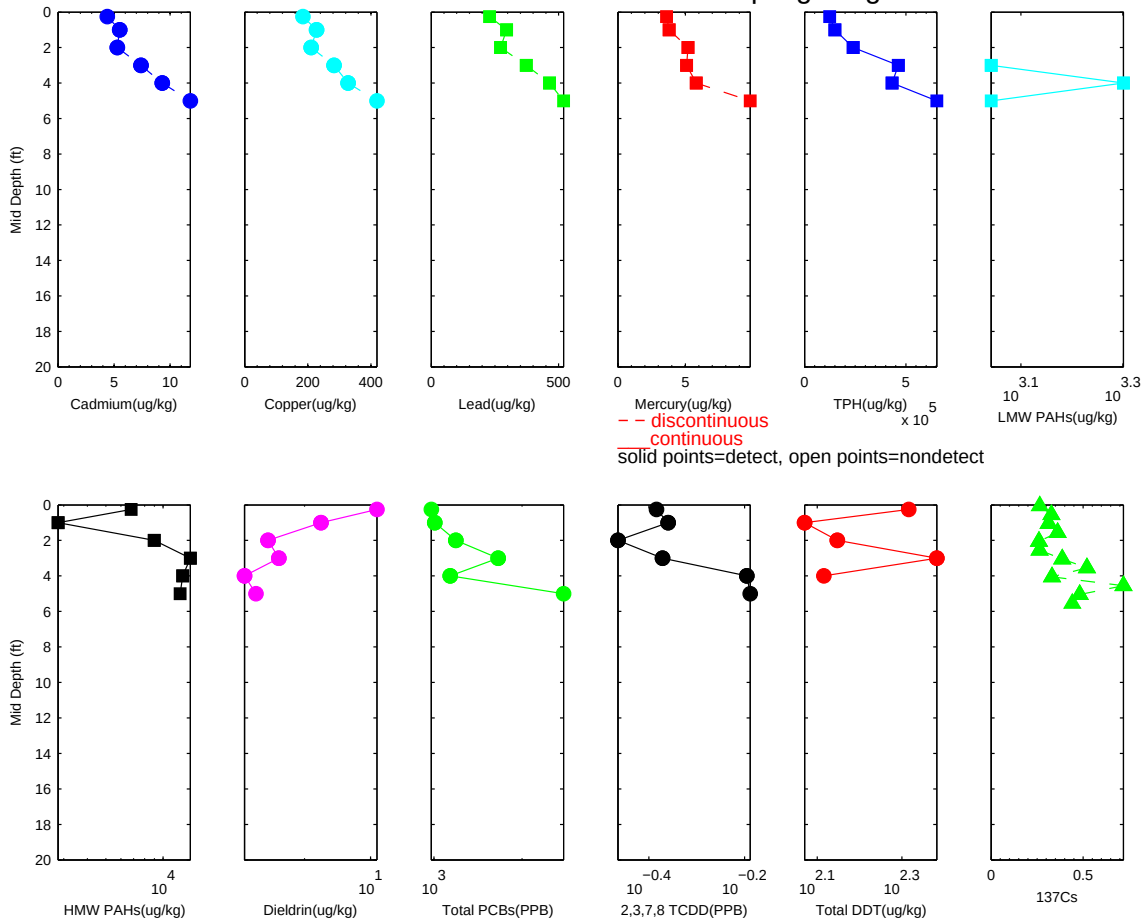
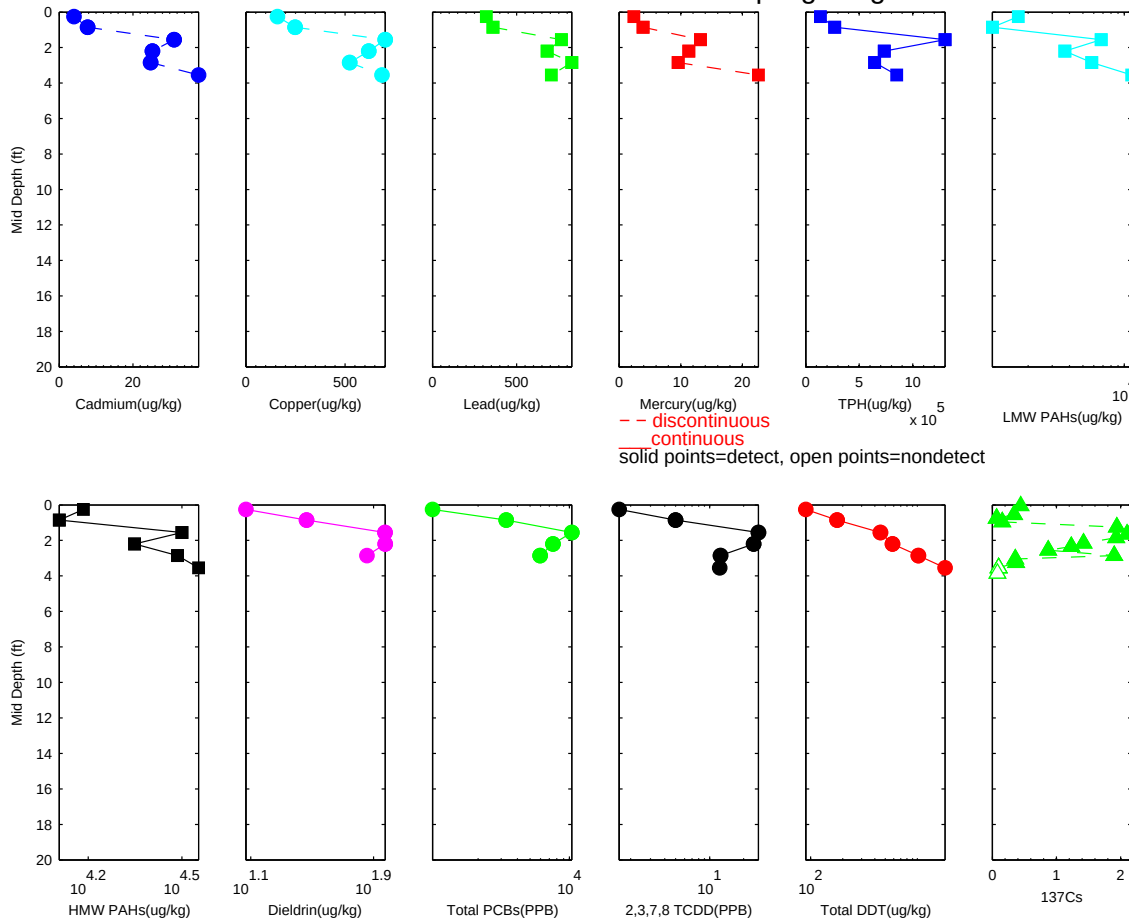


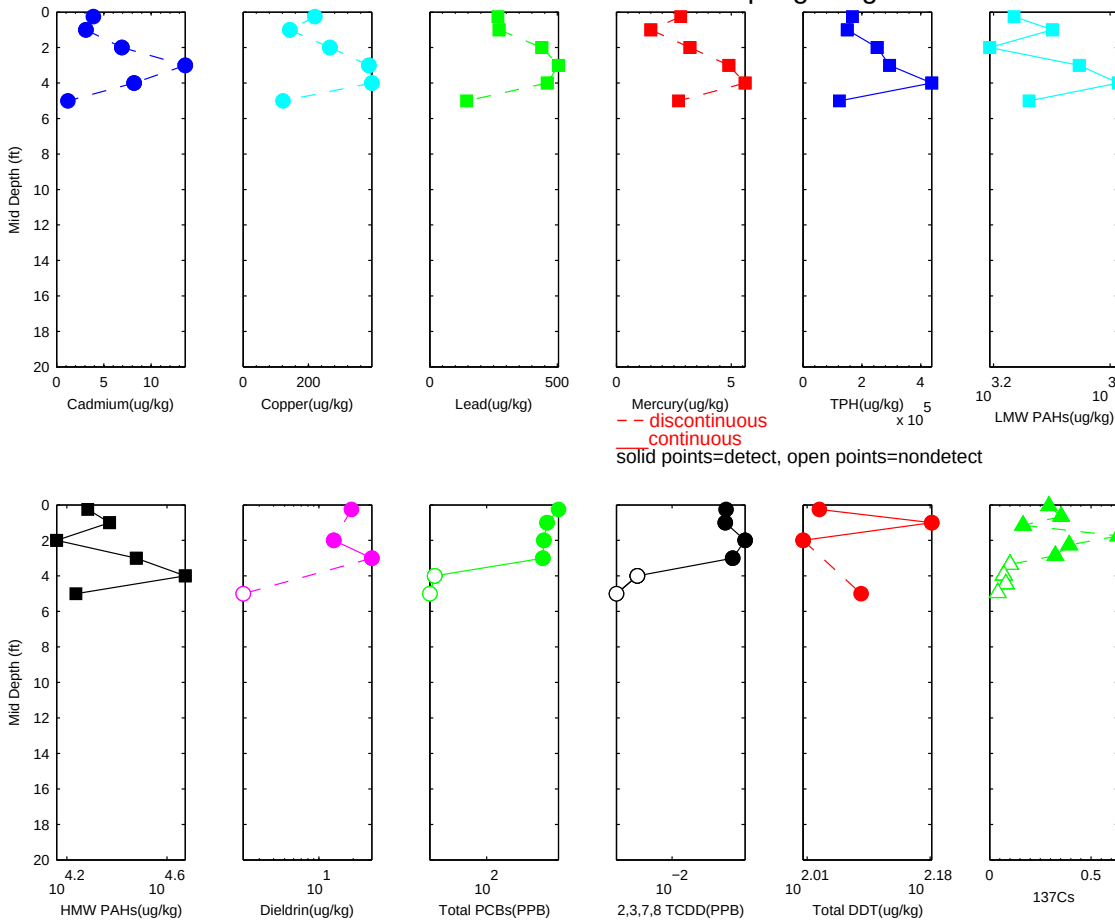
R2-0026905

Sample ID: 278 River Mile 6.74 PASSAIC 1995 RI Sampling Program



R2-0026906

Sample ID: 277 River Mile 6.74 PASSAIC 1995 RI Sampling Program



R2-0026907

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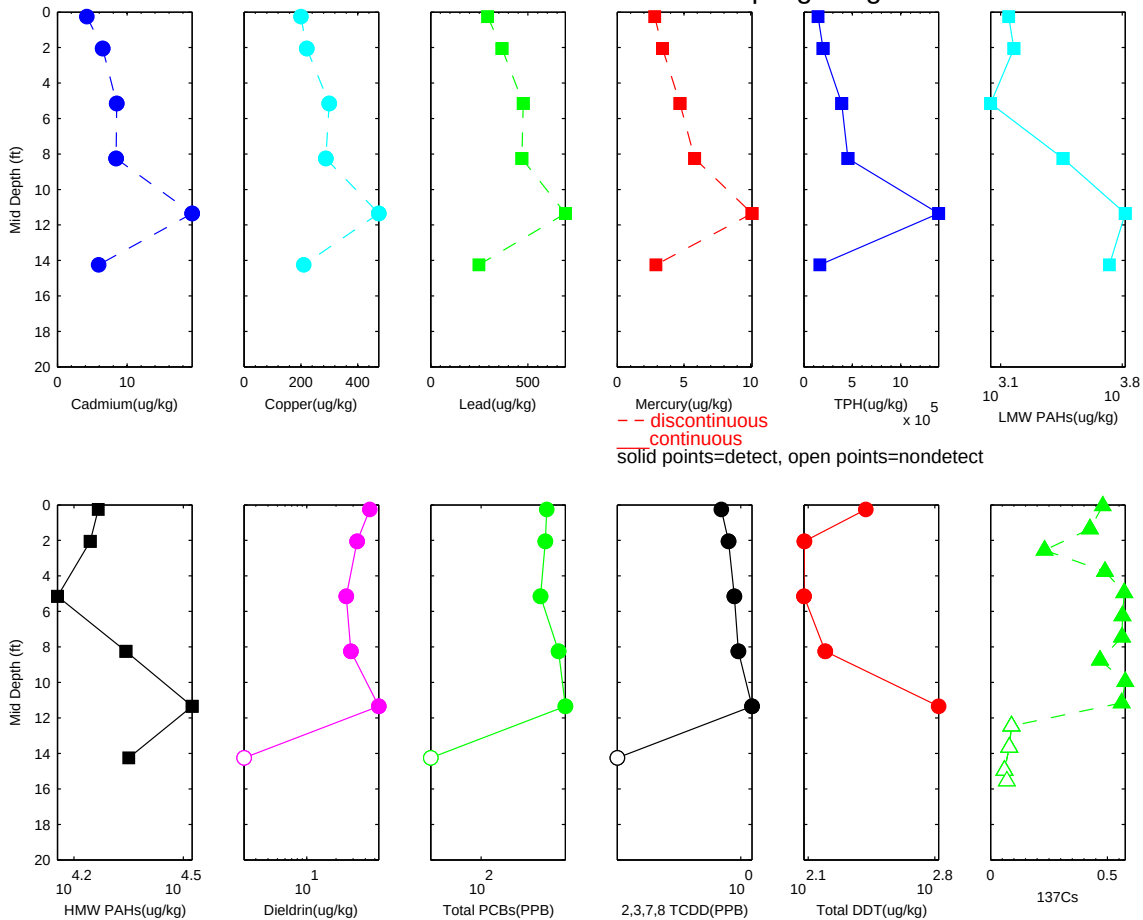

R2-0026908

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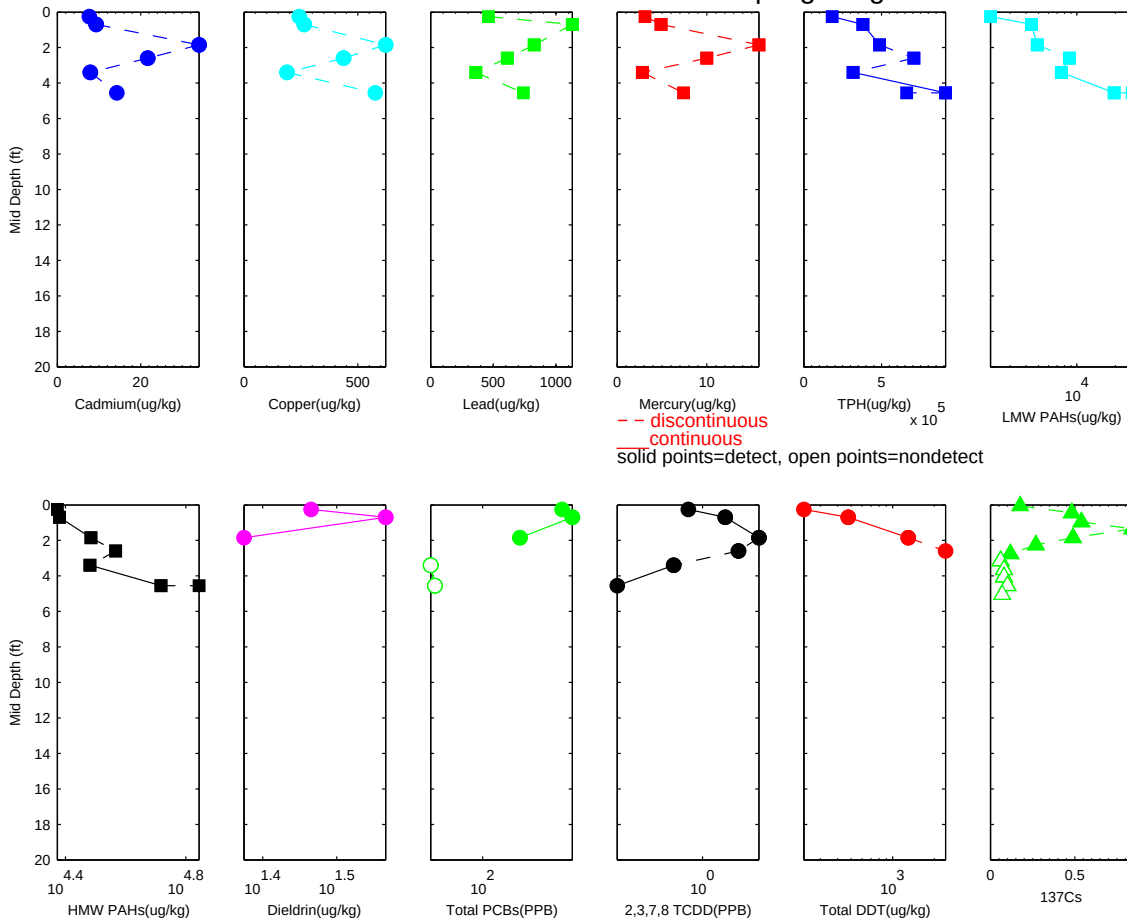

R2-0026909

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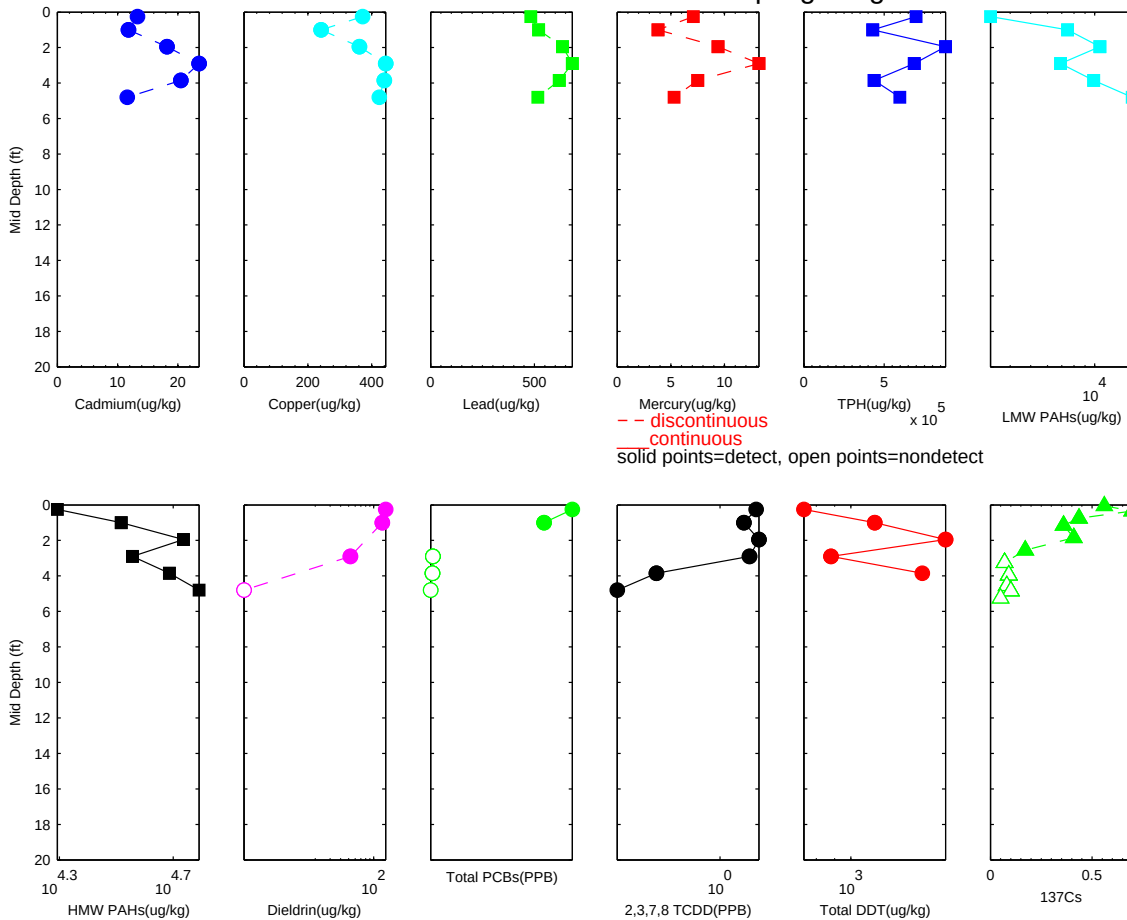

R2-0026910

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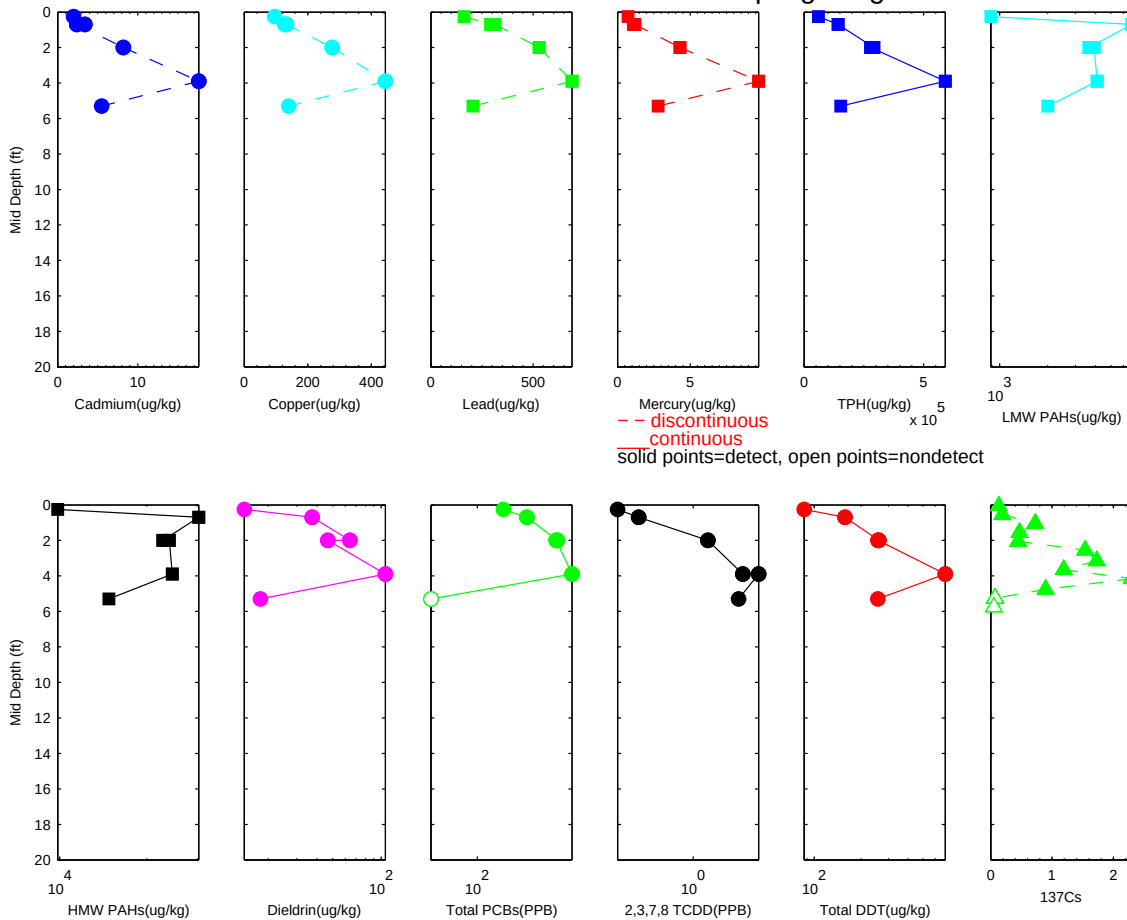

R2-0026911

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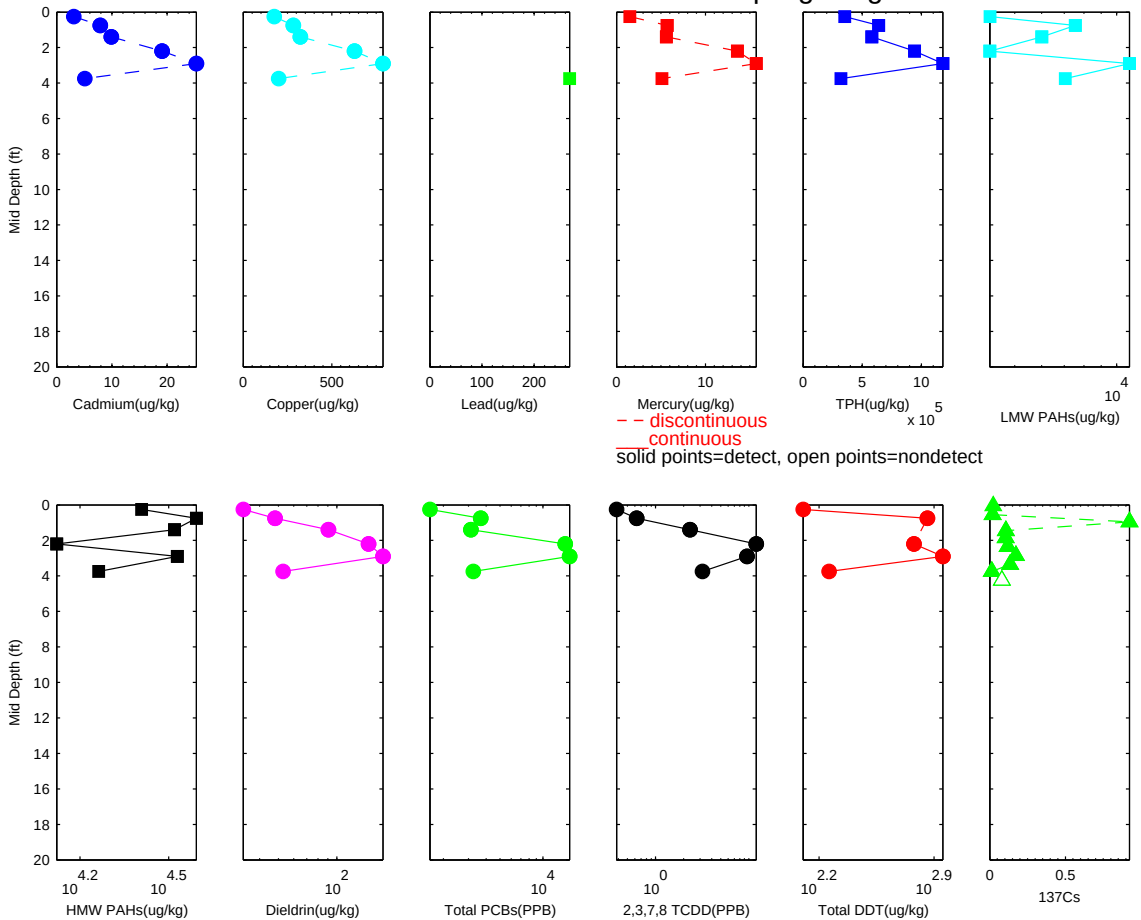

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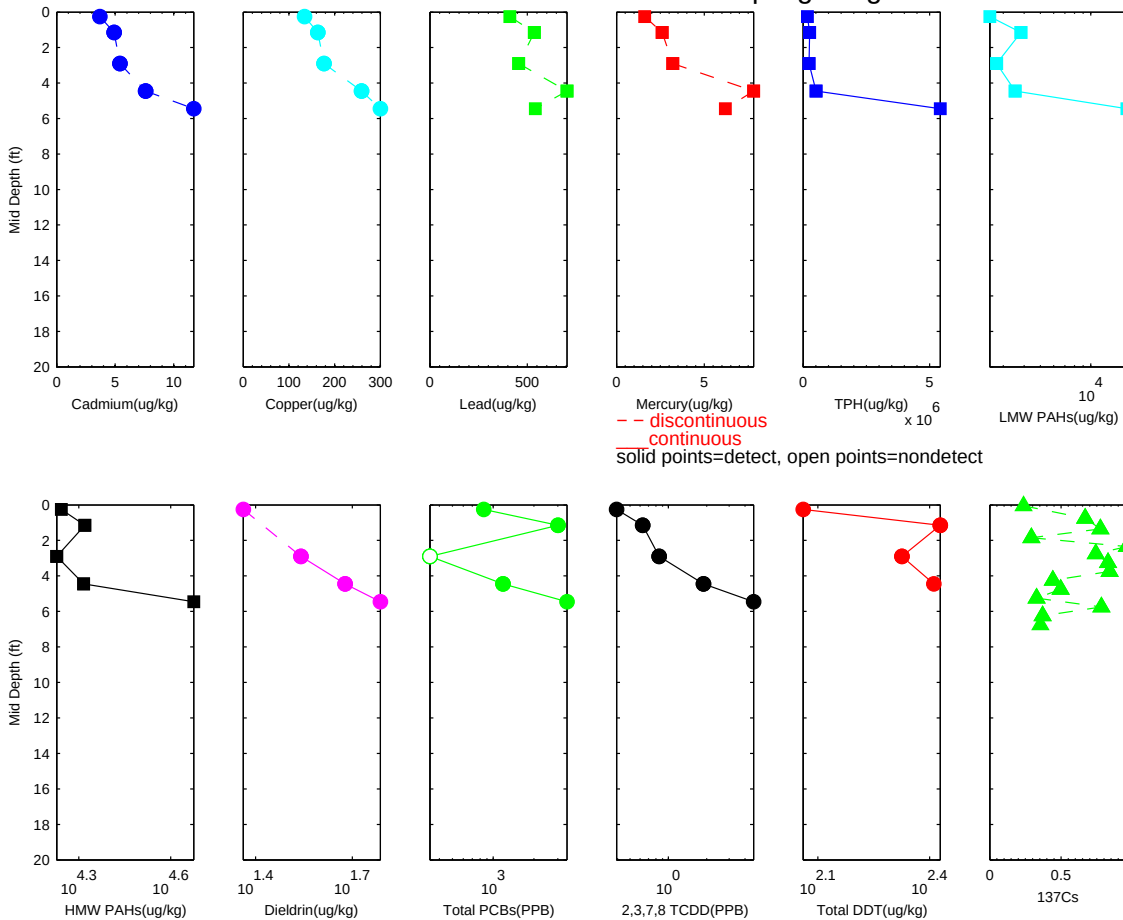

R2-0026913

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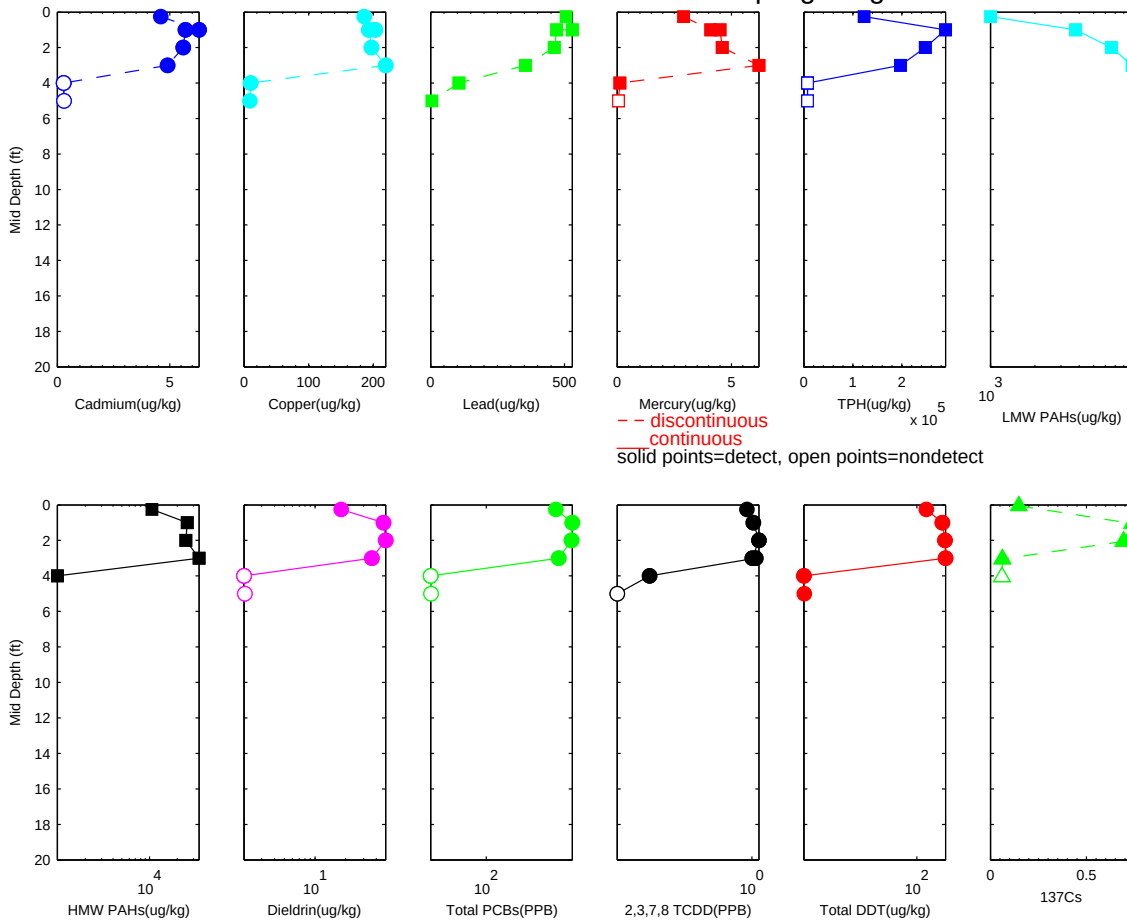

R2-0026914

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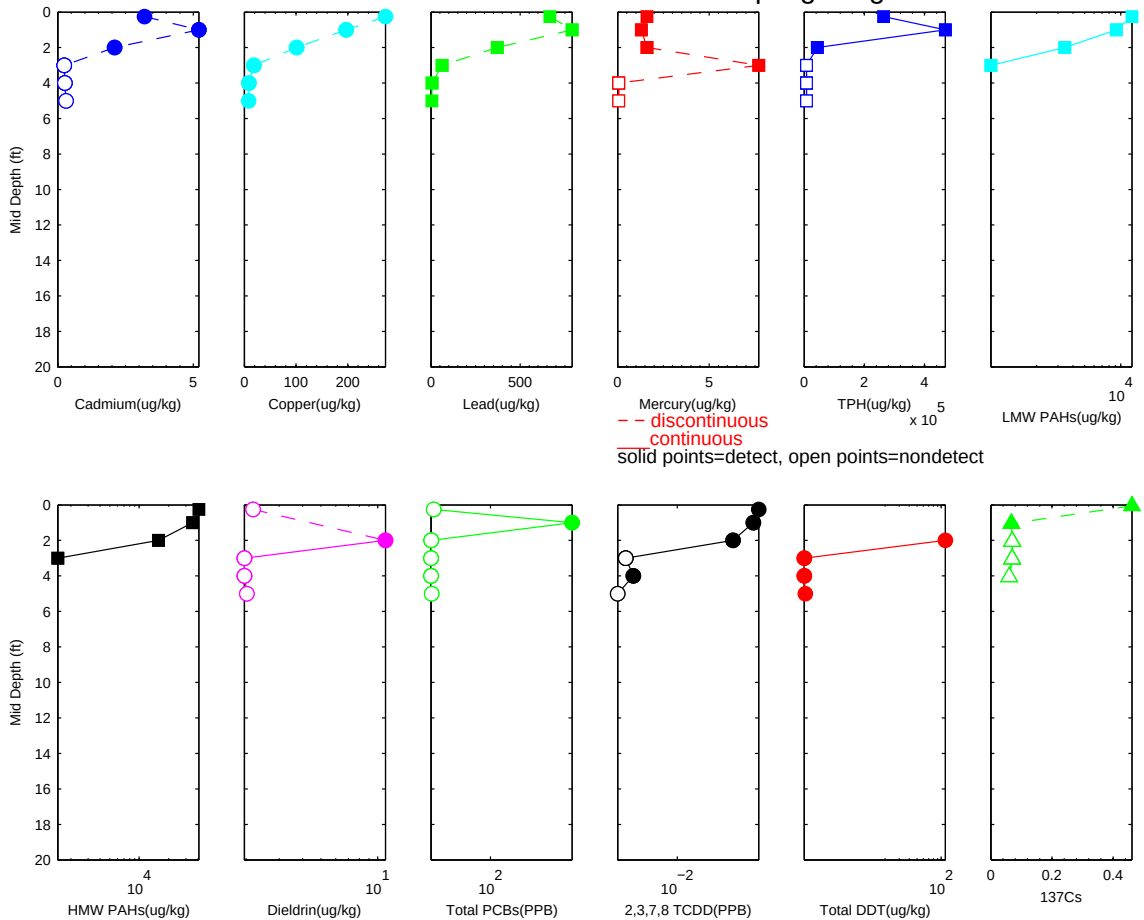

R2-0026915

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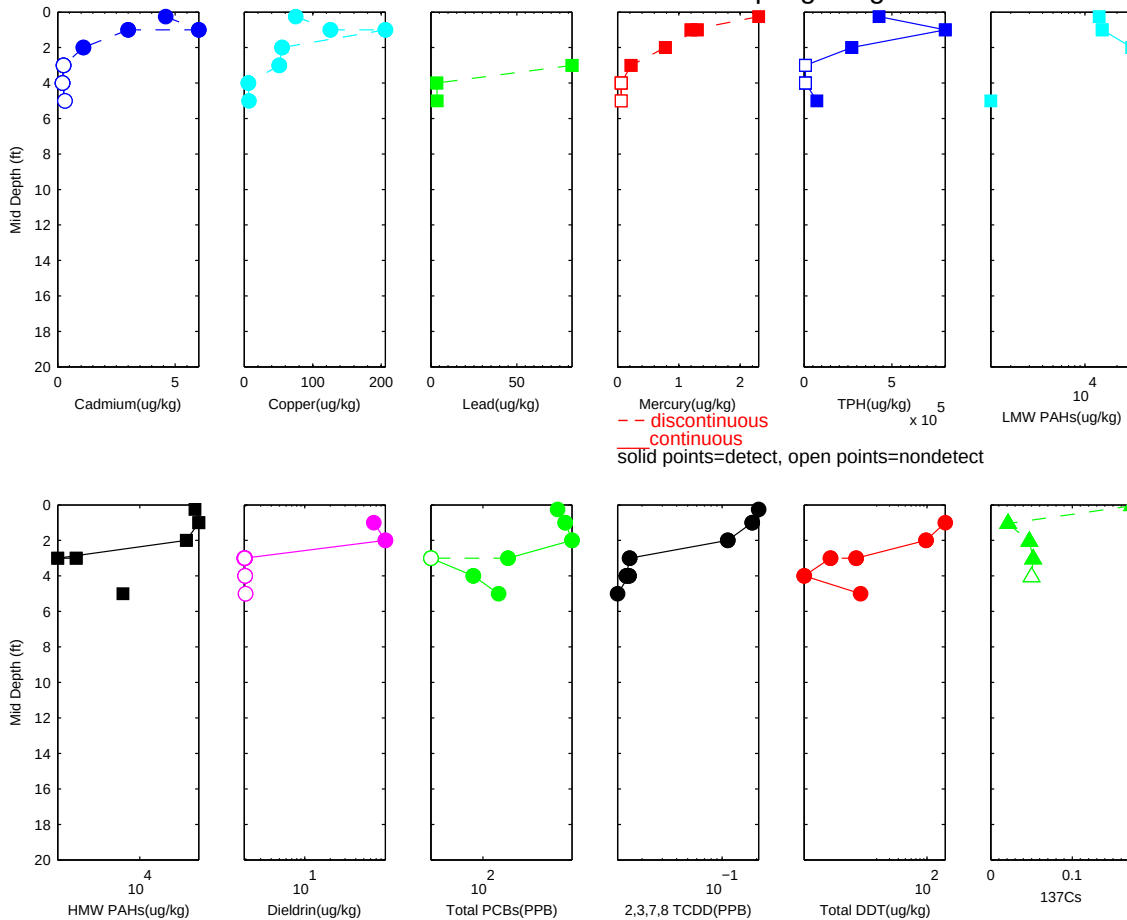

R2-0026916

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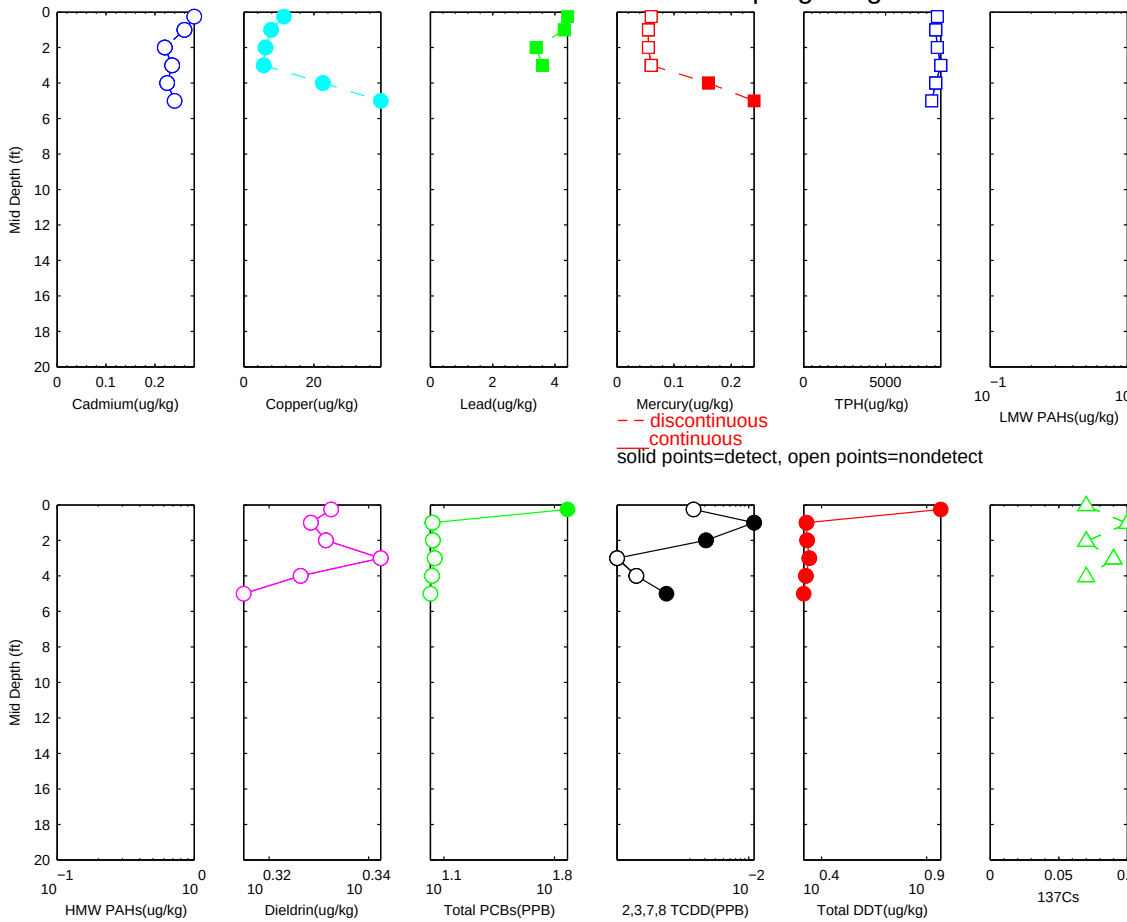

R2-0026917

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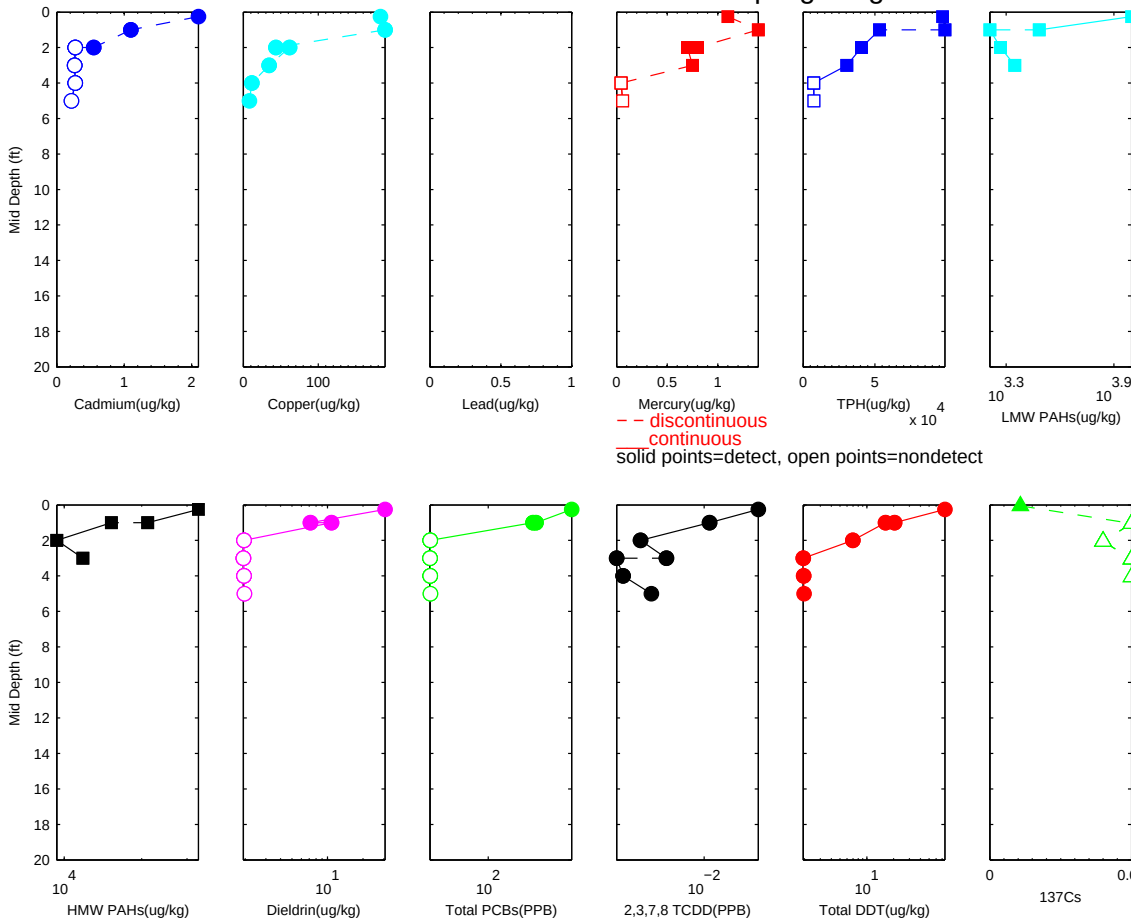

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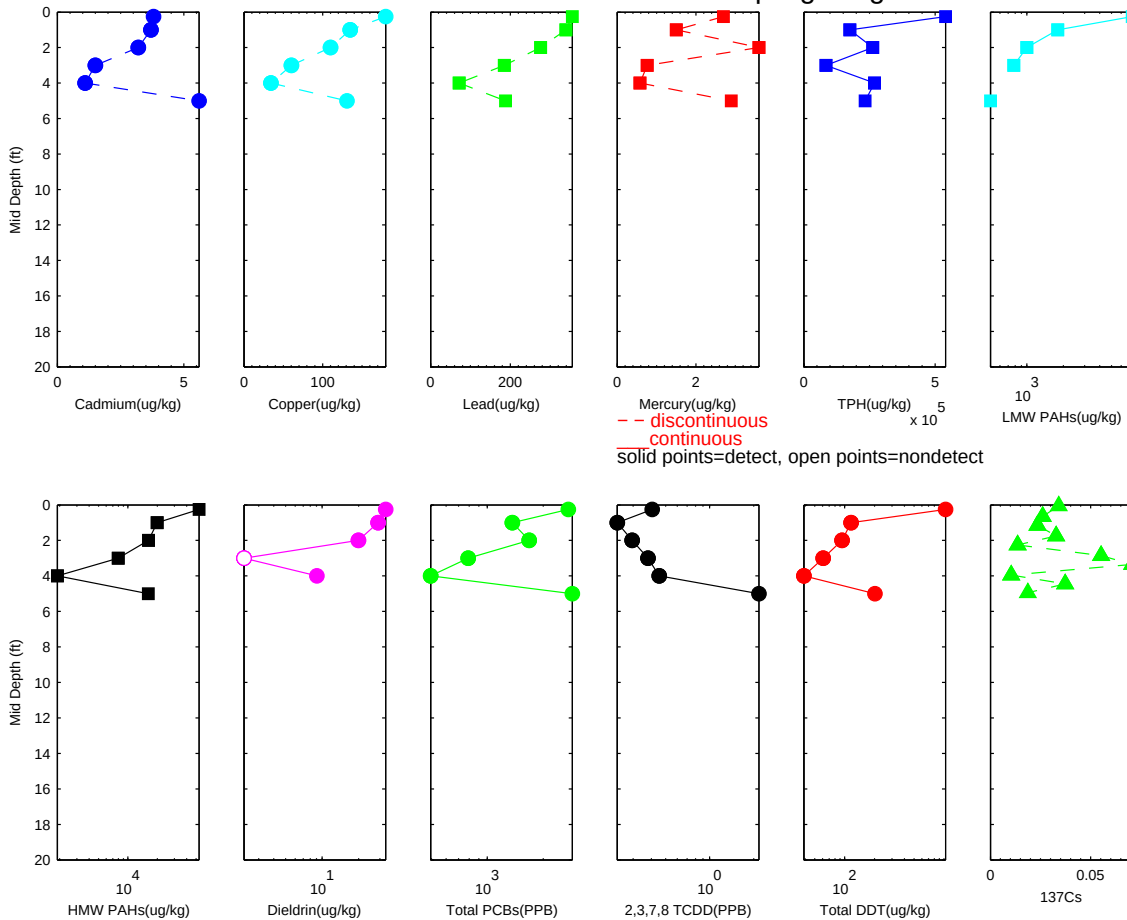

R2-0026919

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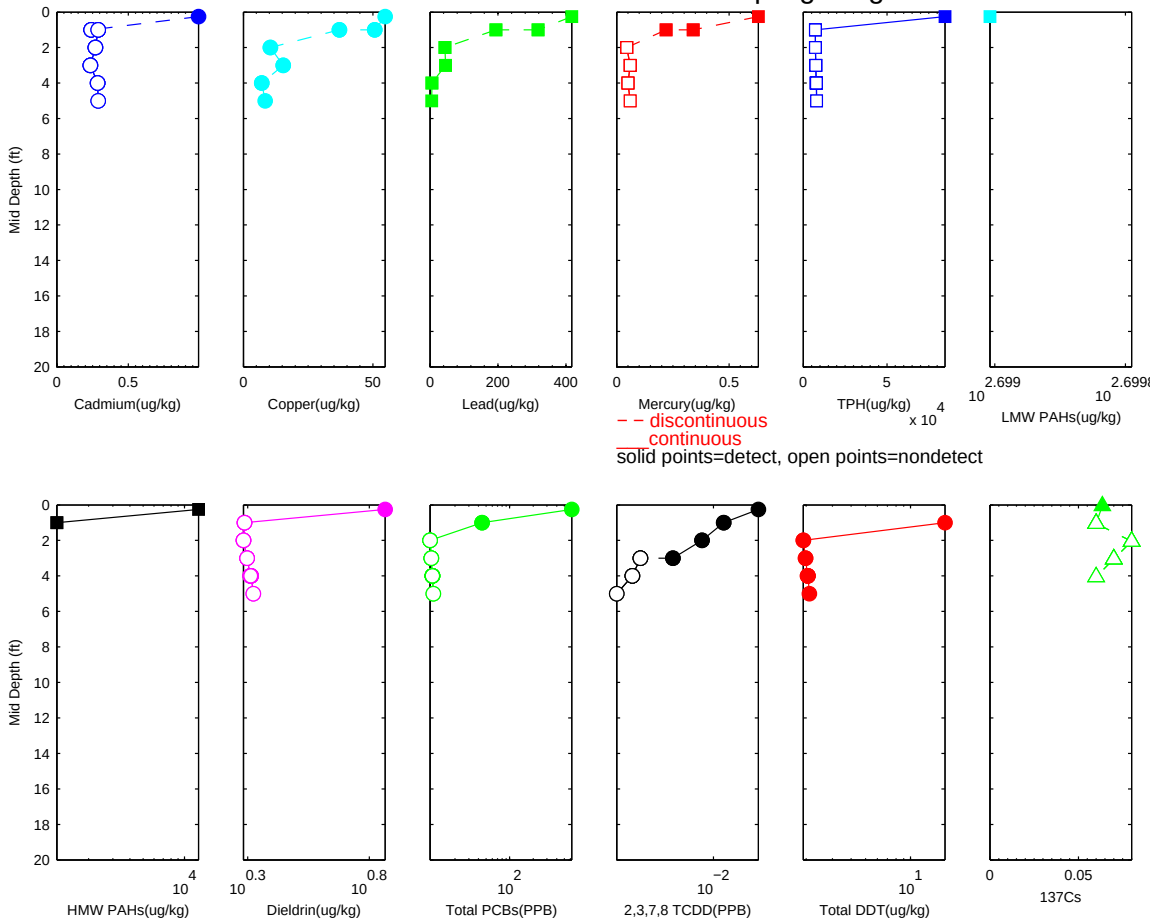

R2-0026920

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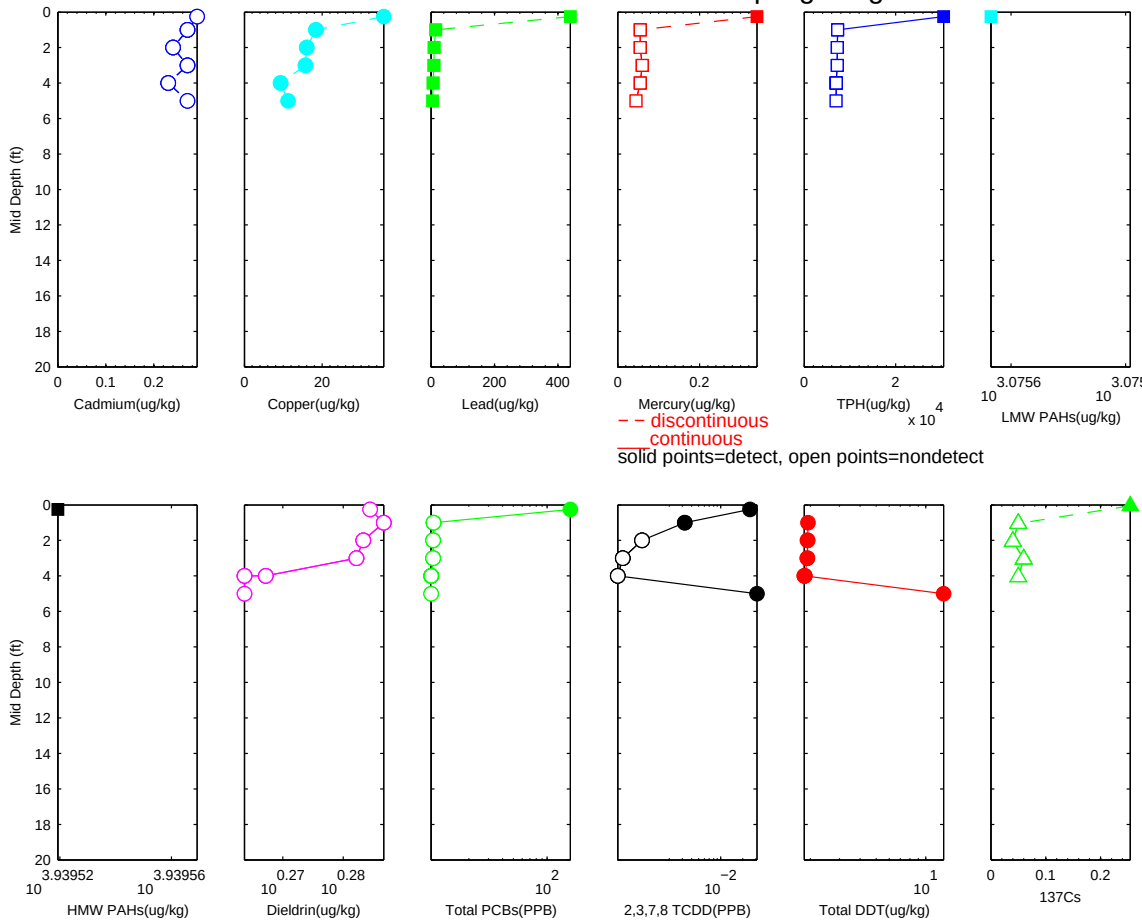

R2-0026921

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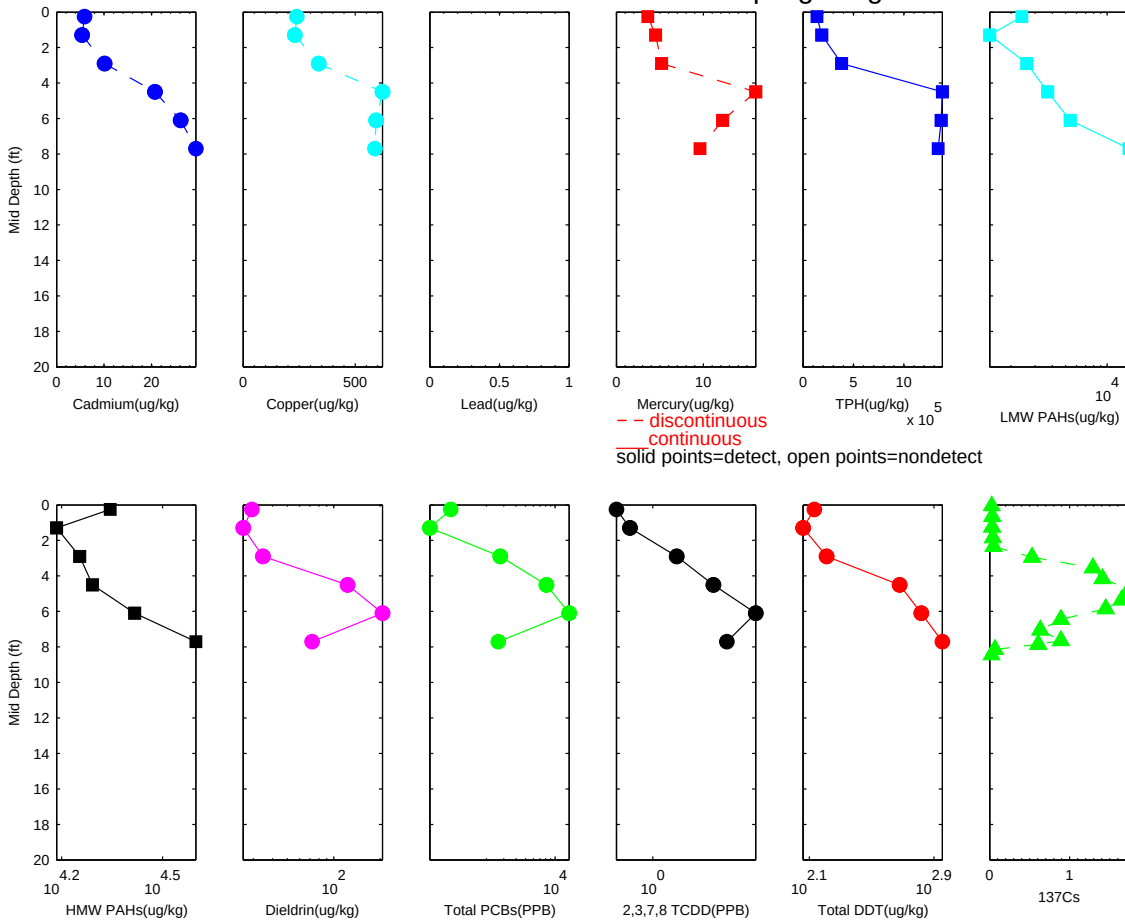

R2-0026922

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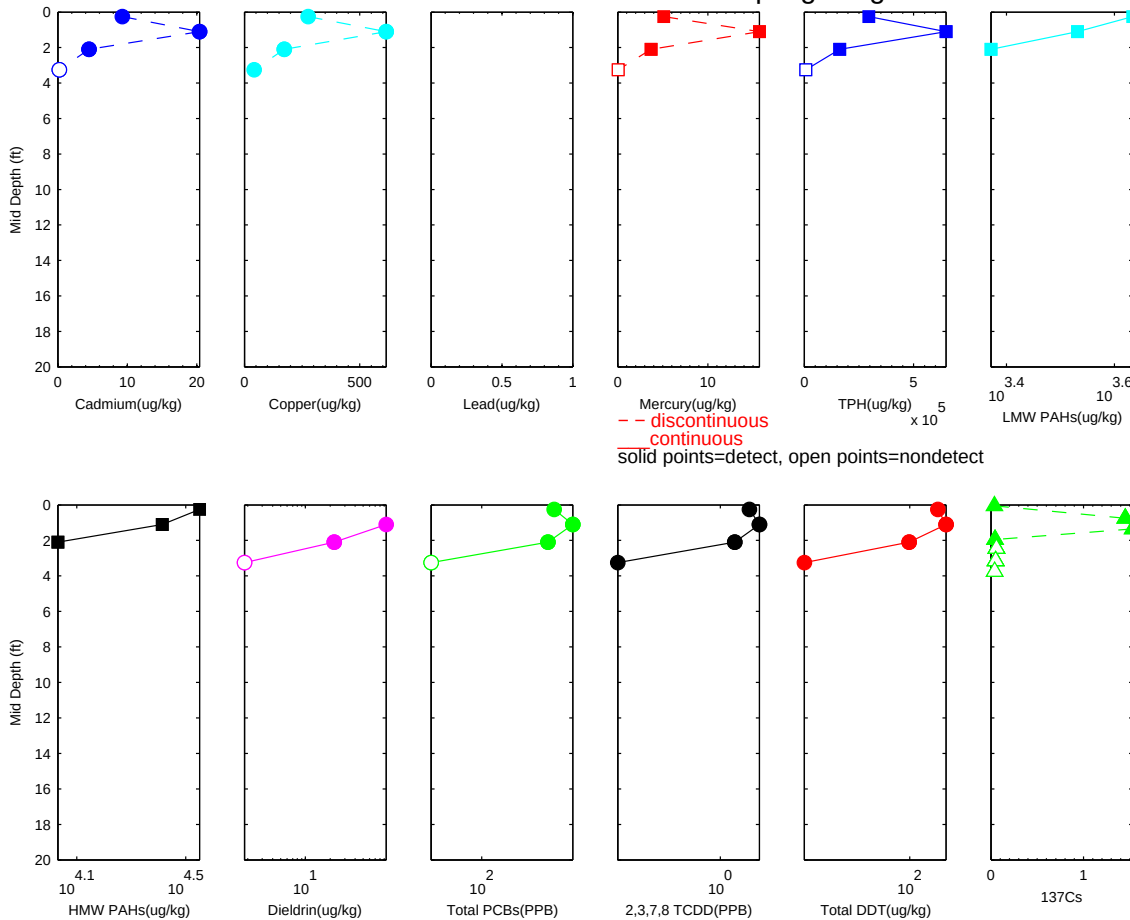

R2-0026923

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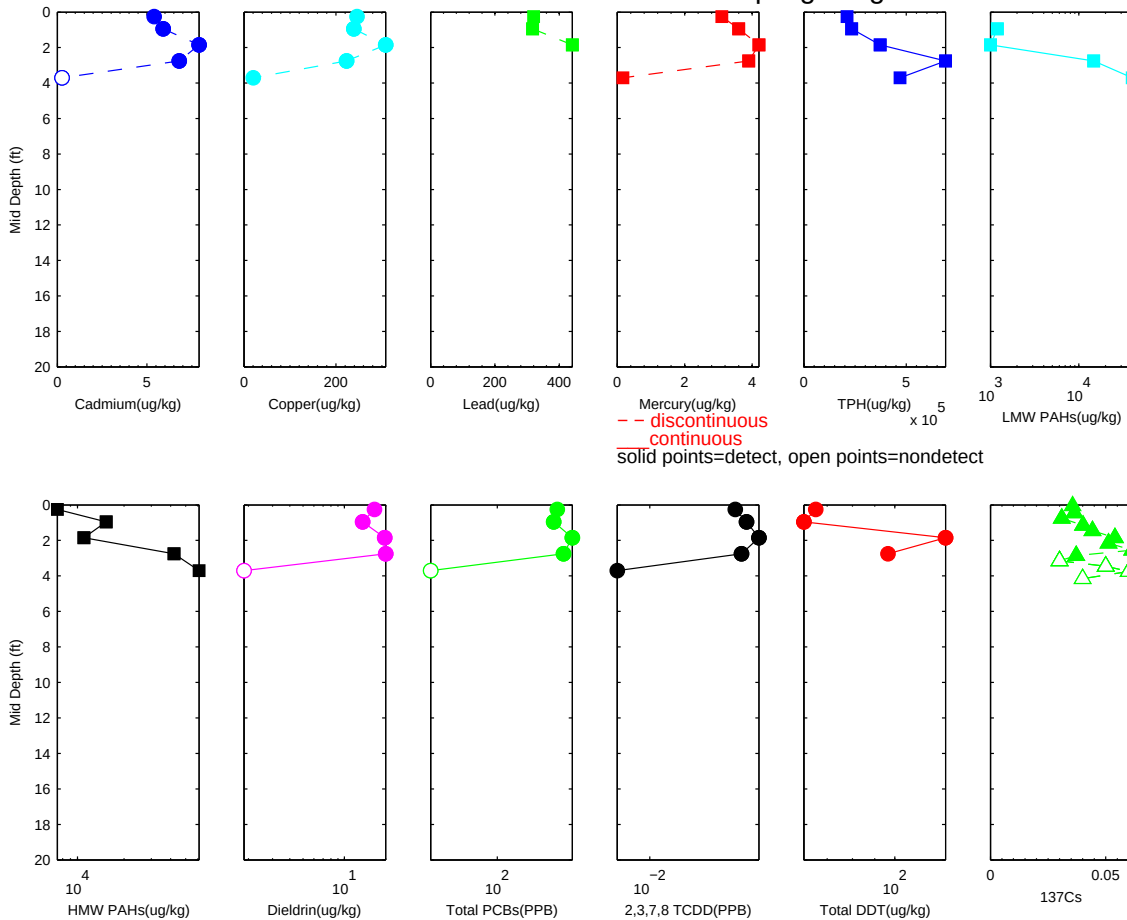

R2-0026924

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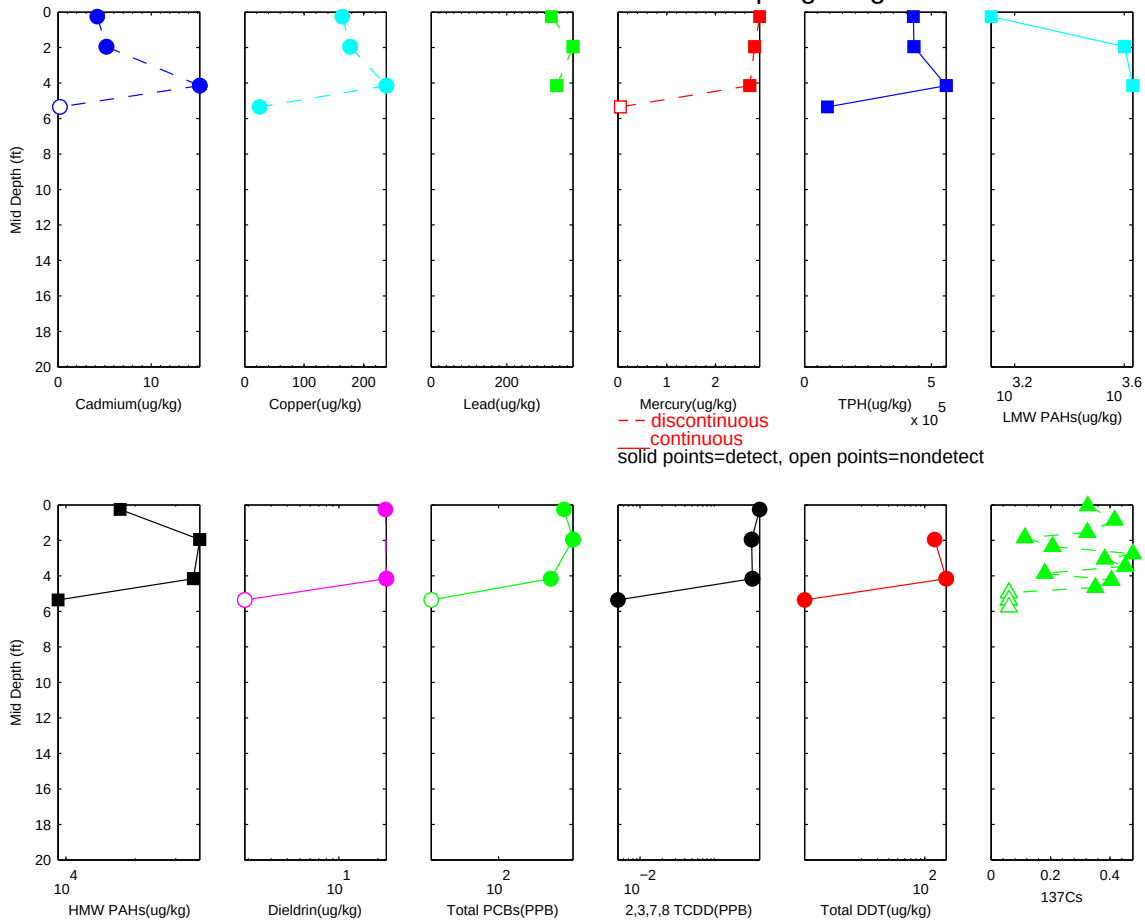

R2-0026925

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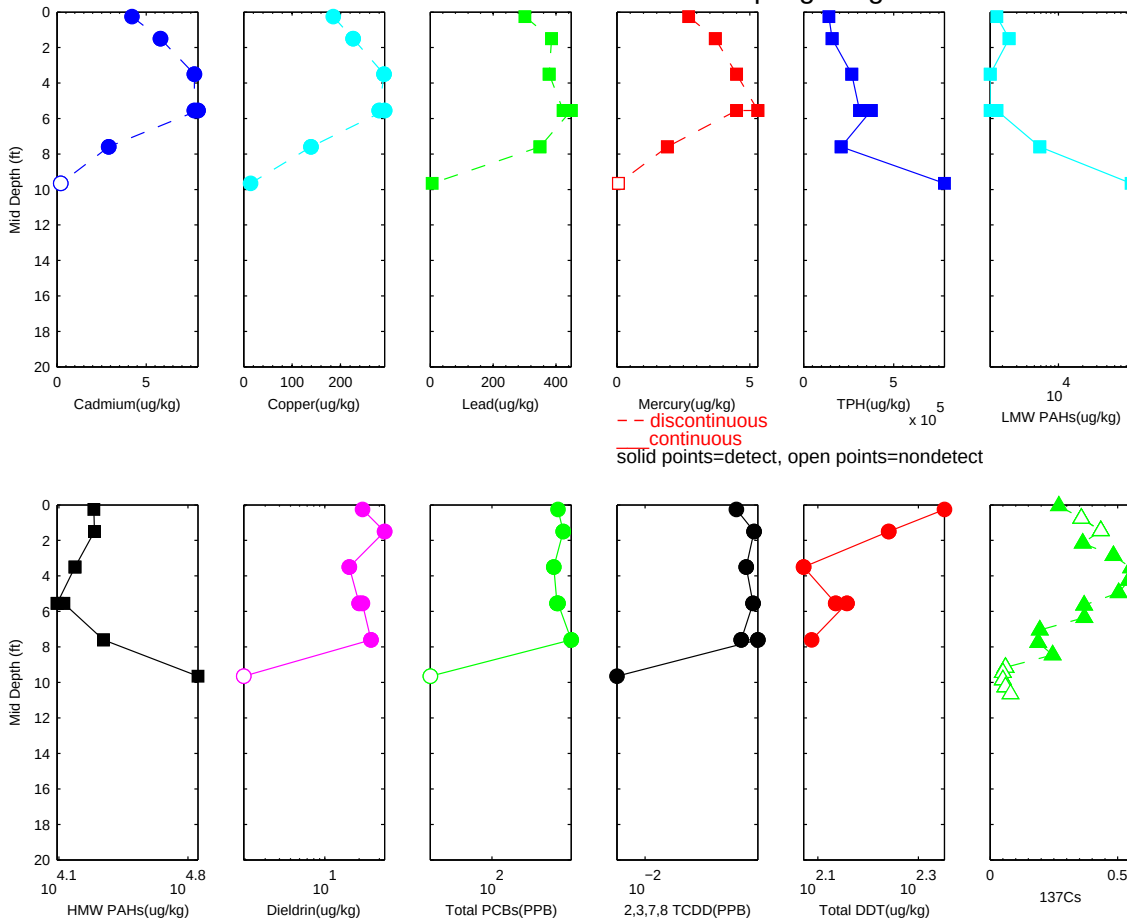

R2-0026926

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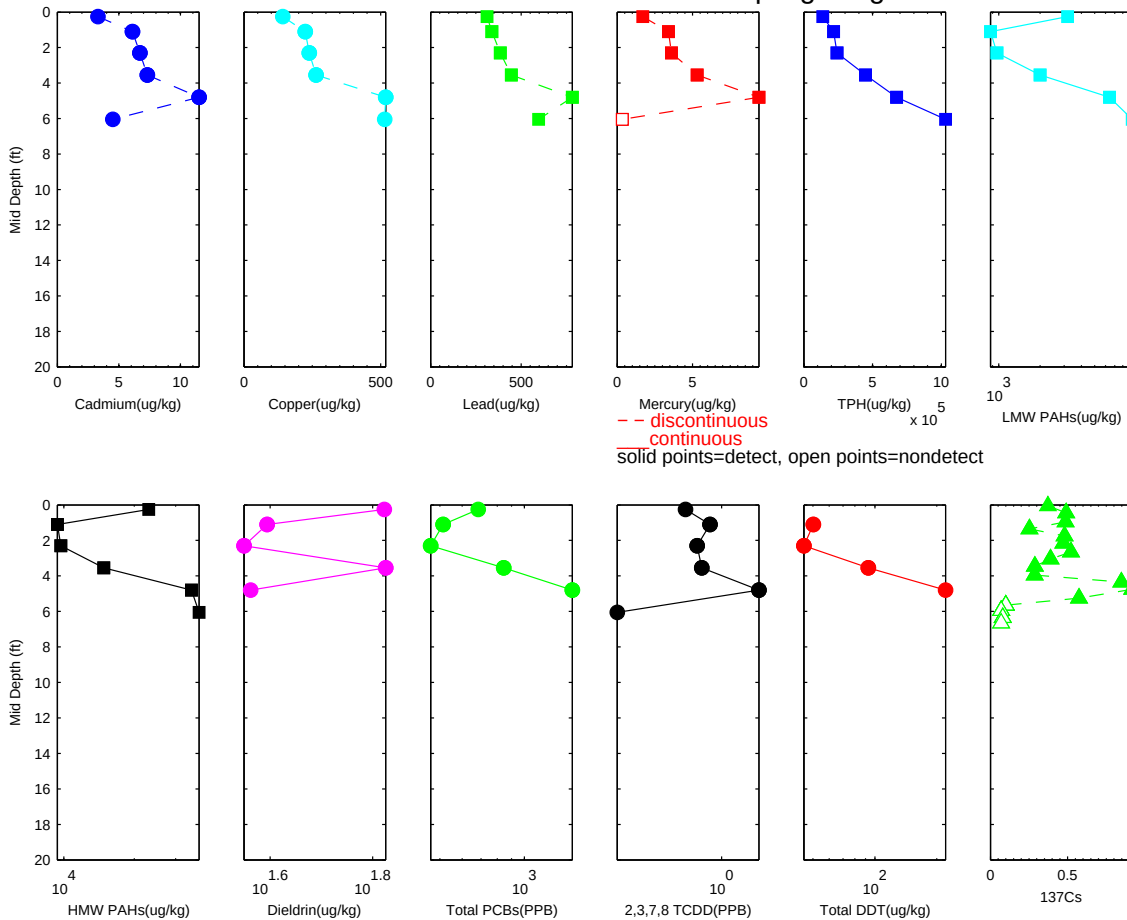

R2-0026927

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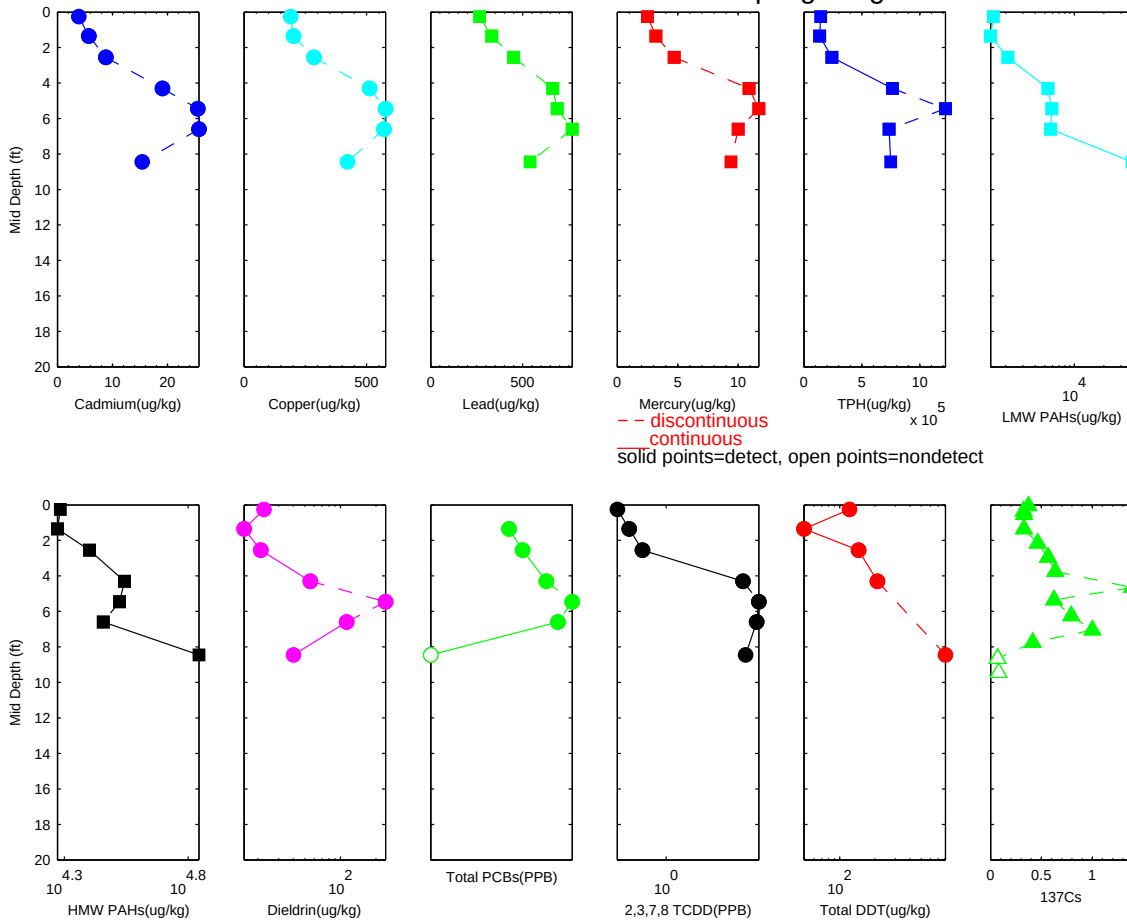

R2-0026928

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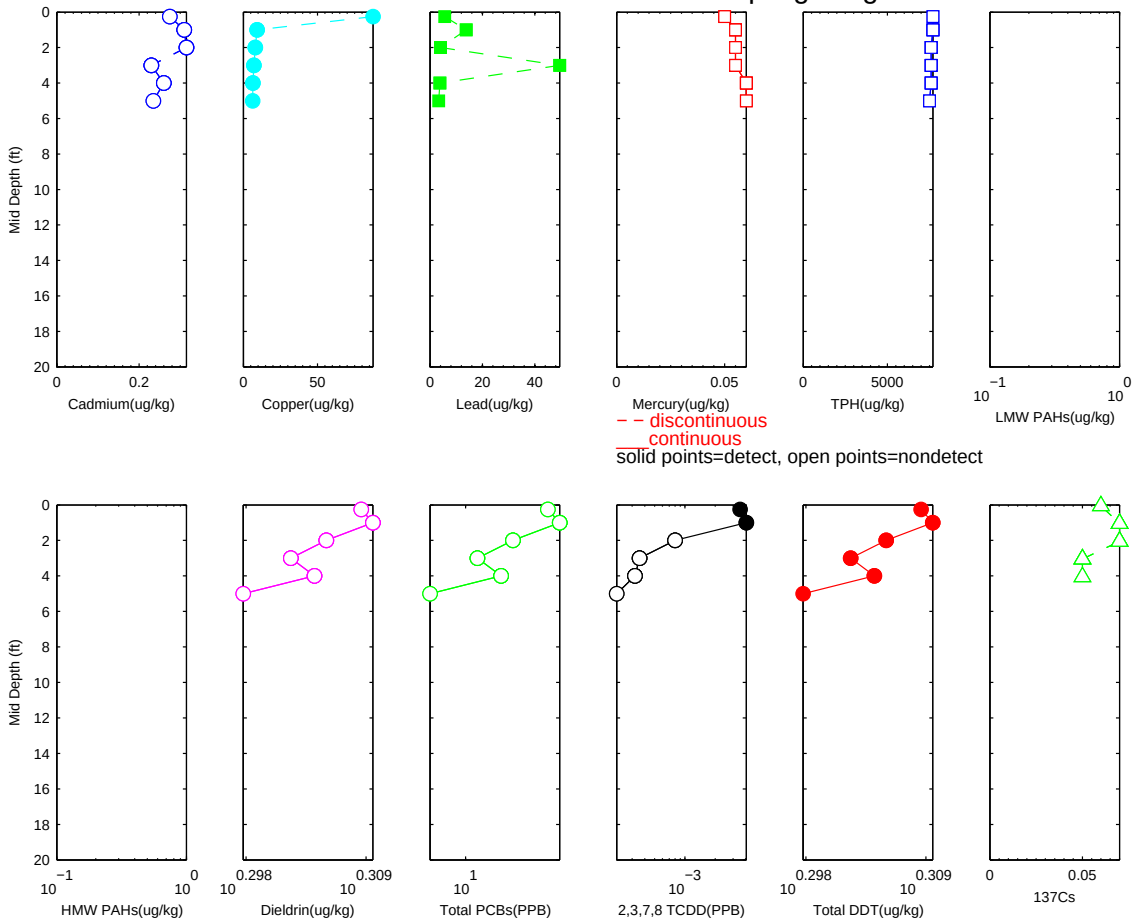

R2-0026929

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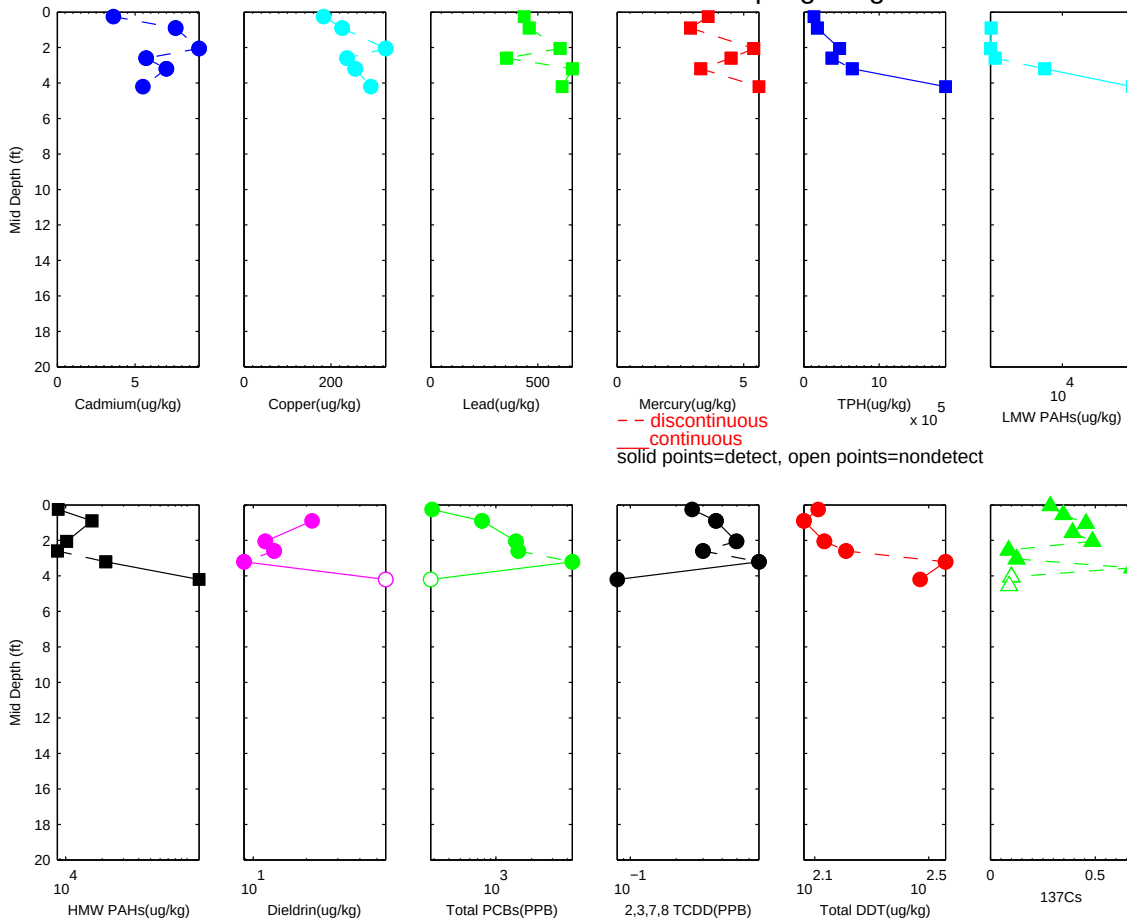

R2-0026930

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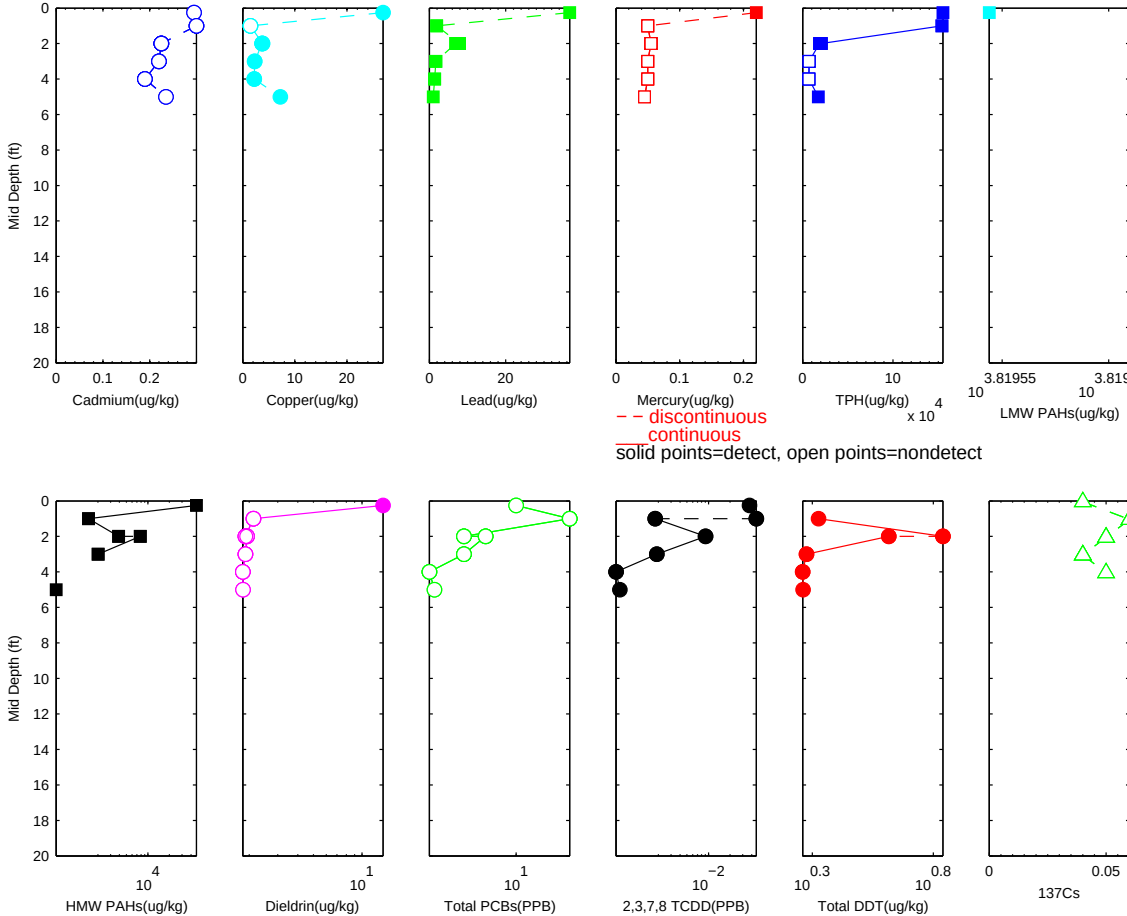

R2-0026931

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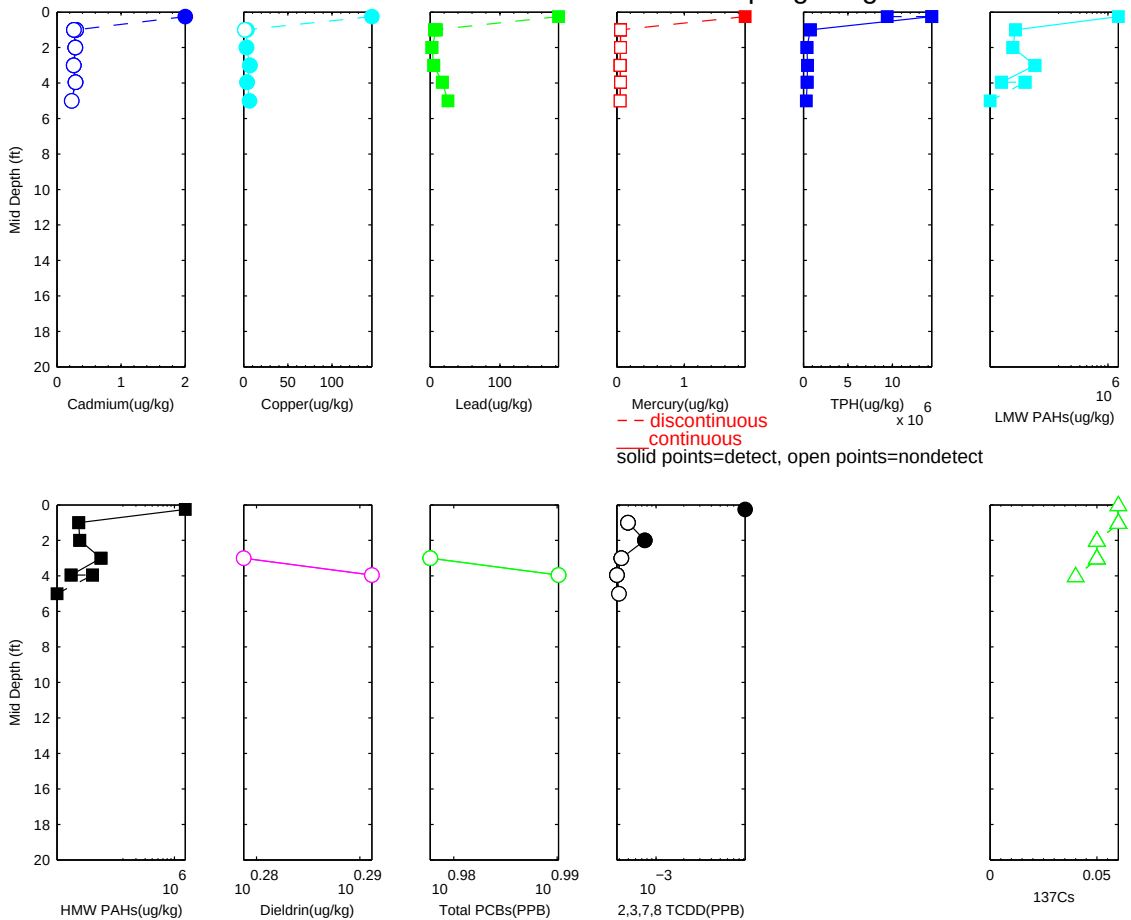

R2-0026932

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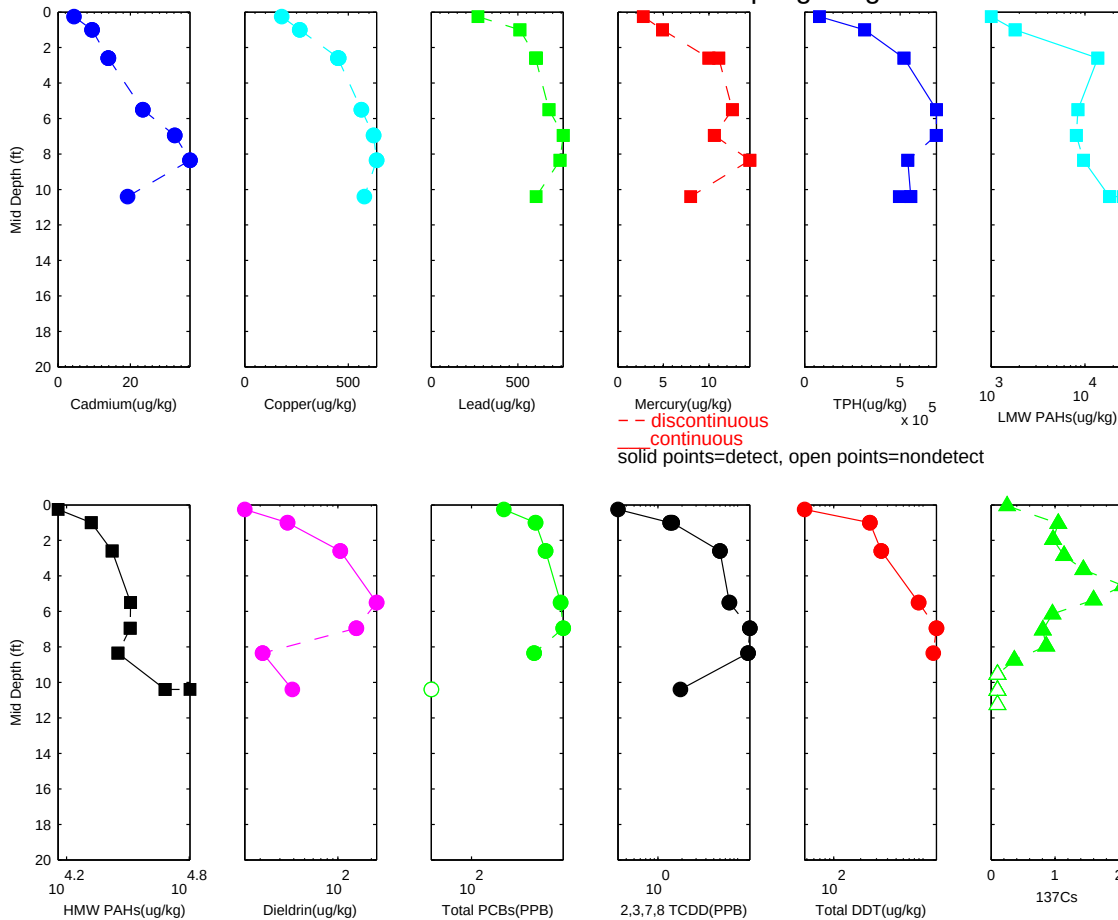

R2-0026933

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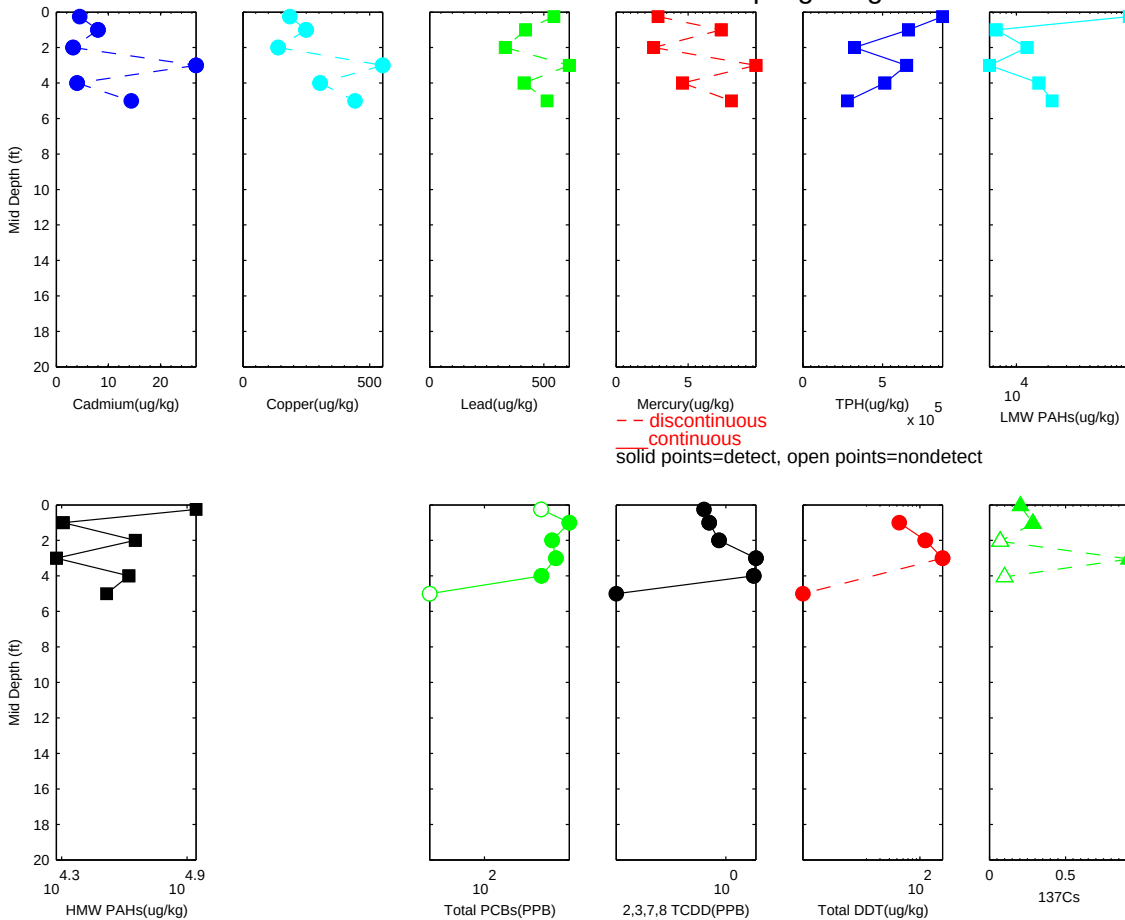

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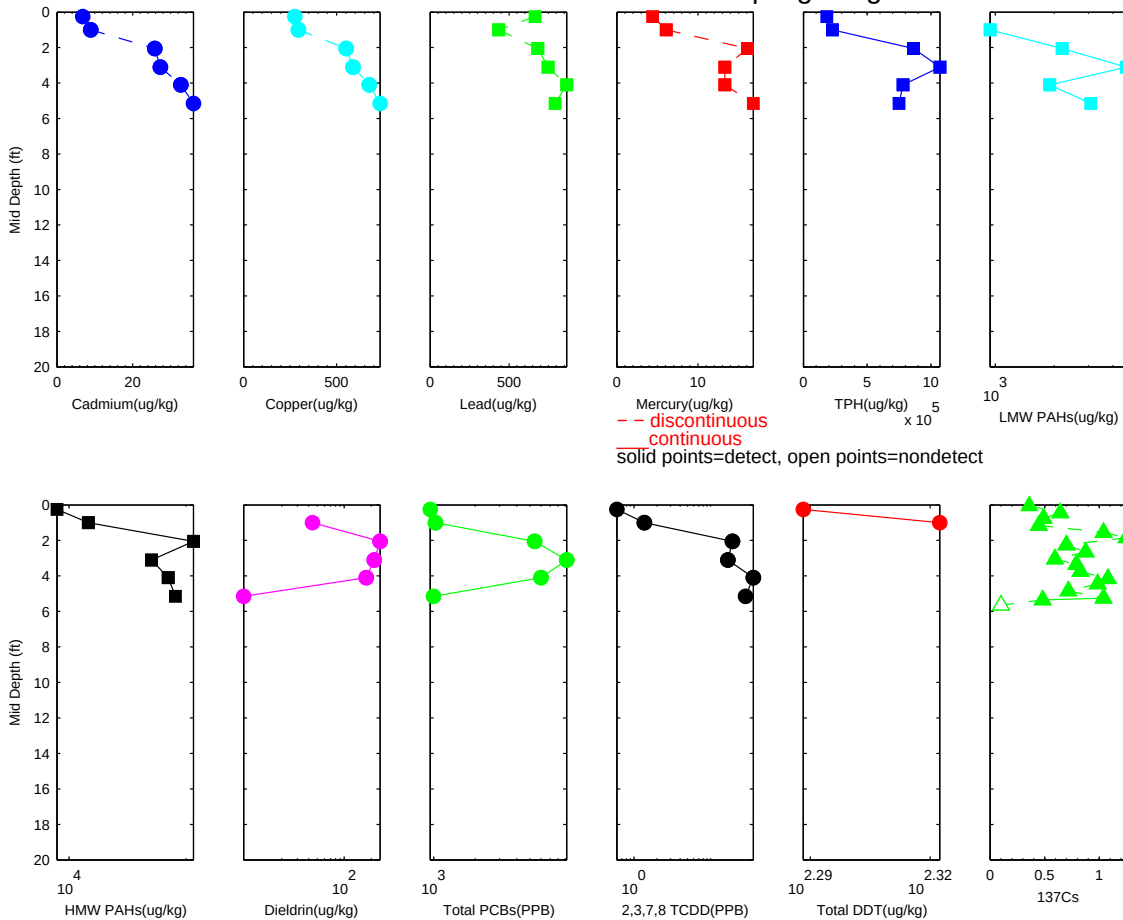
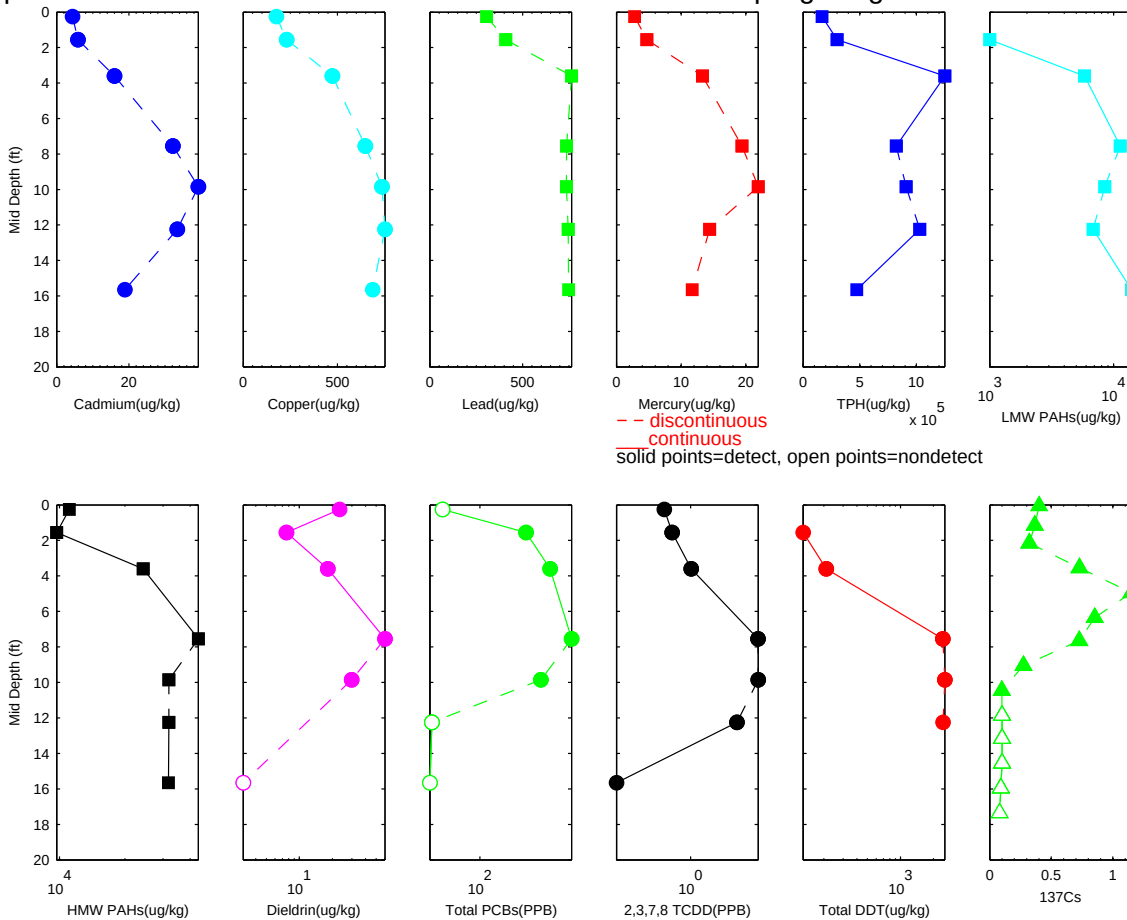


R2-0026935

Sample ID: 242 River Mile 4

PASSAIC 1995 RI Sampling Program



R2-0026936

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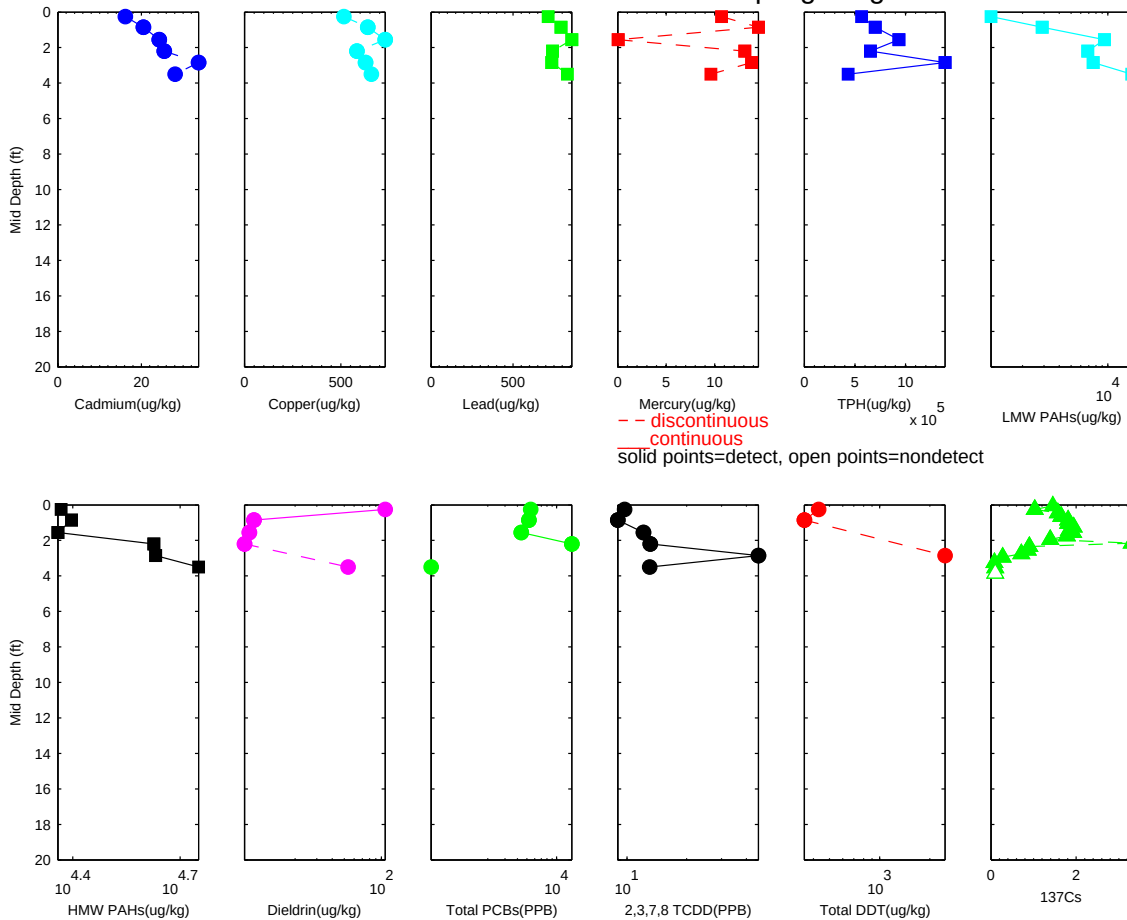

R2-0026937

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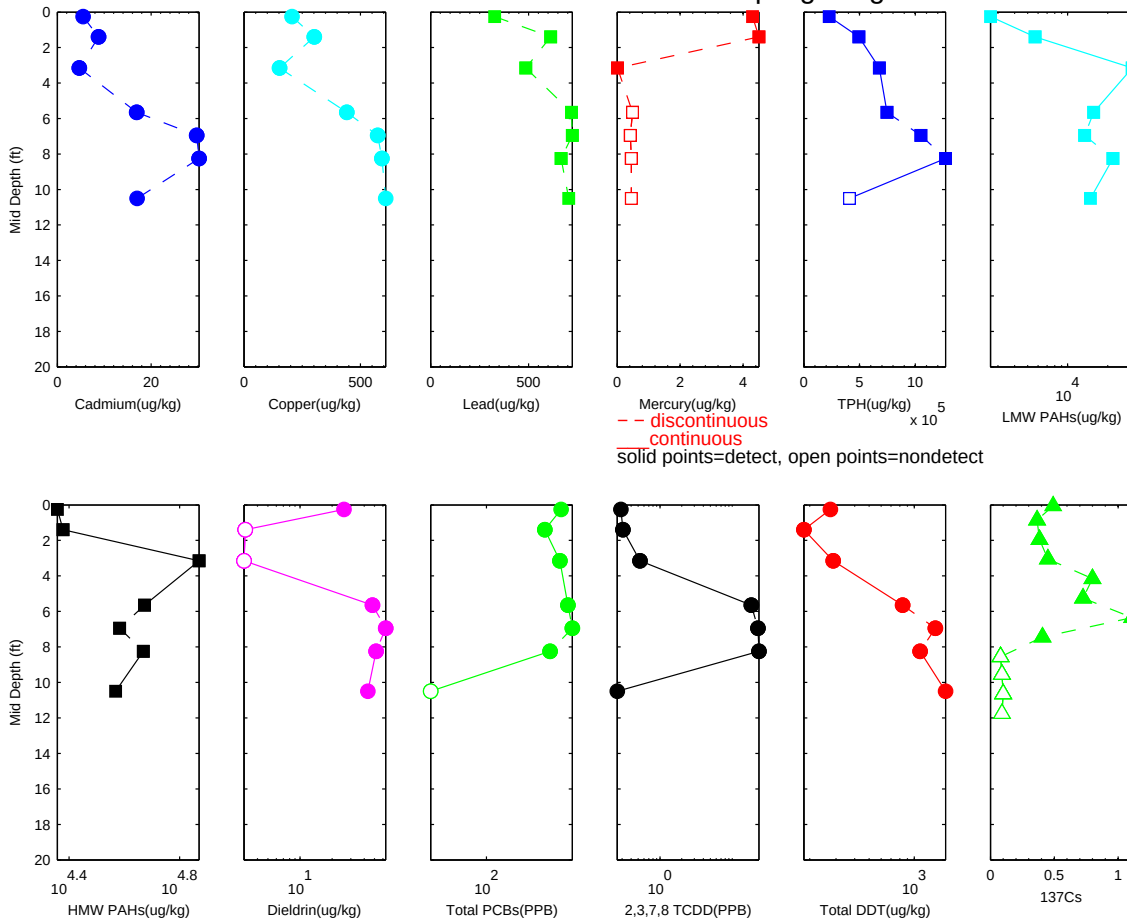
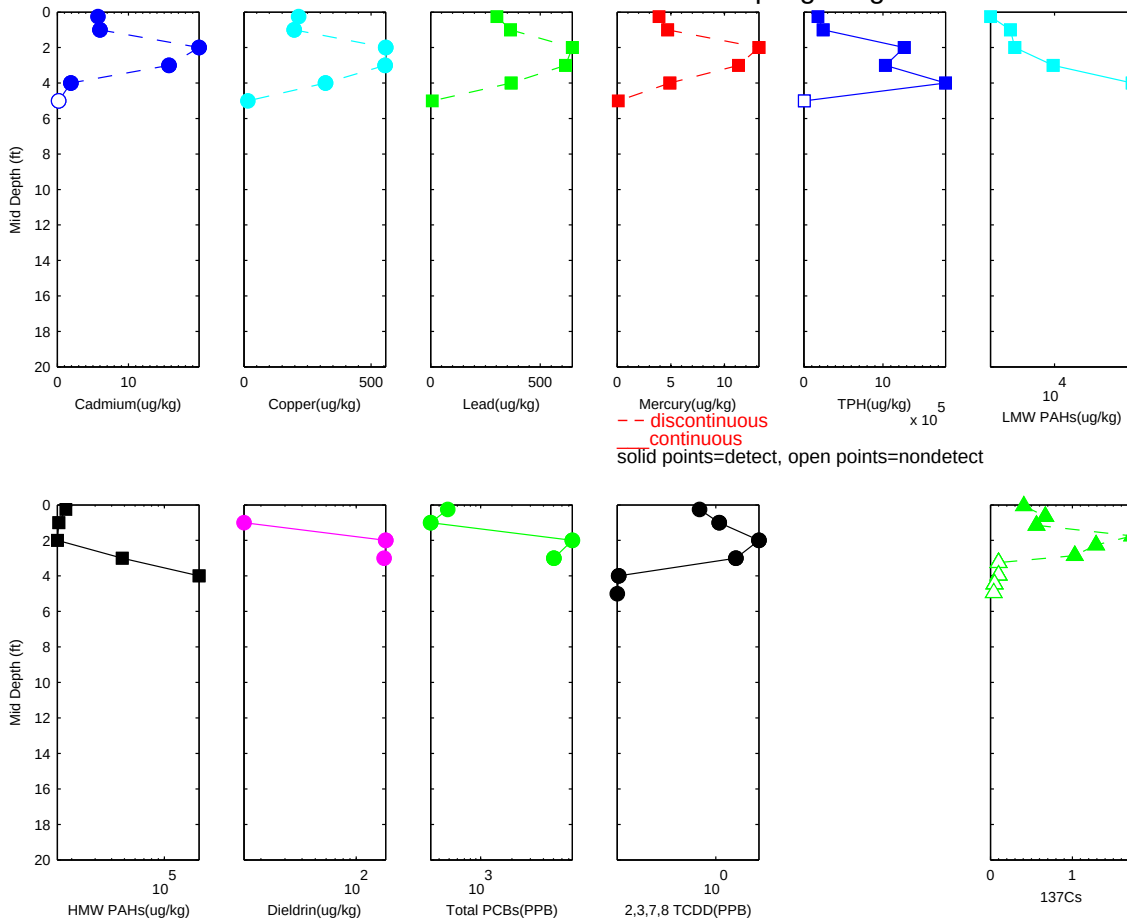


R2-0026938

Sample ID: 238 River Mile 3.77 PASSAIC 1995 RI Sampling Program



R2-0026939

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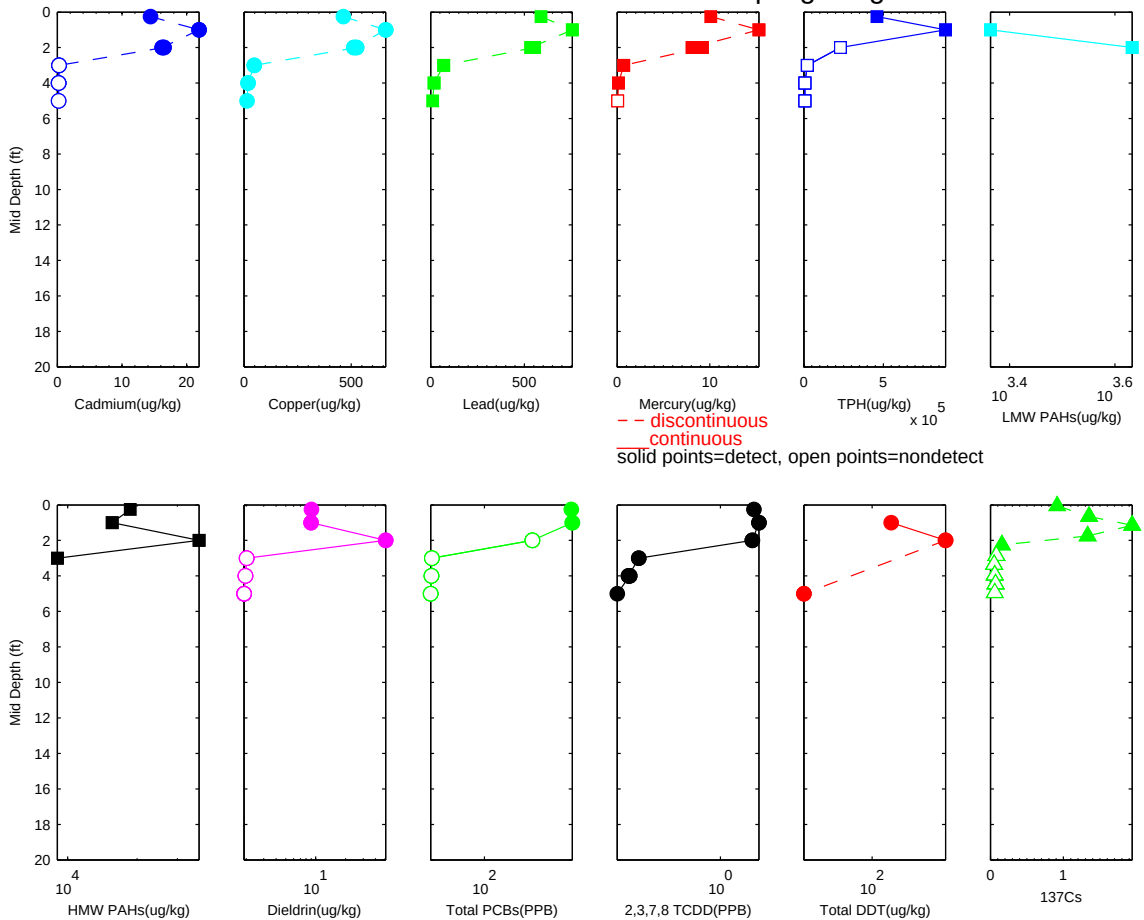
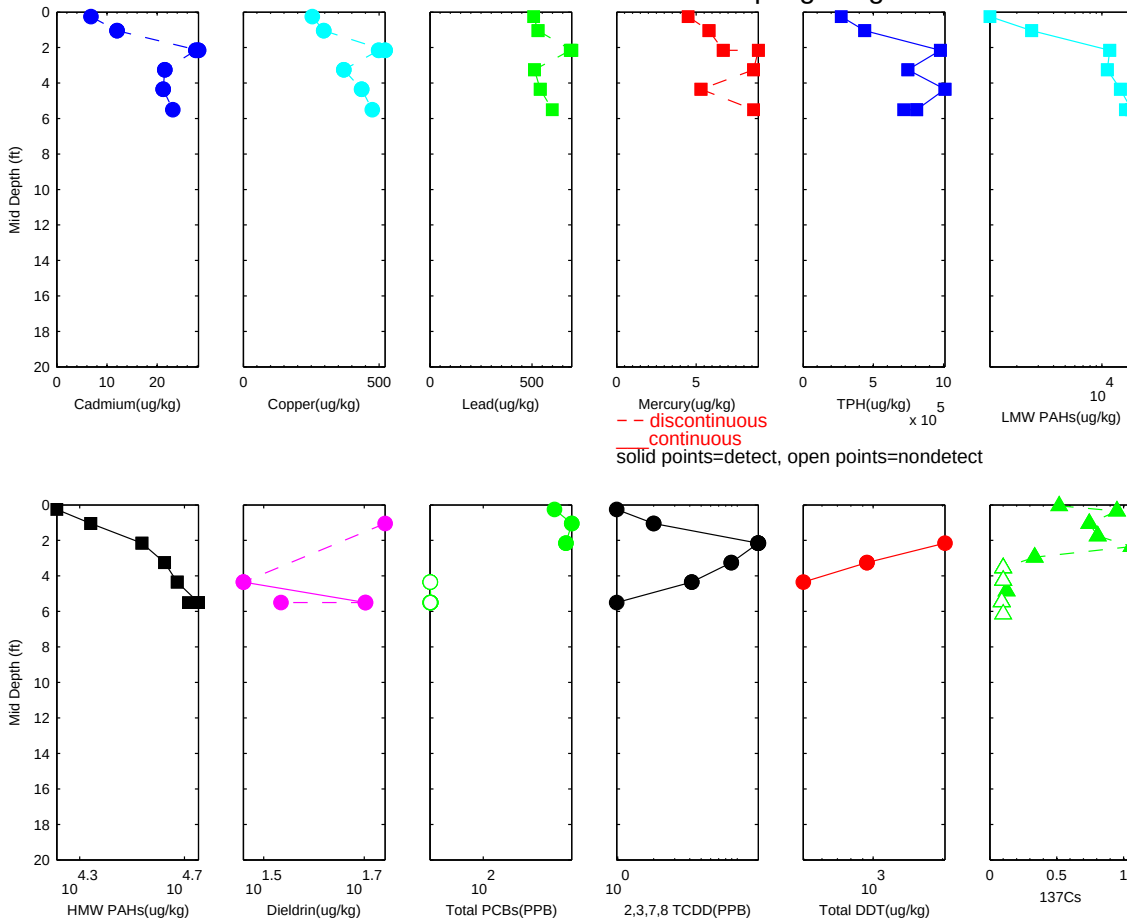


R2-0026940

Sample ID: 236 River Mile 3.54 PASSAIC 1995 RI Sampling Program



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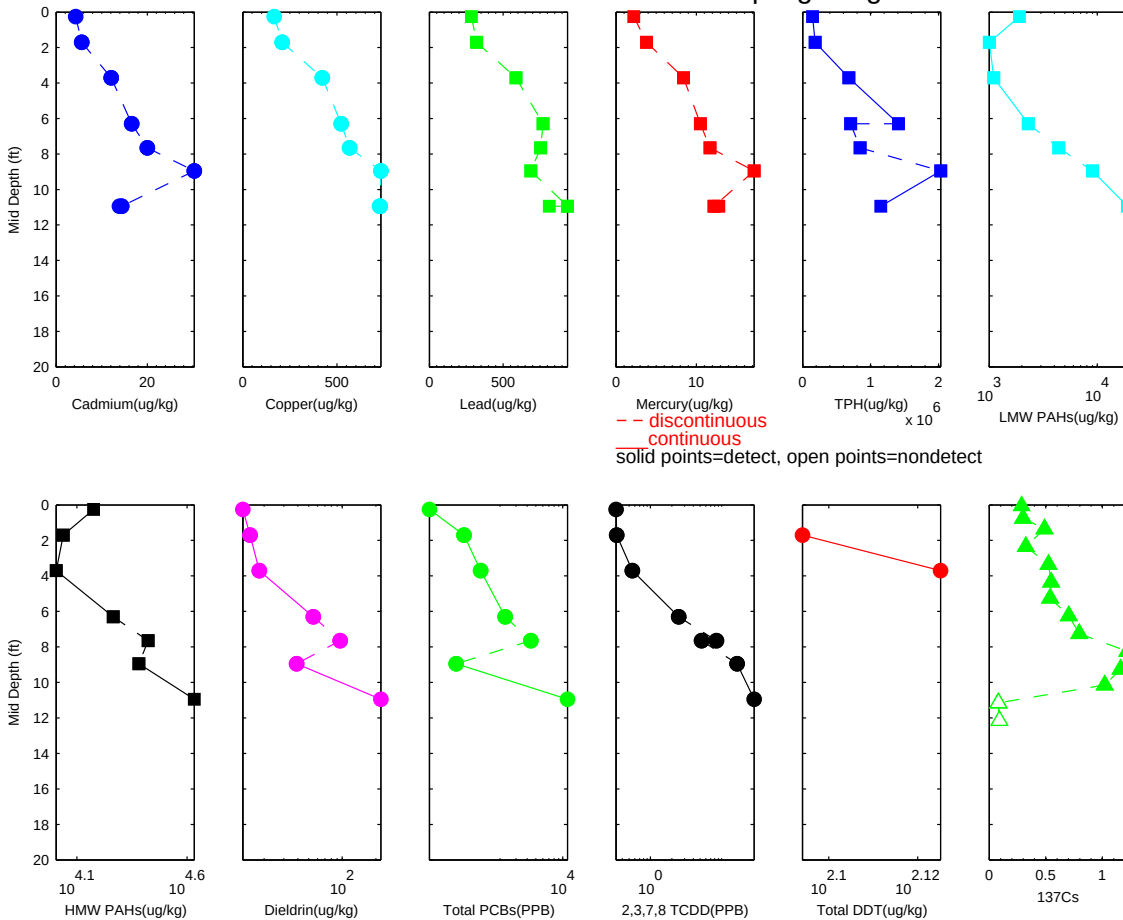

R2-0026942

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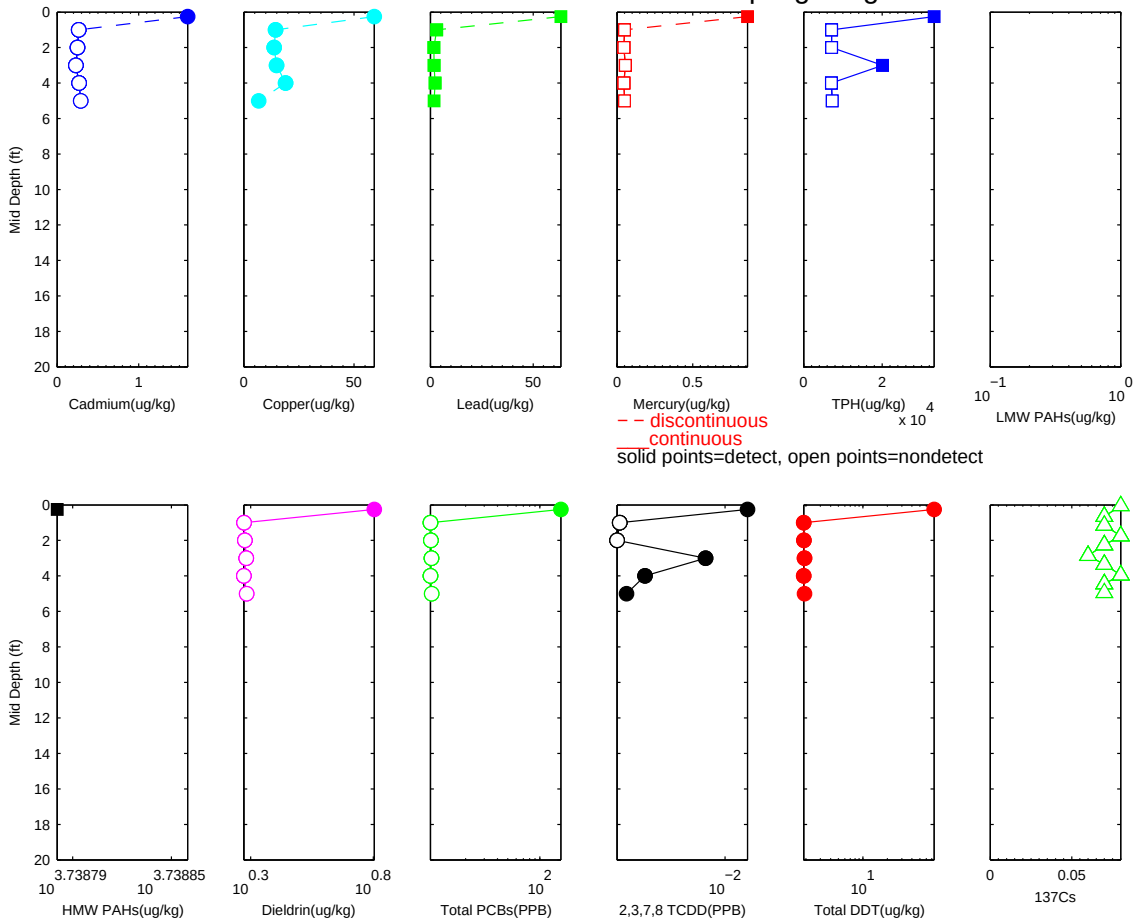

R2-0026943

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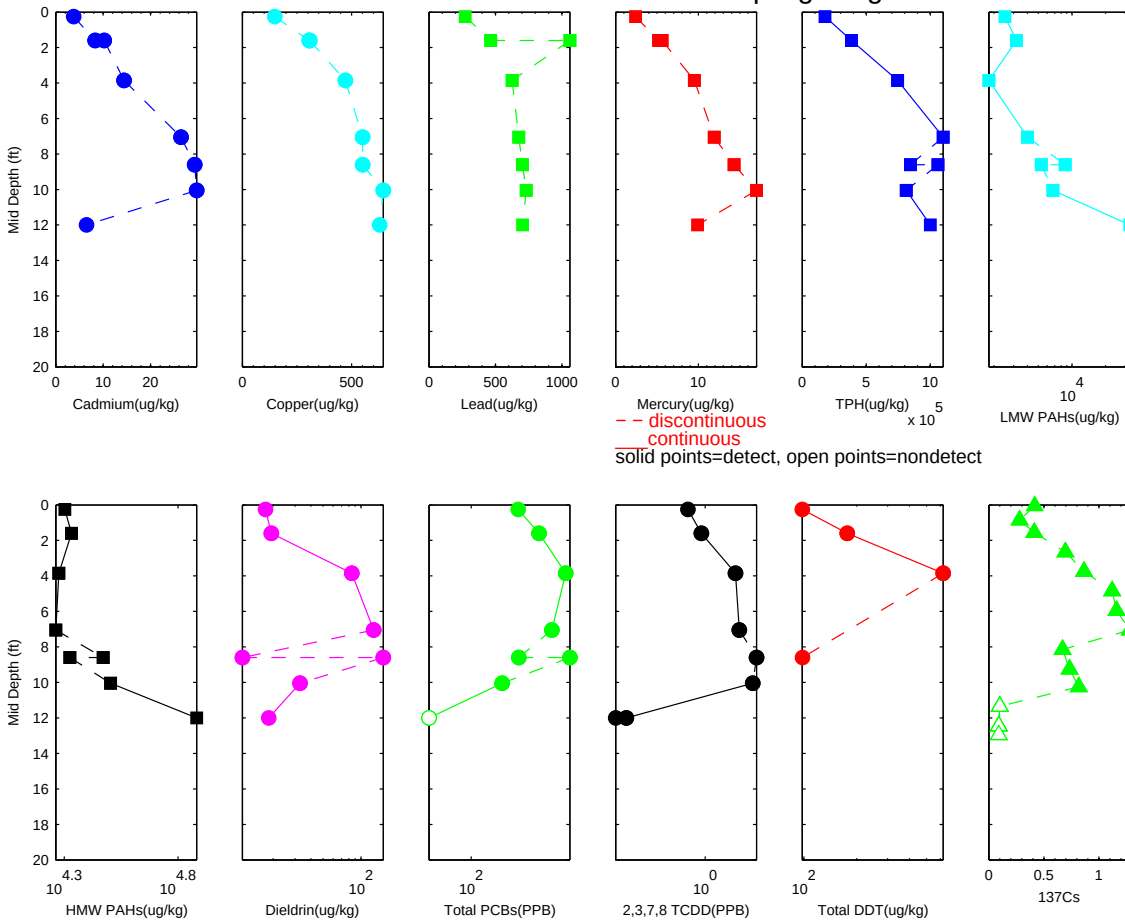
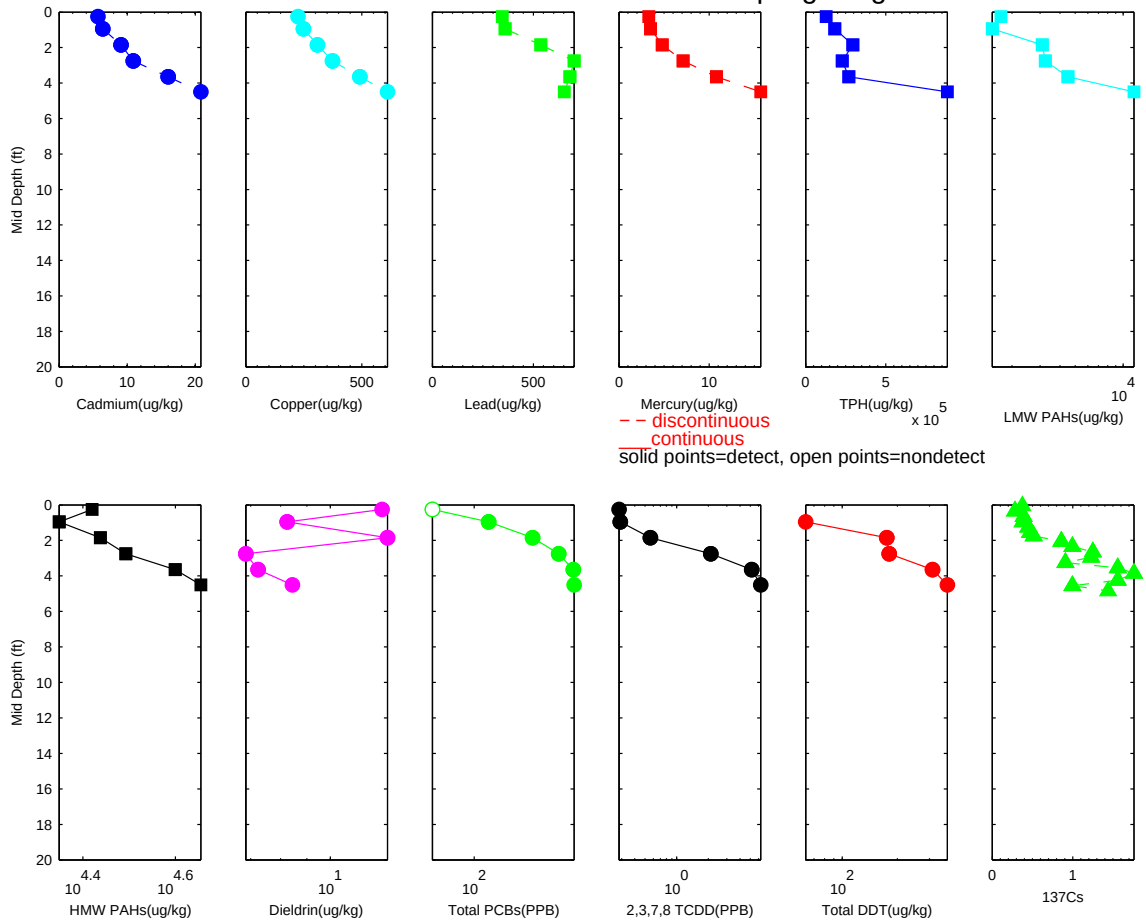


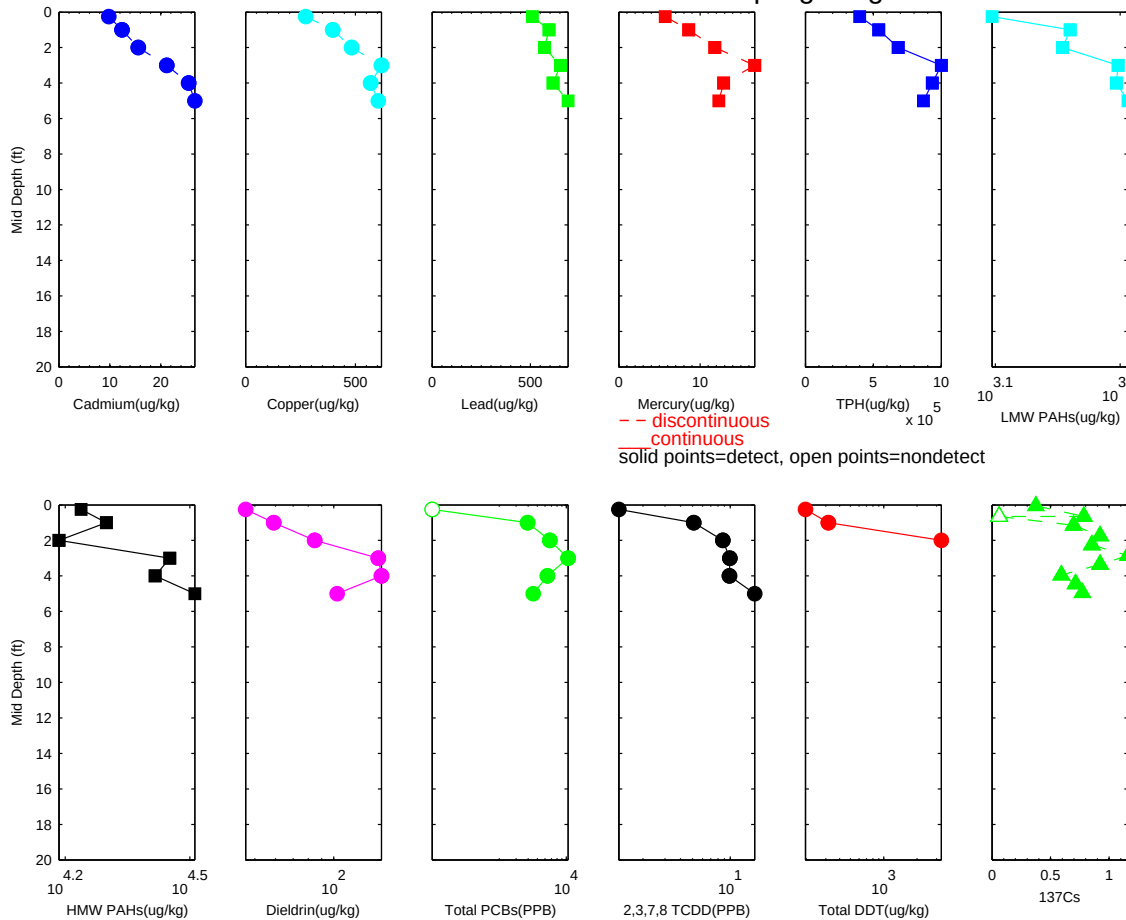
R2-0026944

Sample ID: 229 River Mile 3.08 PASSAIC 1995 RI Sampling Program



R2-0026945

Sample ID: 227 River Mile 2.86 PASSAIC 1995 RI Sampling Program



R2-0026946

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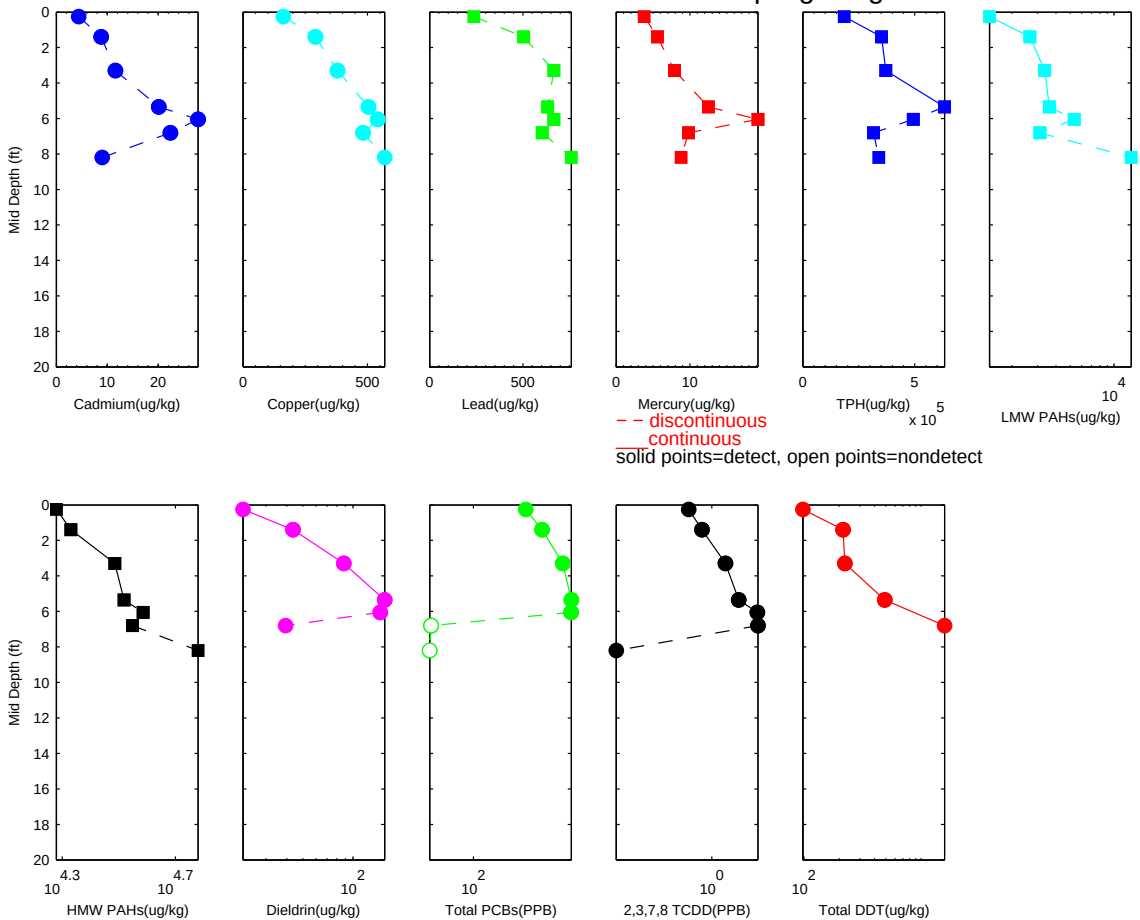
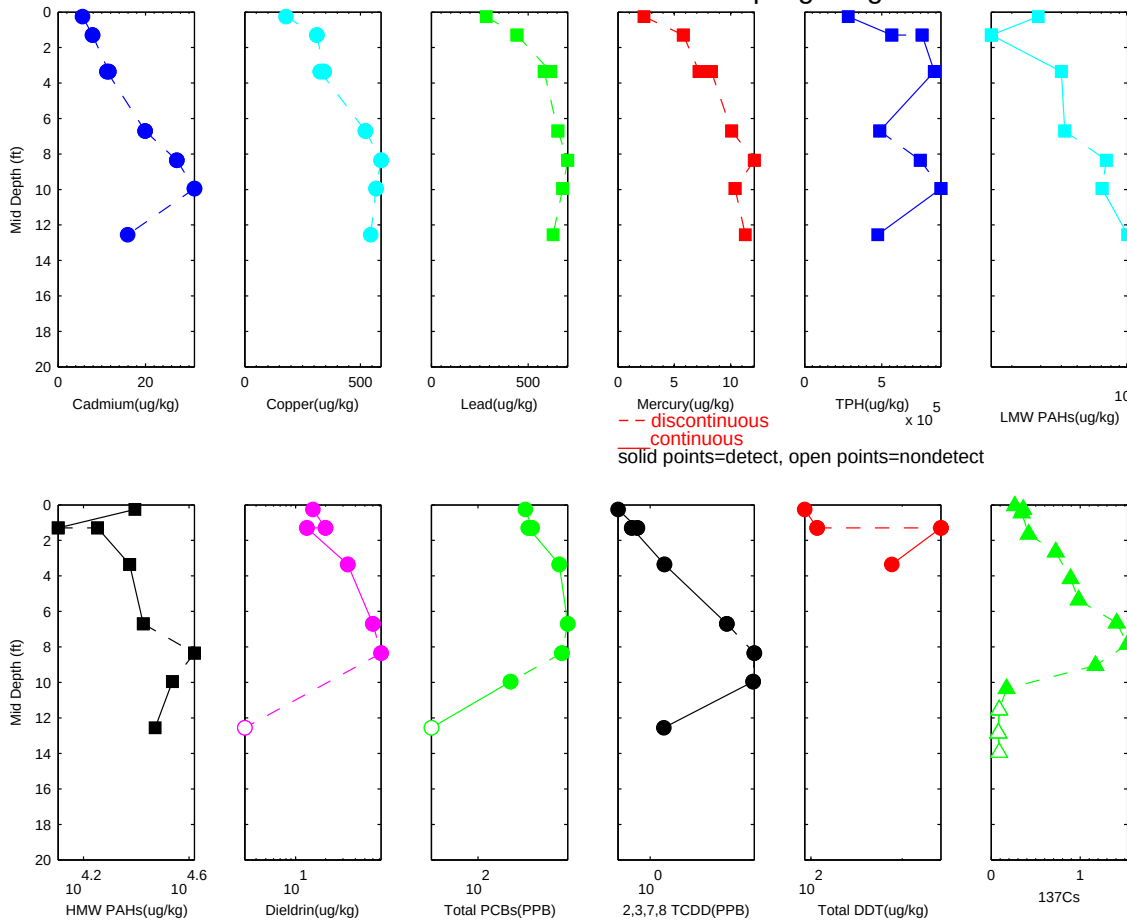


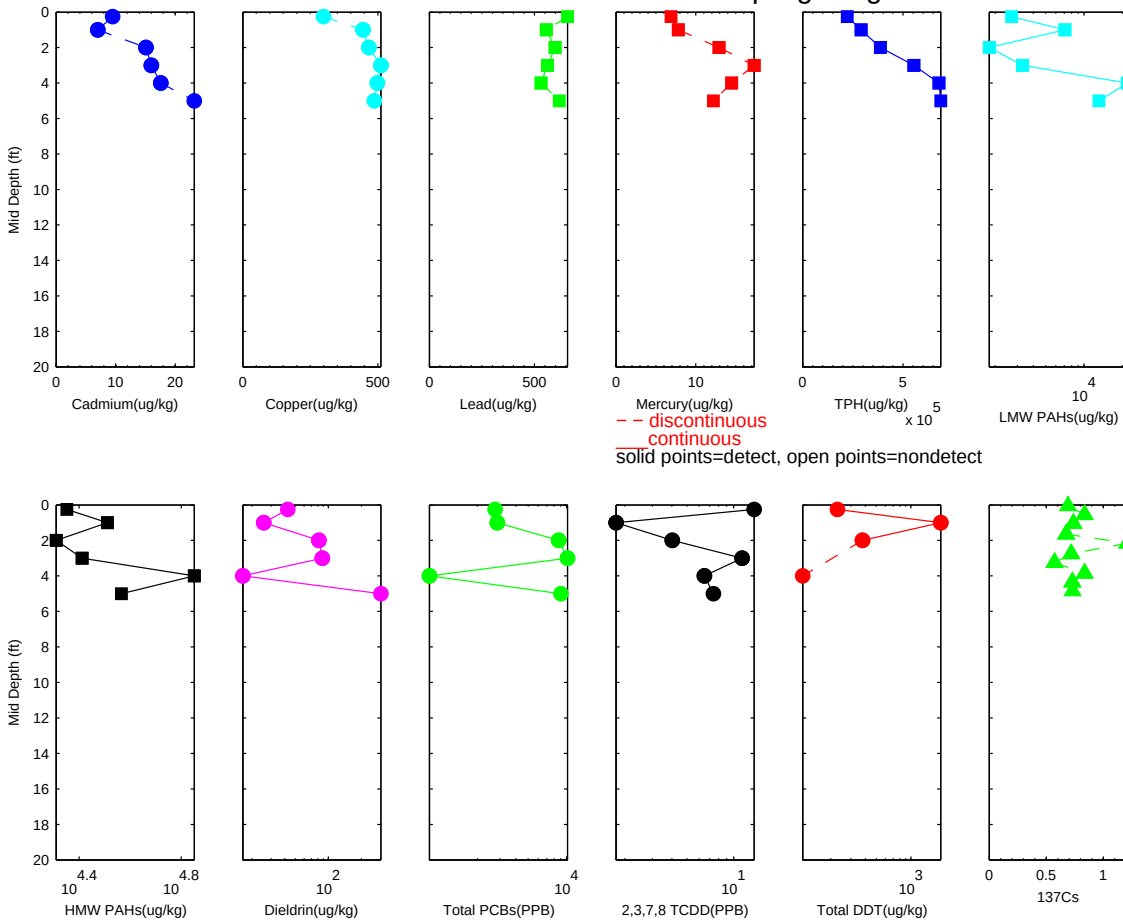
R2-0026947

Sample ID: 225 River Mile 2.86 PASSAIC 1995 RI Sampling Program



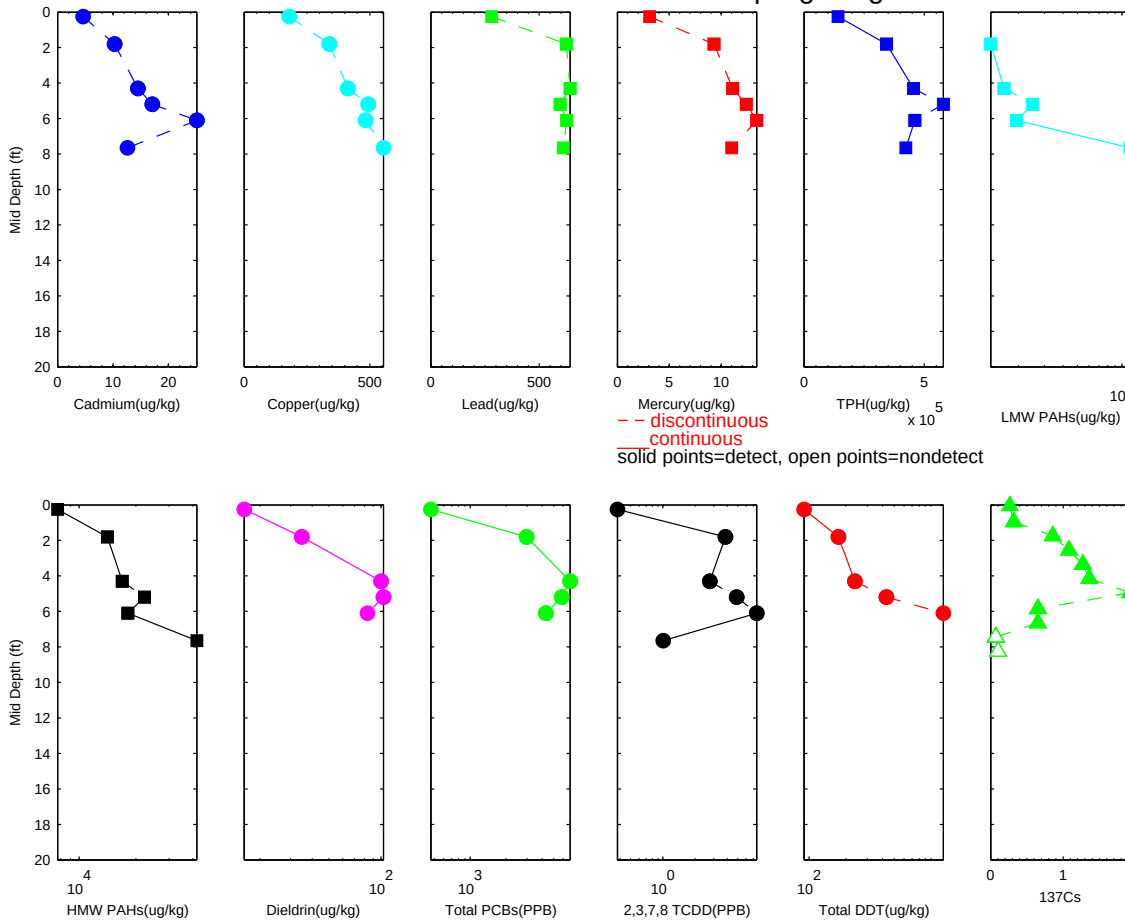
R2-0026948

Sample ID: 224 River Mile 2.63 PASSAIC 1995 RI Sampling Program



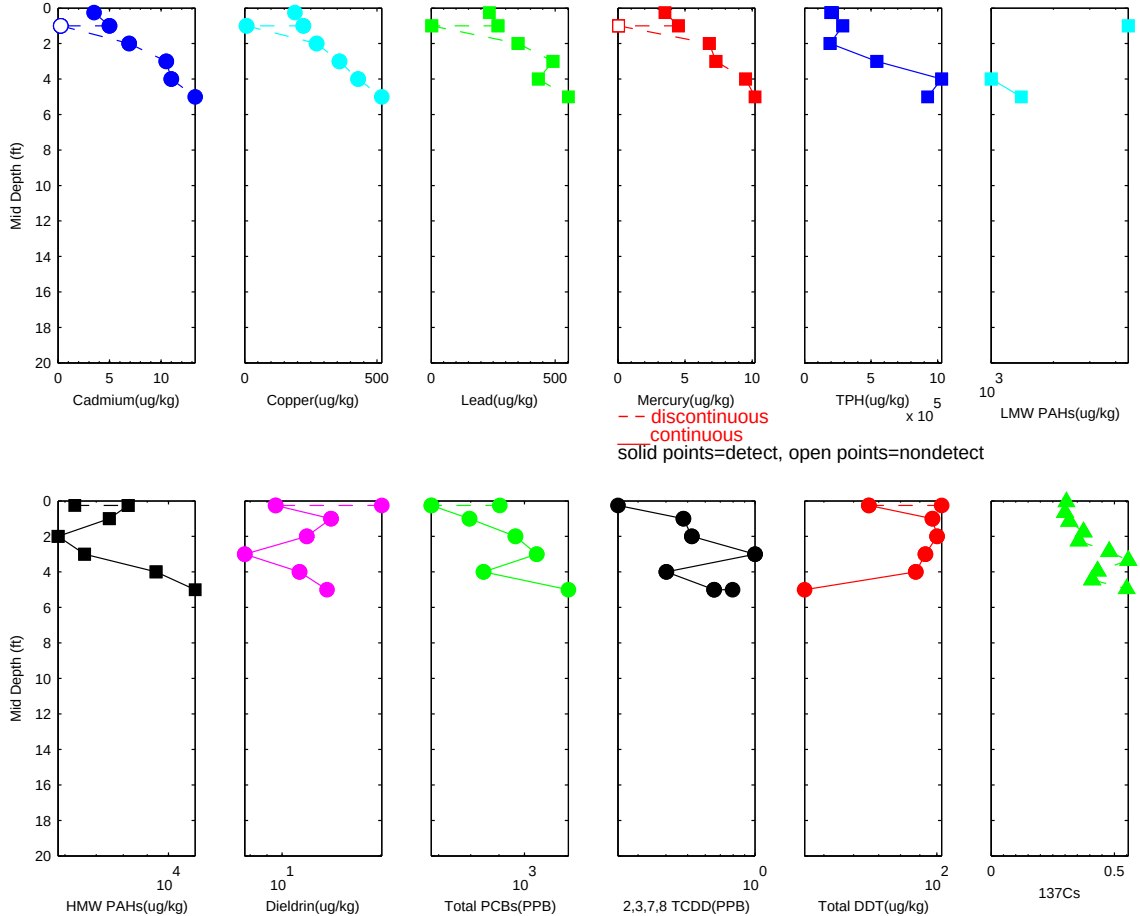
R2-0026949

Sample ID: 223 River Mile 2.63 PASSAIC 1995 RI Sampling Program



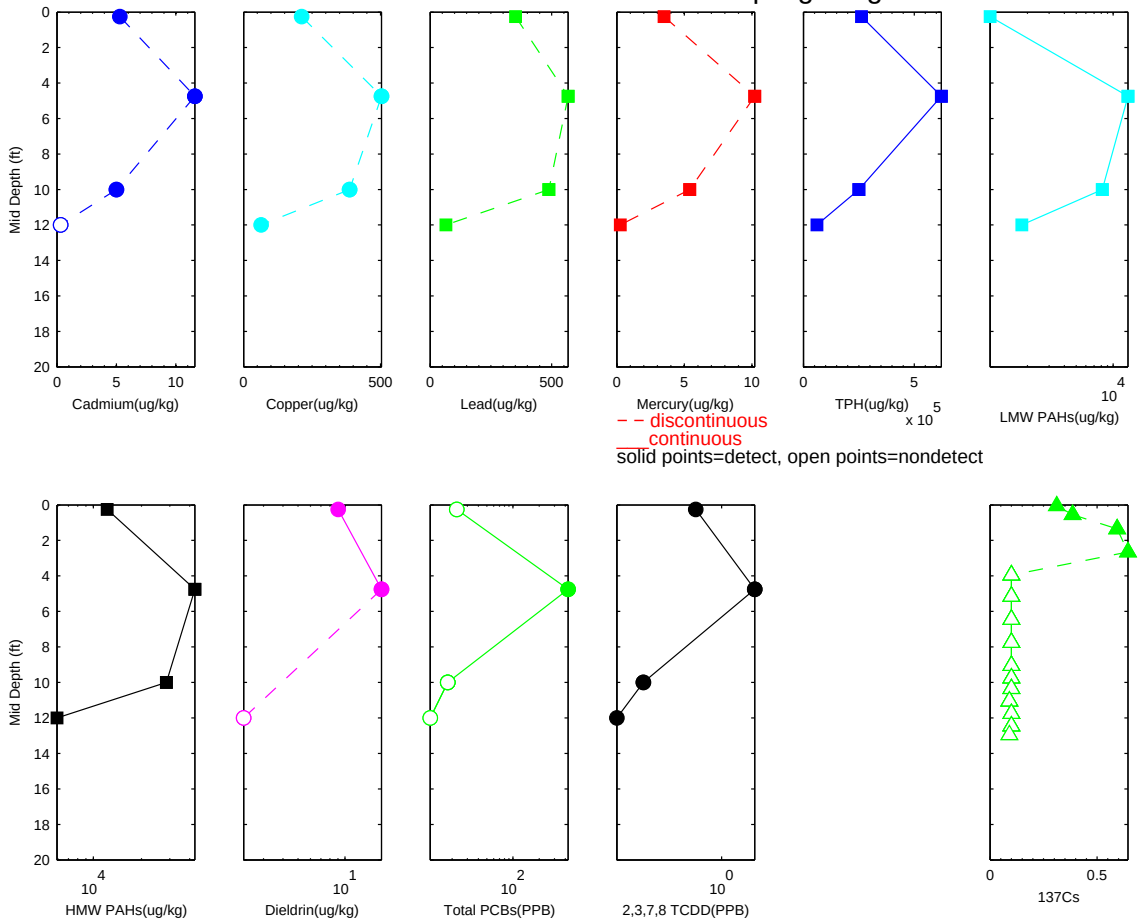
R2-0026950

Sample ID: 218 River Mile 2.2 PASSAIC 1995 RI Sampling Program



R2-0026951

Sample ID: 217 River Mile 2.2 PASSAIC 1995 RI Sampling Program



R2-0026952

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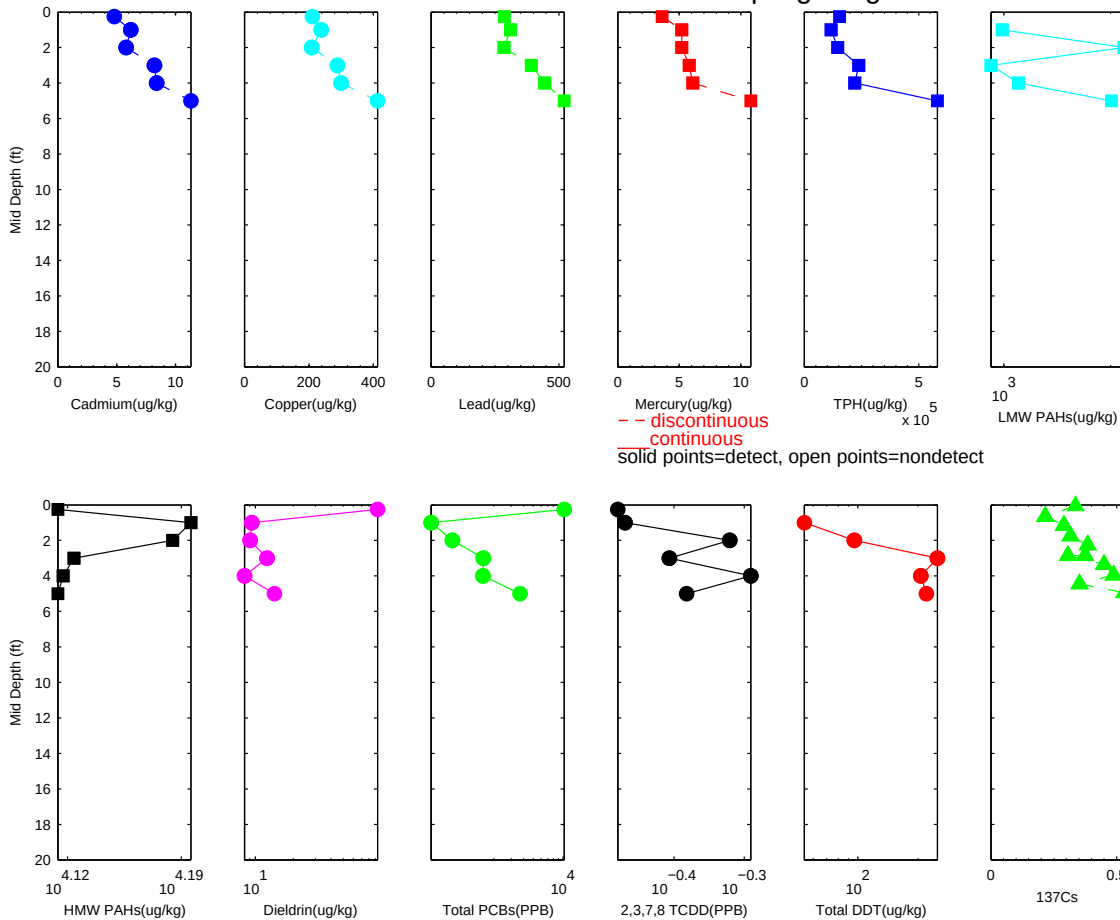
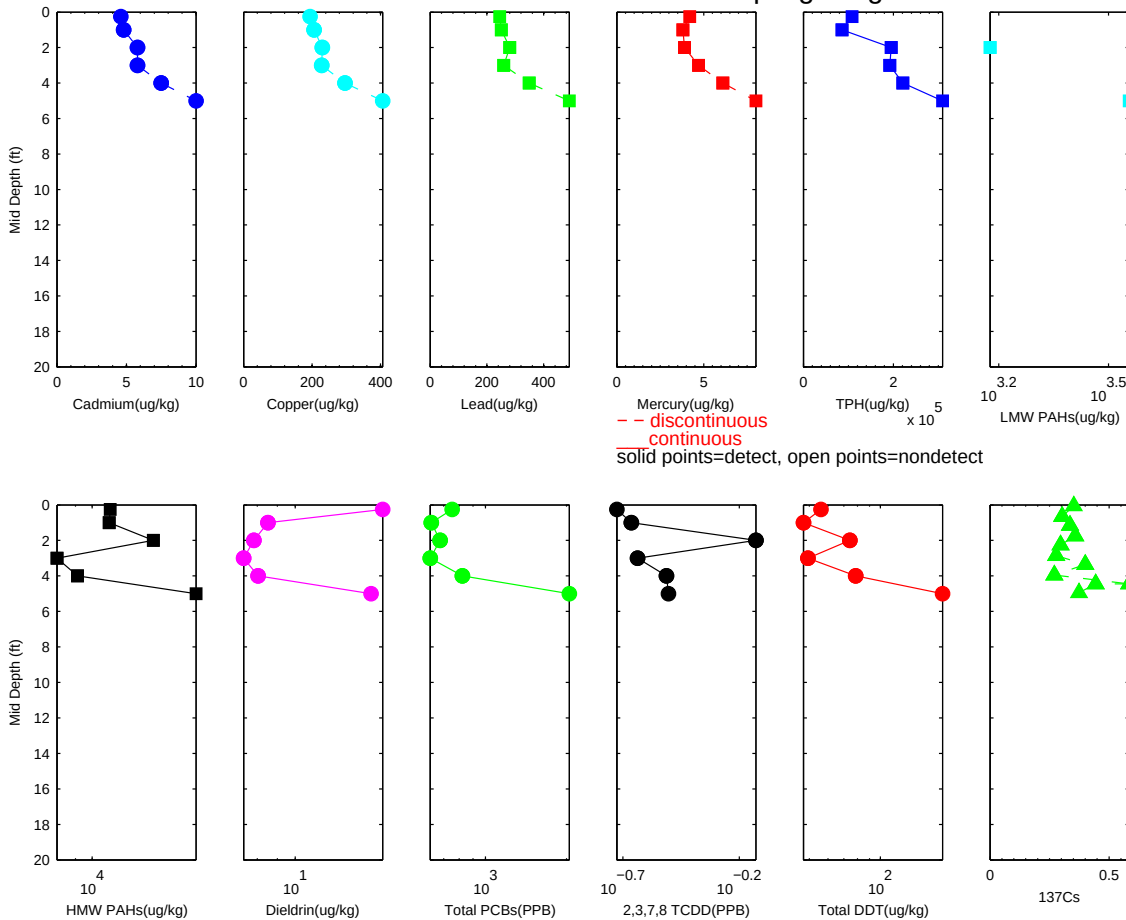


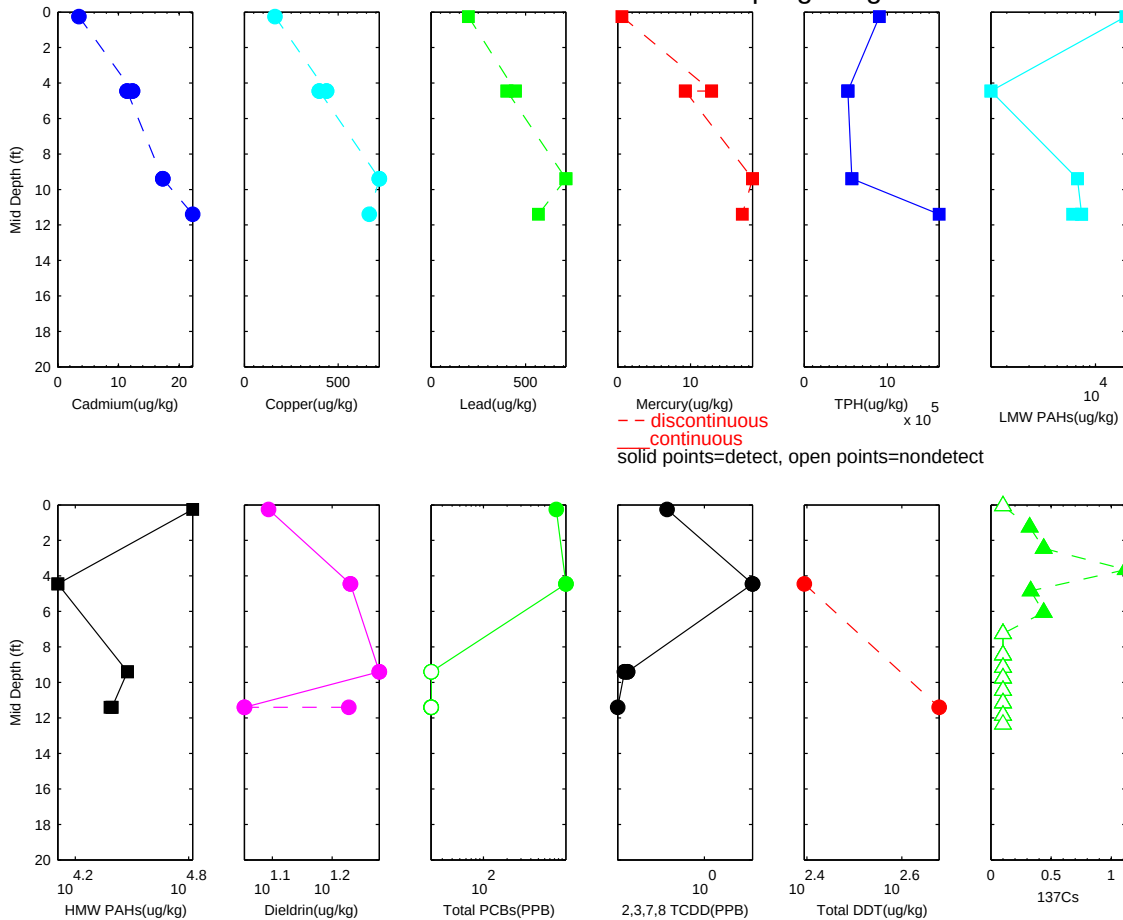
R2-0026953

Sample ID: 215 River Mile 1.95 PASSAIC 1995 RI Sampling Program



R2-0026954

Sample ID: 214 River Mile 1.95 PASSAIC 1995 RI Sampling Program



R2-0026955

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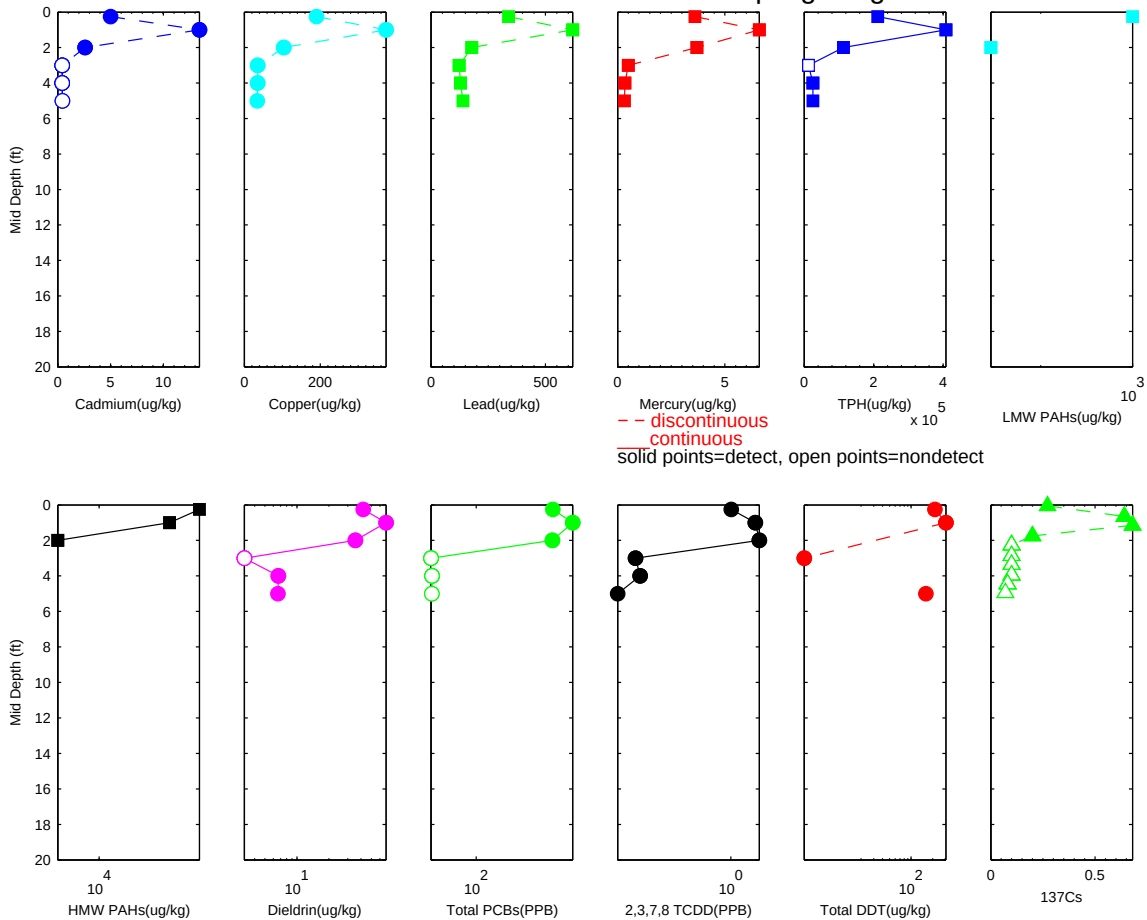

R2-0026956

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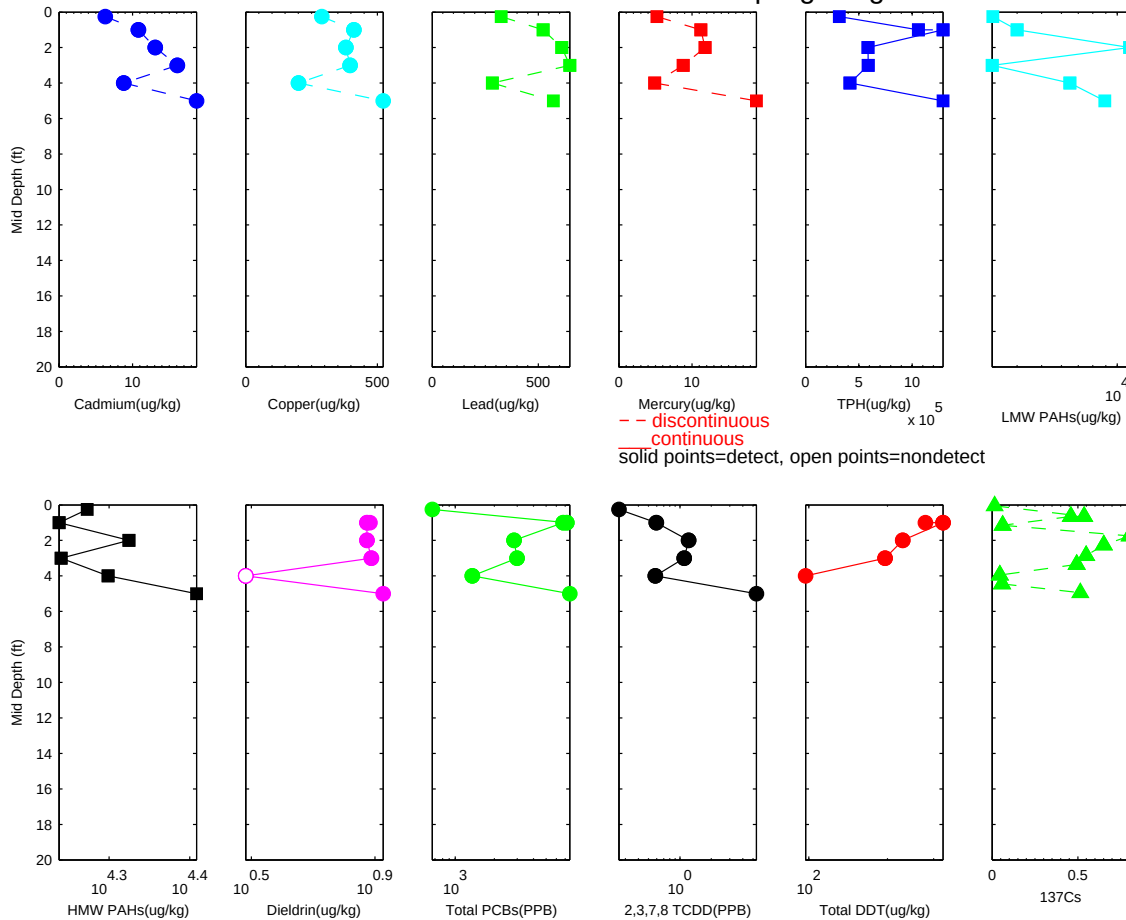

R2-0026957

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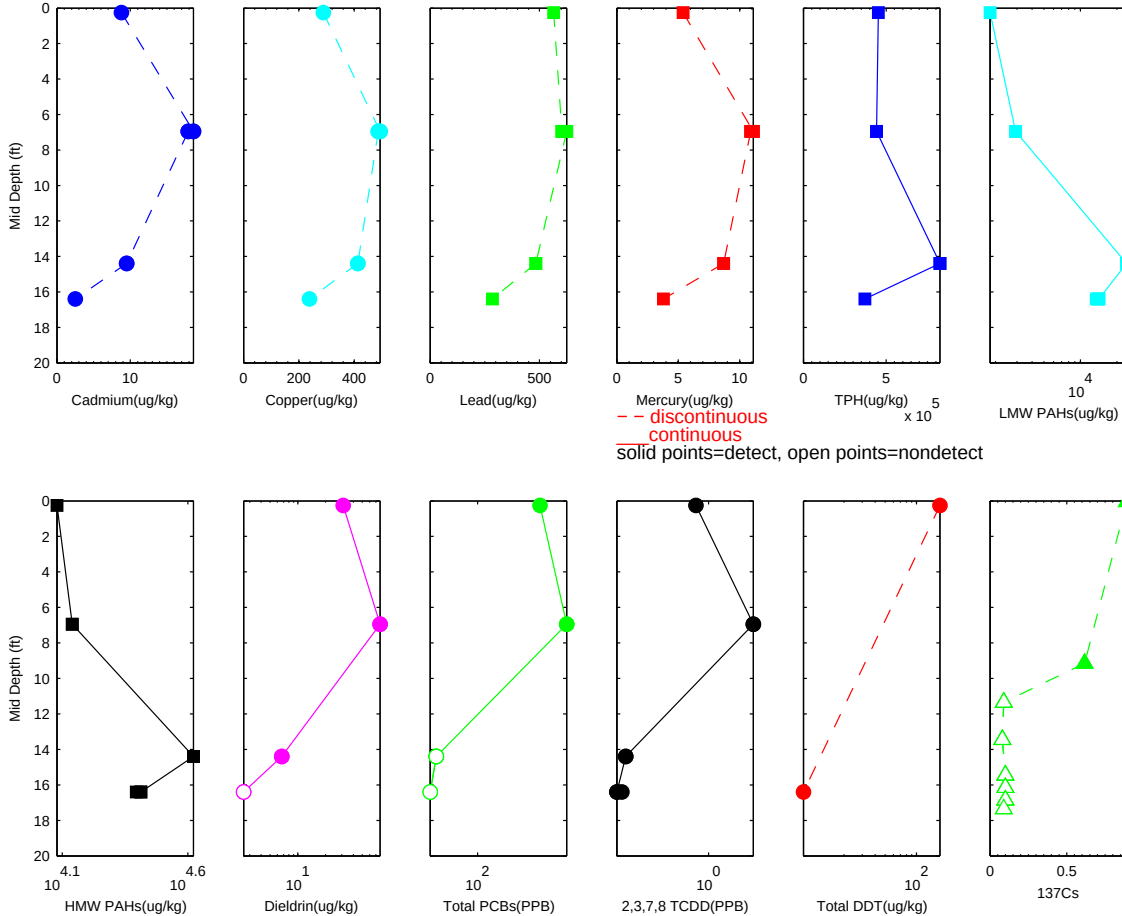

R2-0026958

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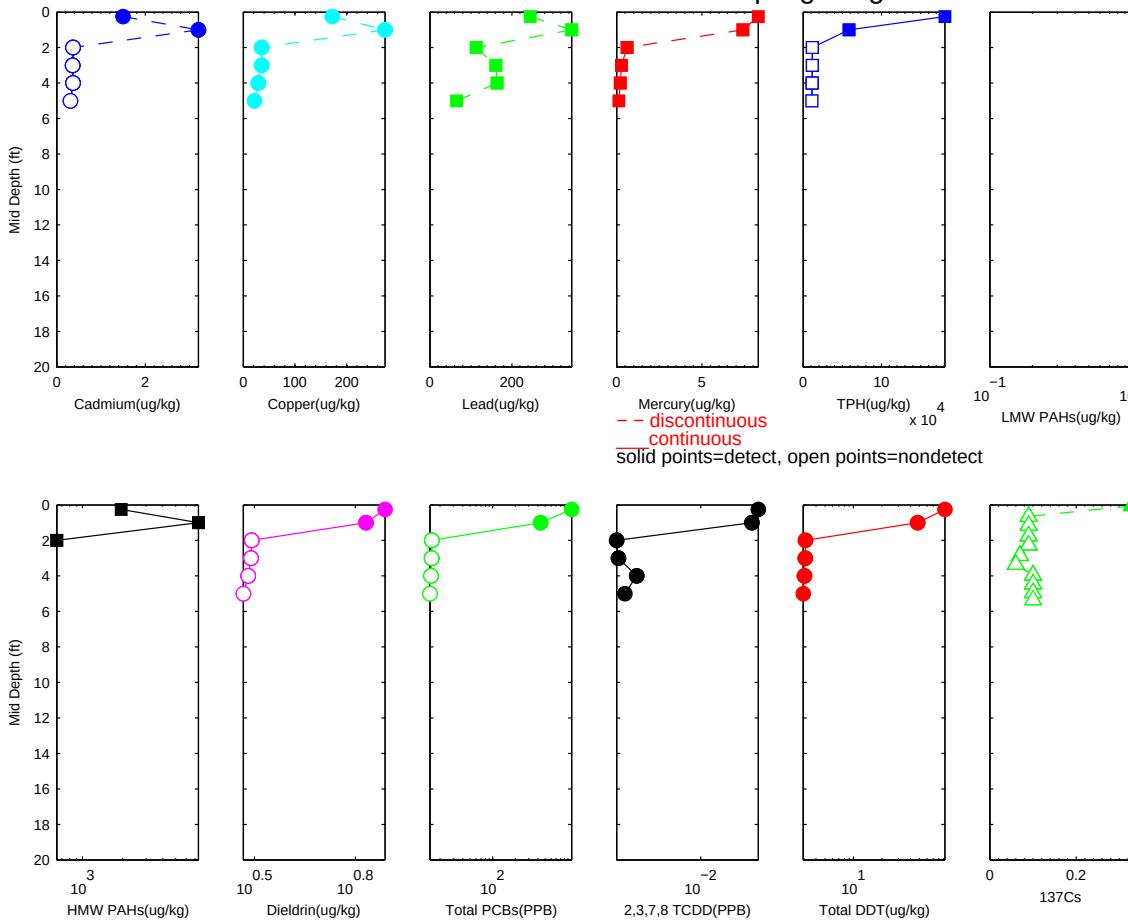
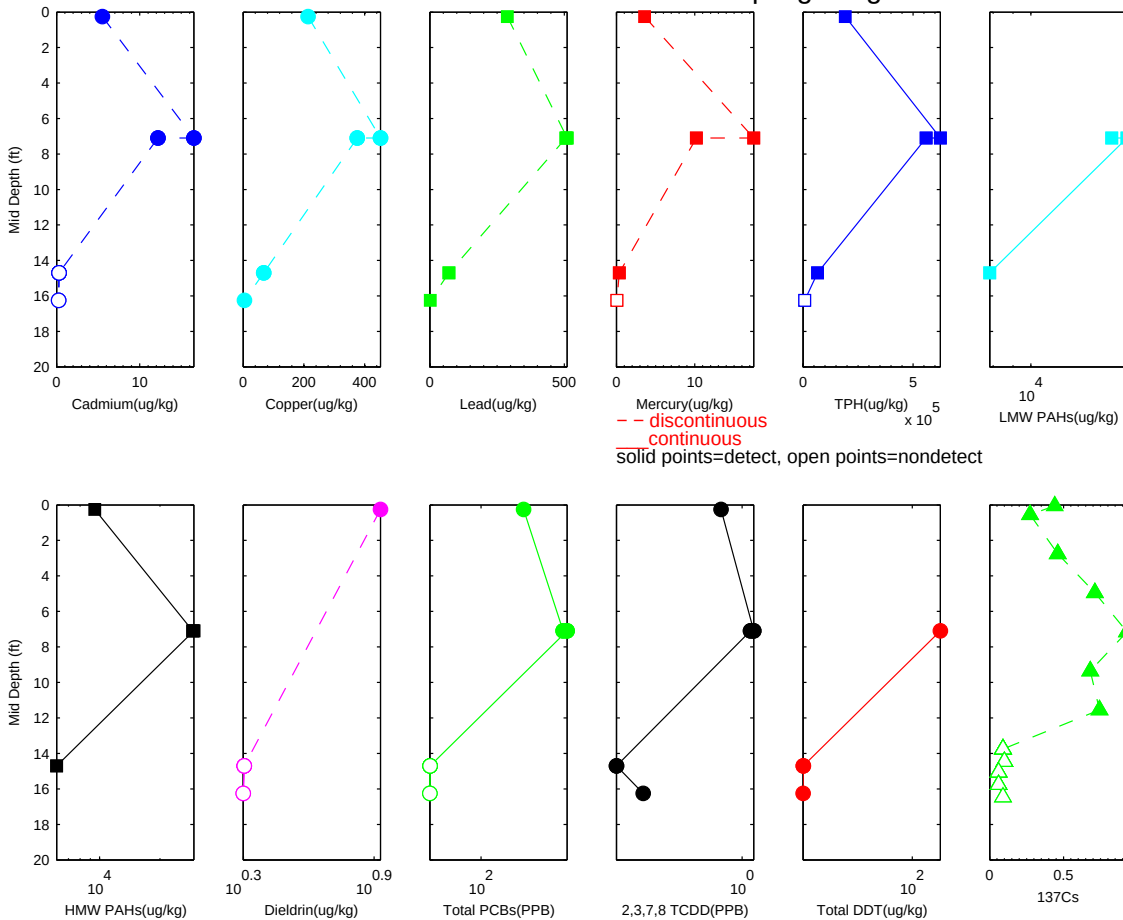


R2-0026959

Sample ID: 208 River Mile 1.47 PASSAIC 1995 RI Sampling Program



R2-0026960

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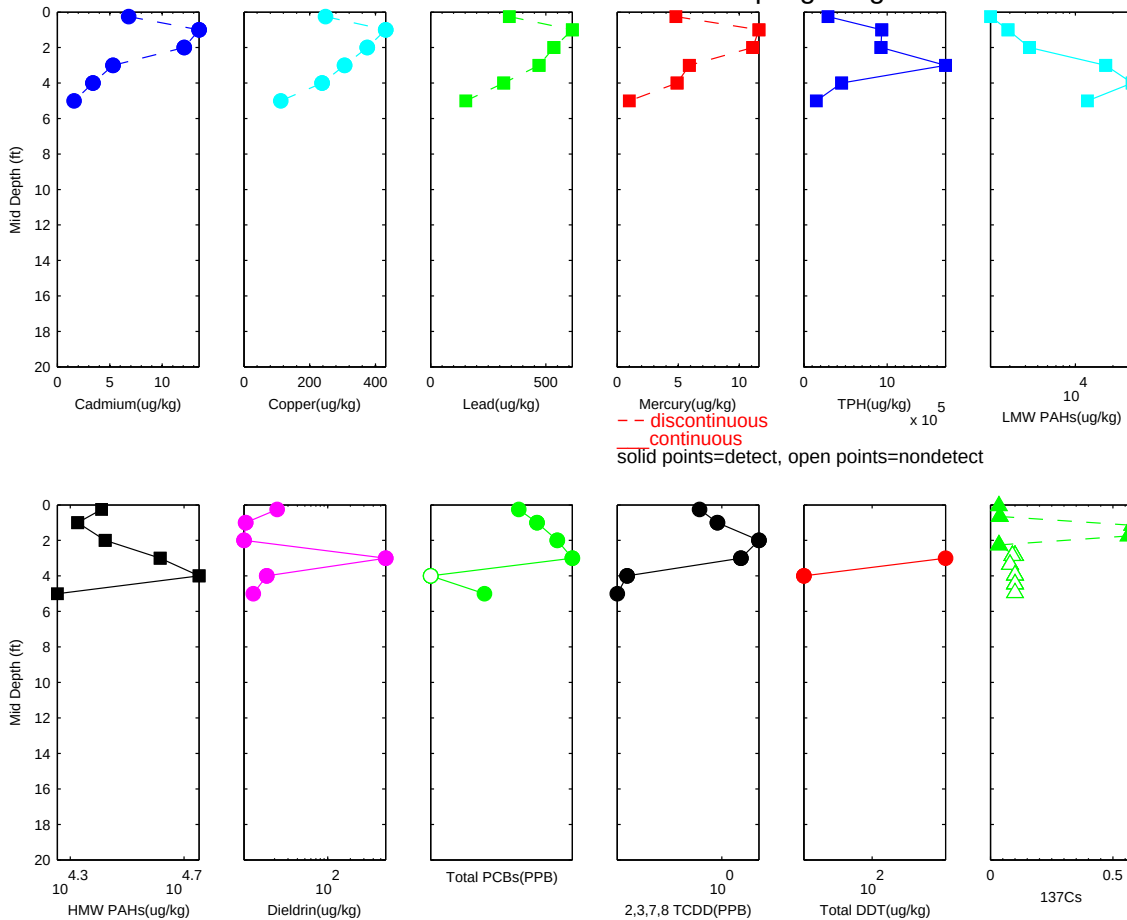
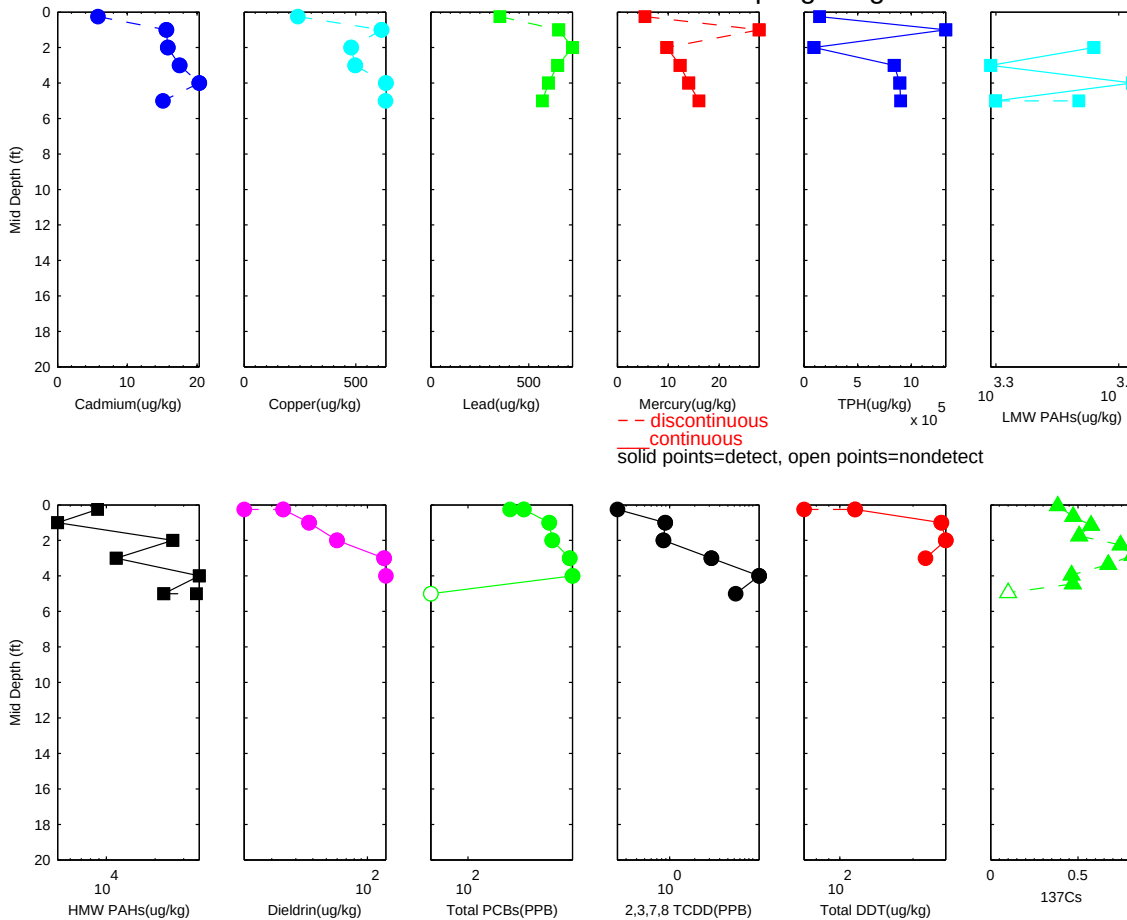


R2-0026961

Sample ID: 206 River Mile 1.25 PASSAIC 1995 RI Sampling Program



R2-0026962

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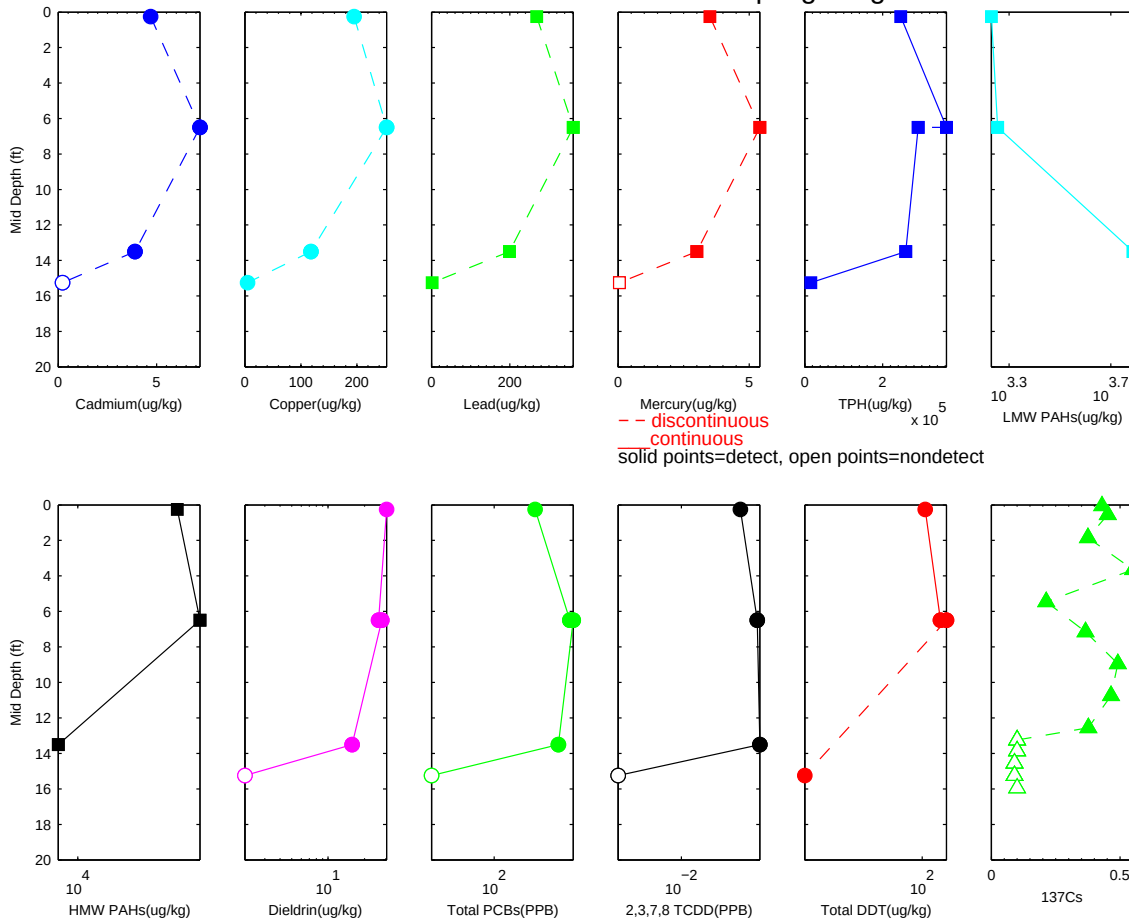
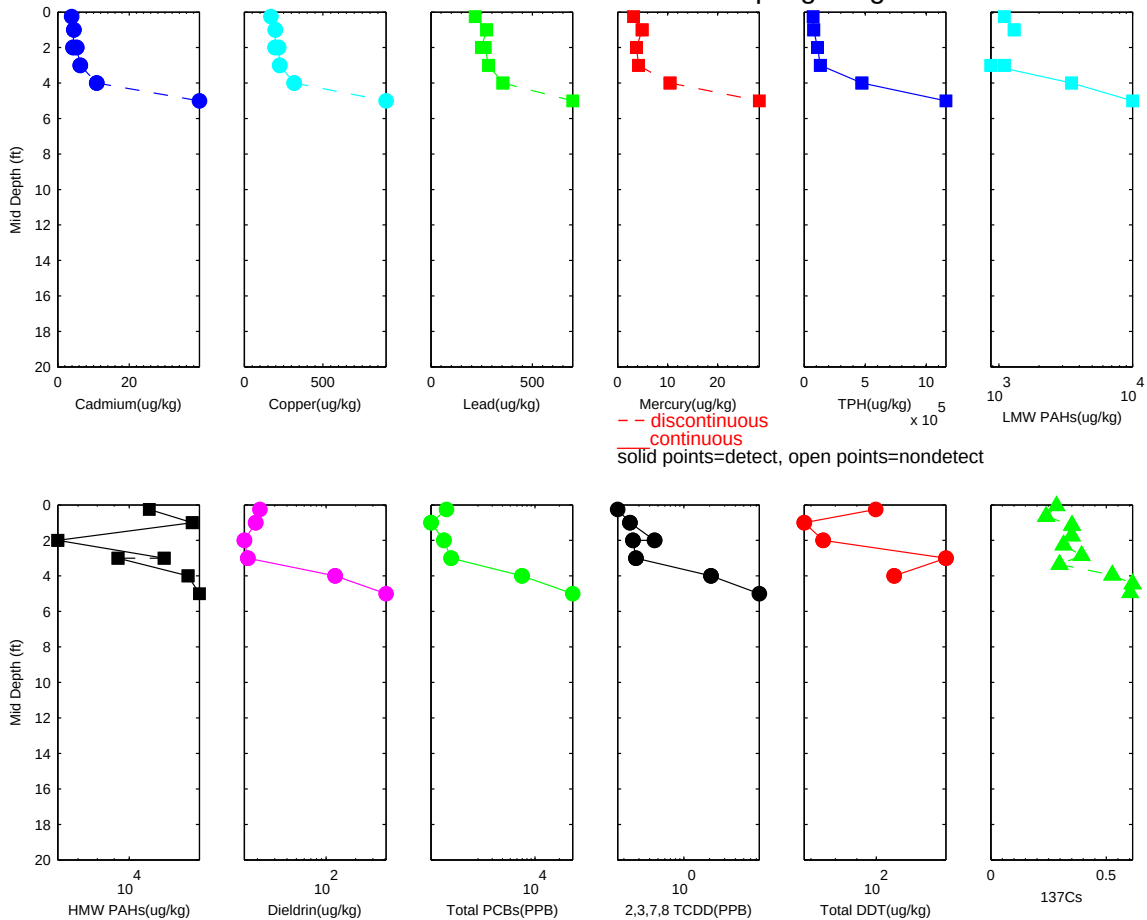


R2-0026963

Sample ID: 204 River Mile 1.25 PASSAIC 1995 RI Sampling Program



R2-0026964

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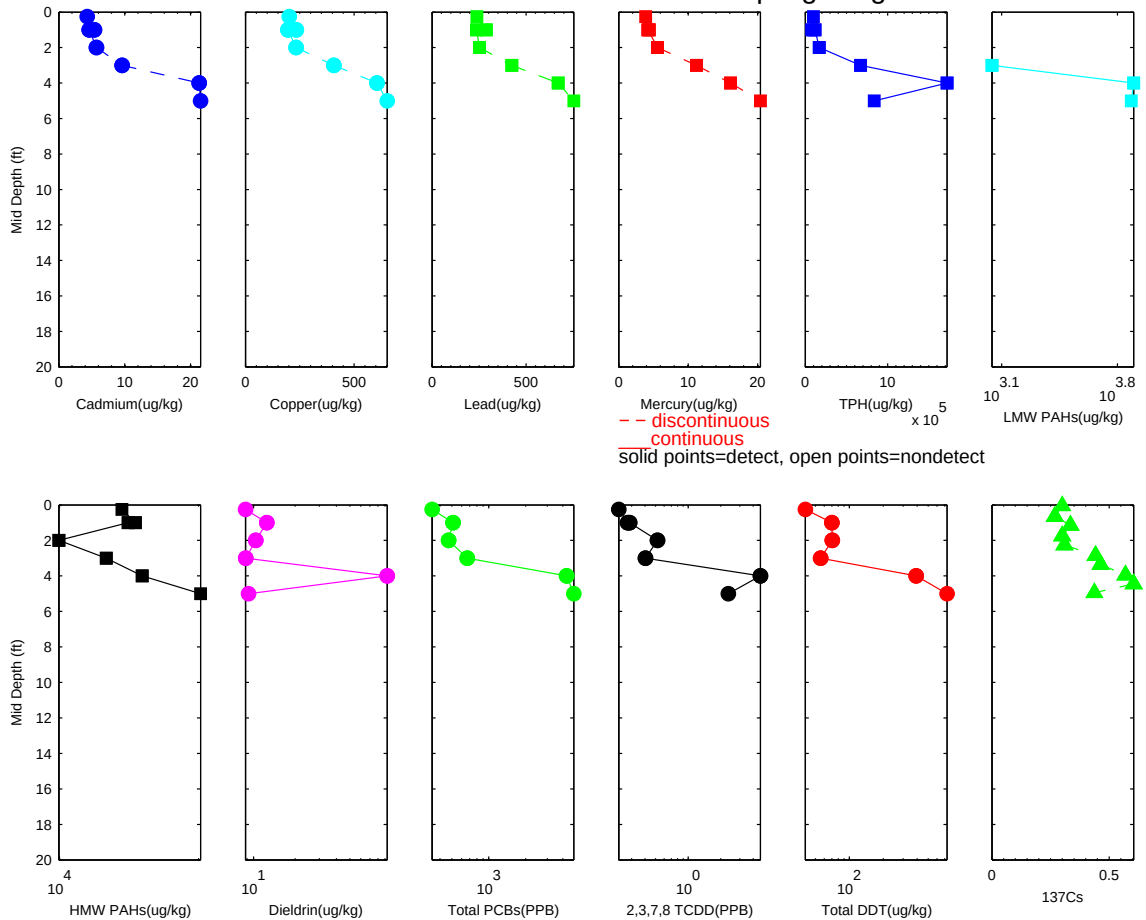

R2-0026965

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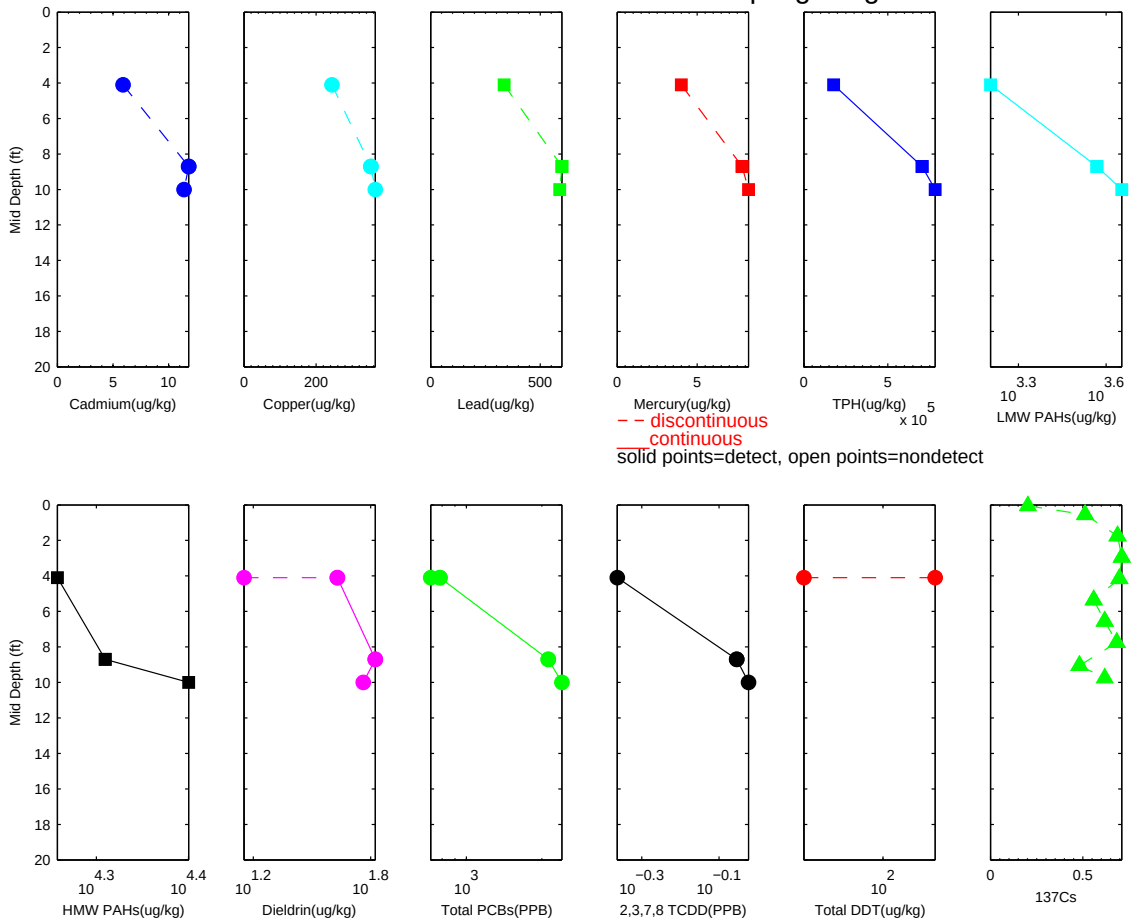
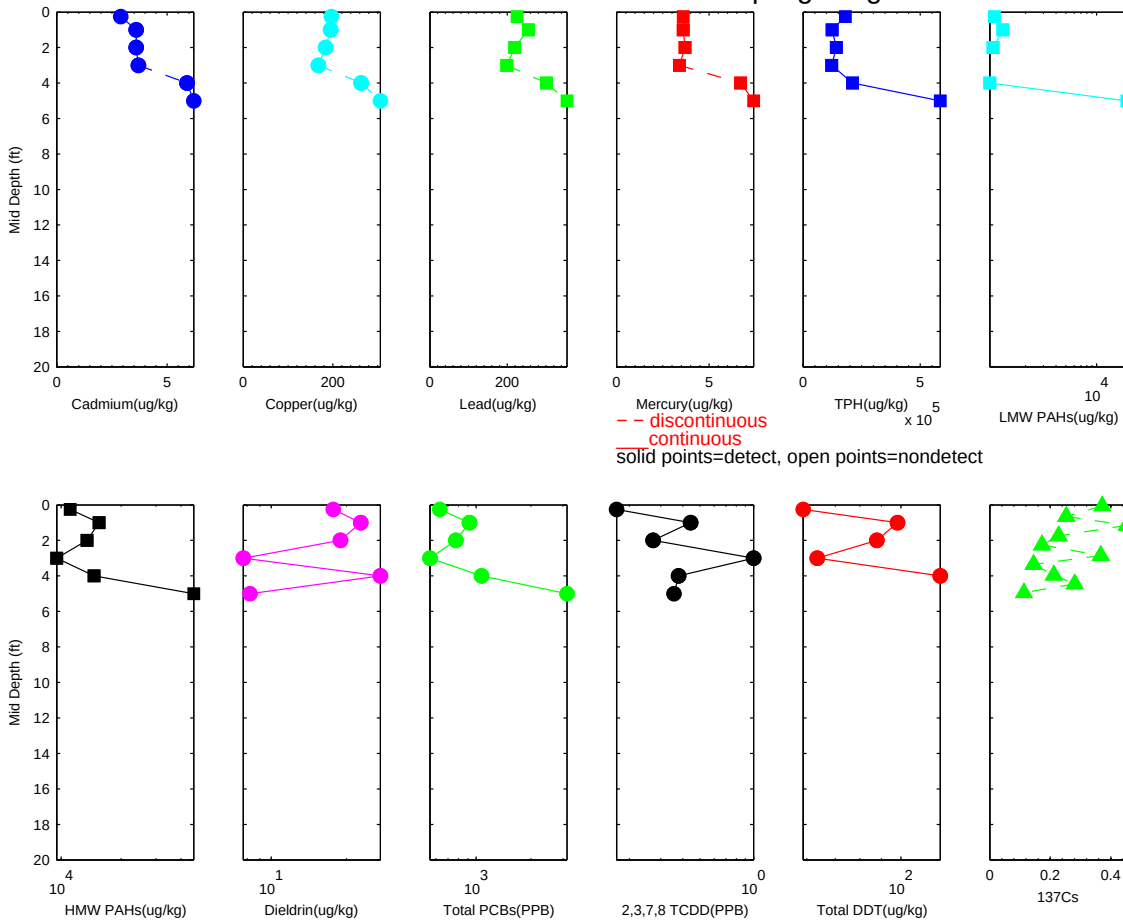


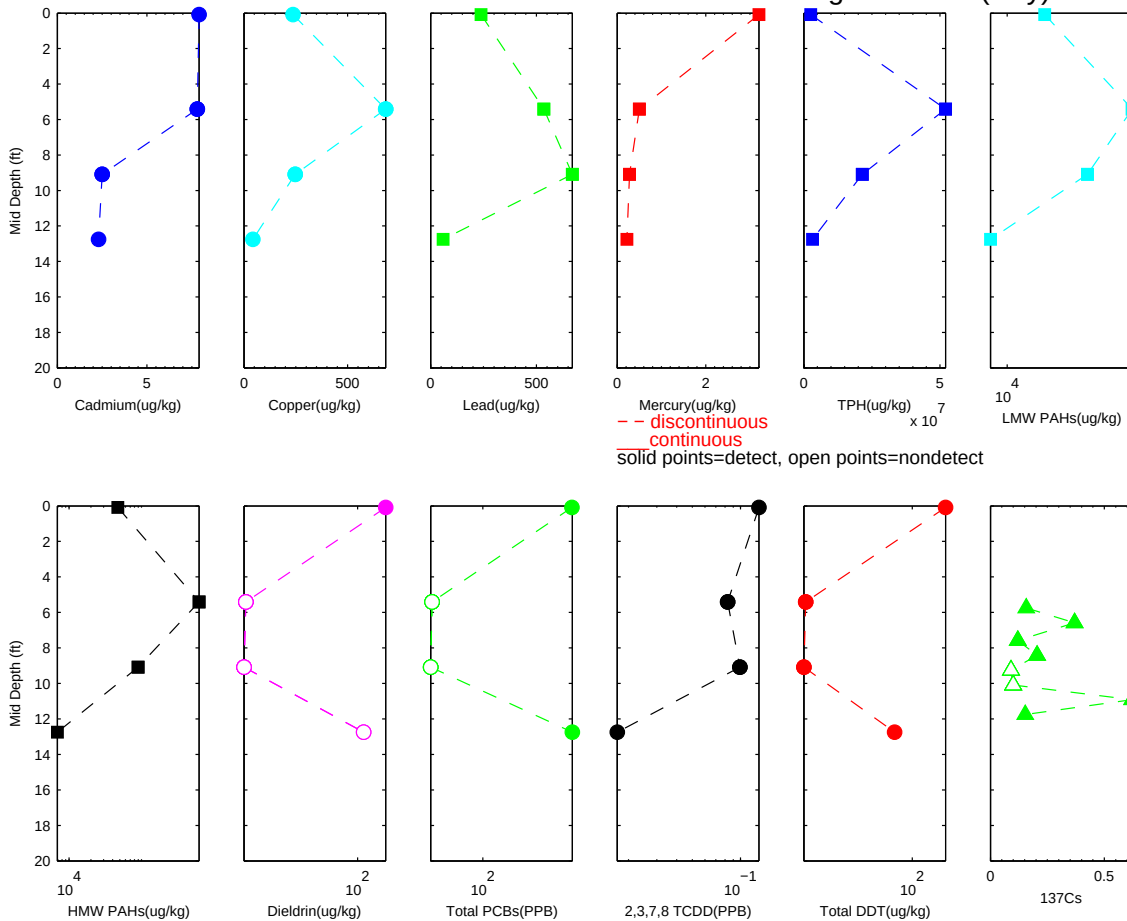
R2-0026966

Sample ID: 201 River Mile 1.02 PASSAIC 1995 RI Sampling Program



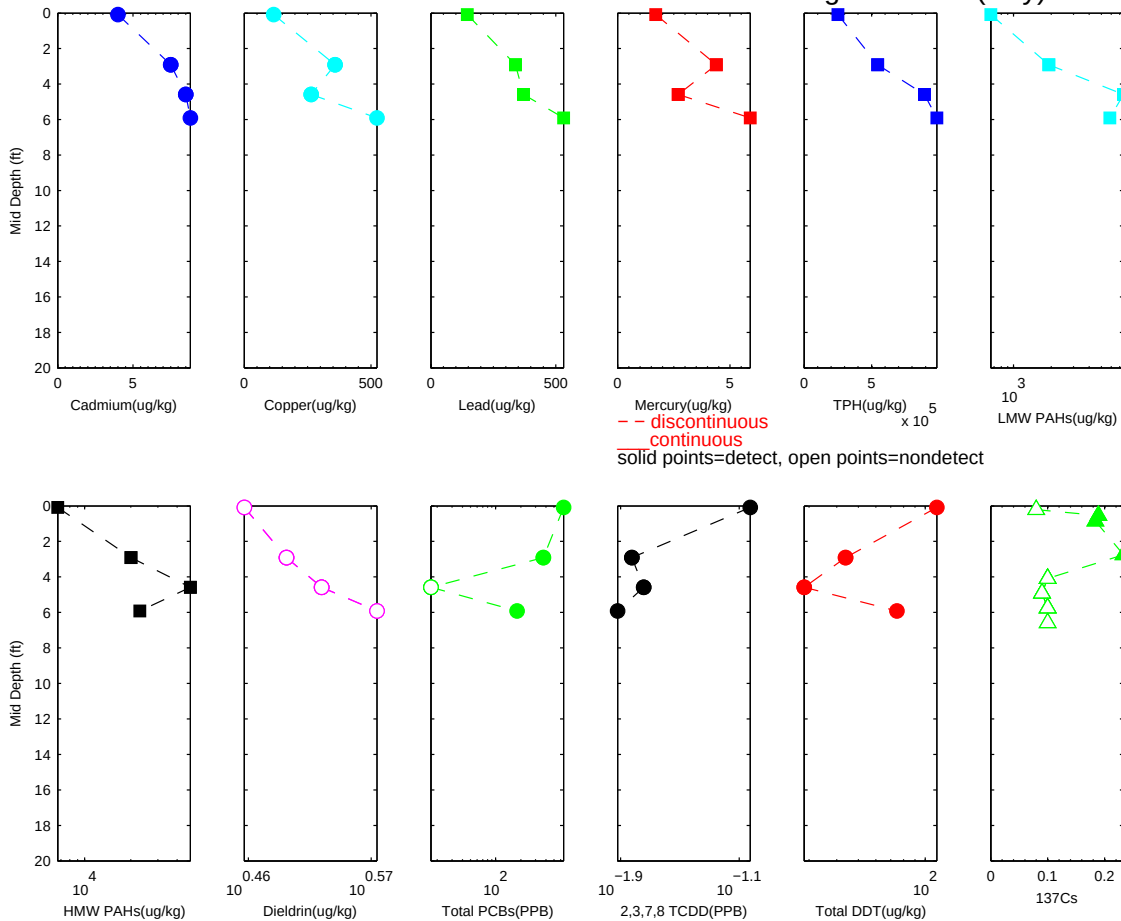
R2-0026967

Sample ID: 100 River Mile 1.13PASSAIC 1993 Core Sediment Investigation − 02 (July)



R2-0026968

Sample ID: 99A River Mile 0.64PASSAIC 1993 Core Sediment Investigation − 02 (July)



R2-0026969

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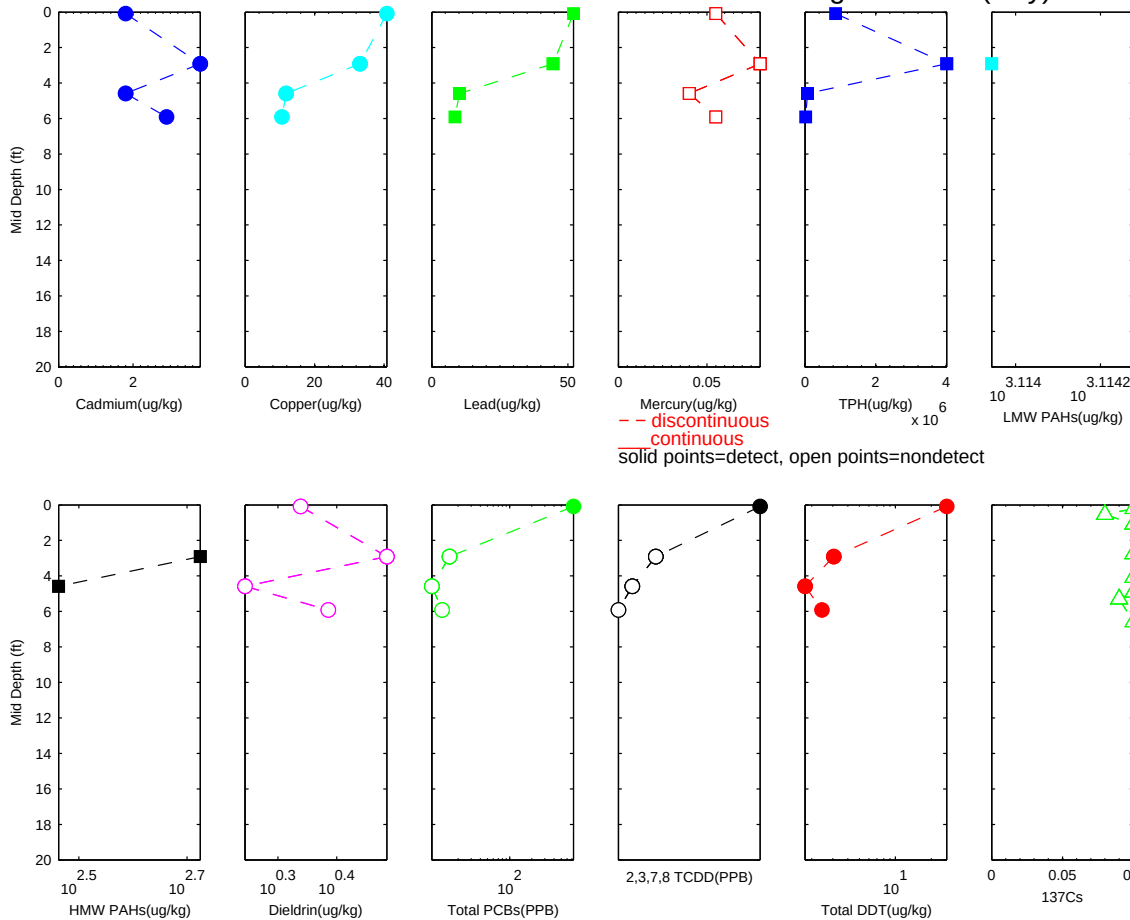
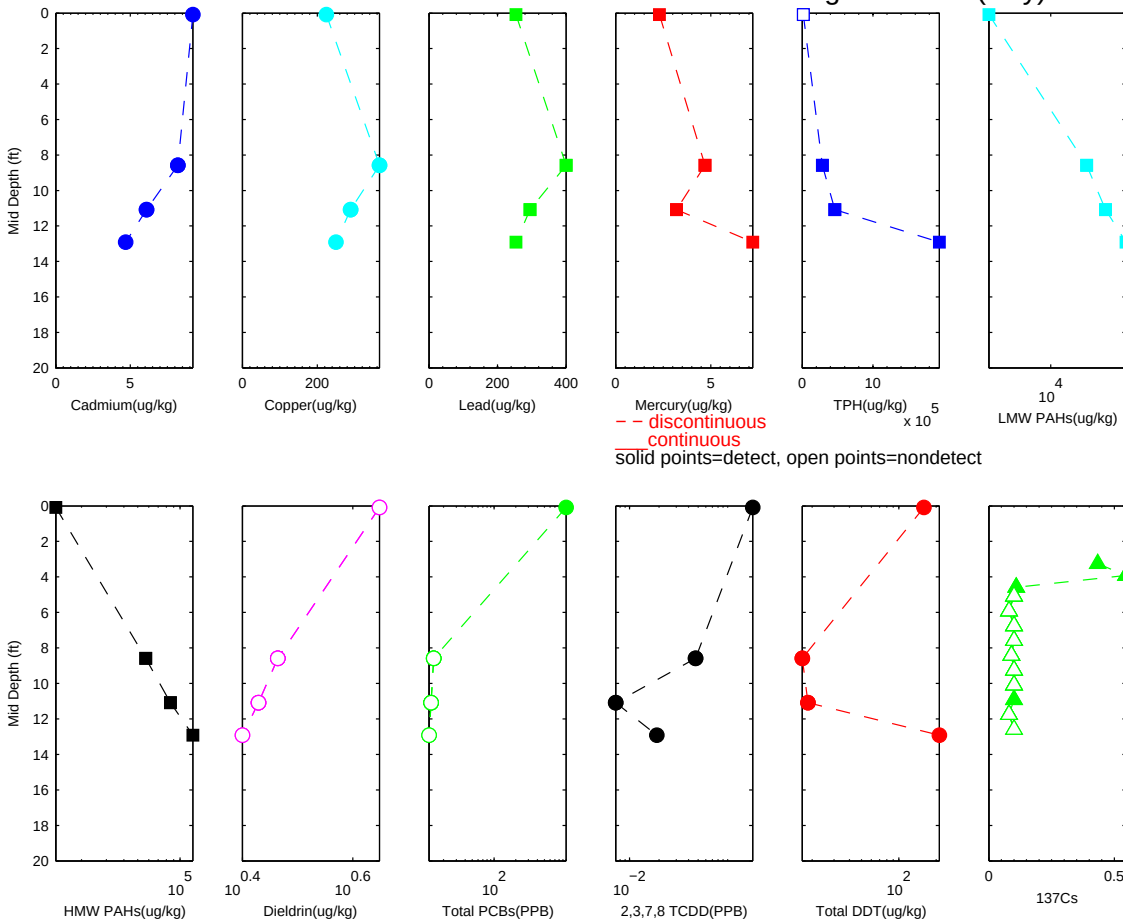


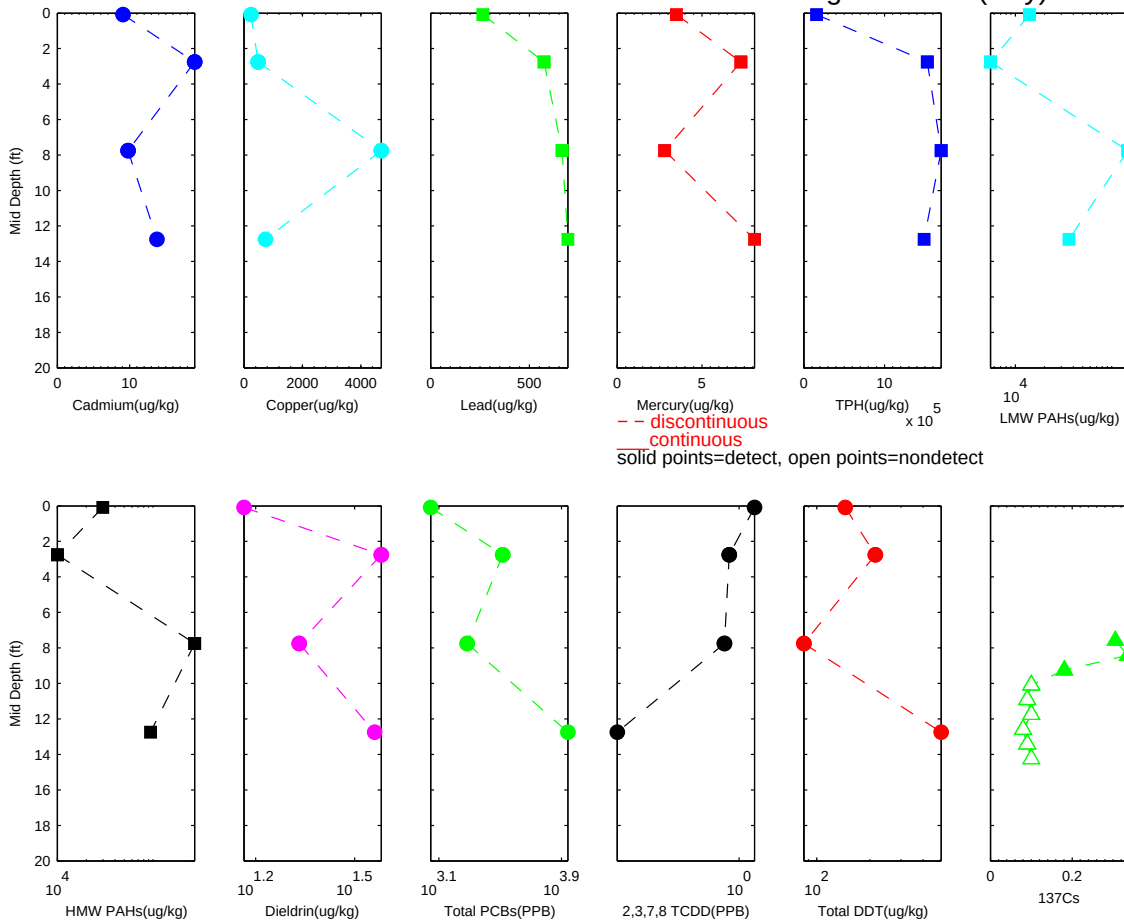
R2-0026970

Sample ID: 97B River Mile 1.51PASSAIC 1993 Core Sediment Investigation − 02 (July)



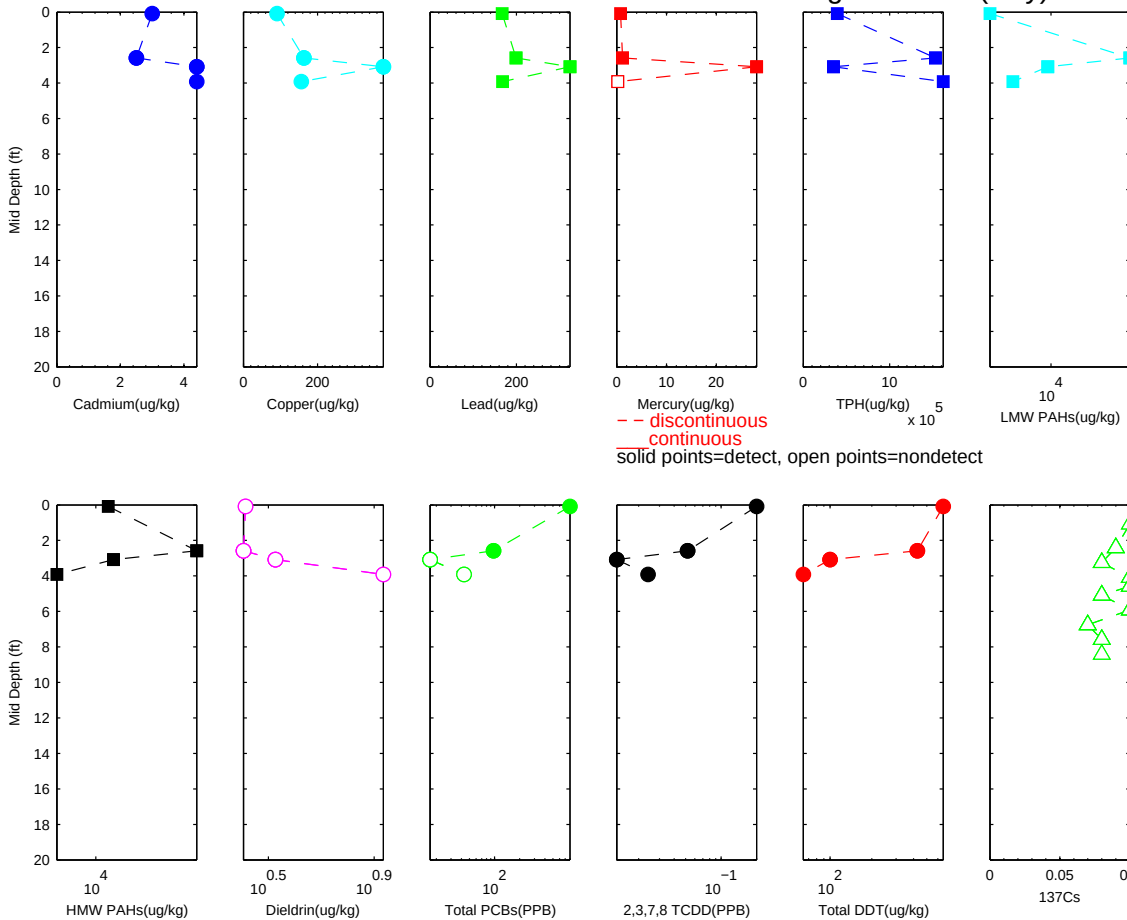
R2-0026971

Sample ID: 96A River Mile 1.1 PASSAIC 1993 Core Sediment Investigation − 02 (July)



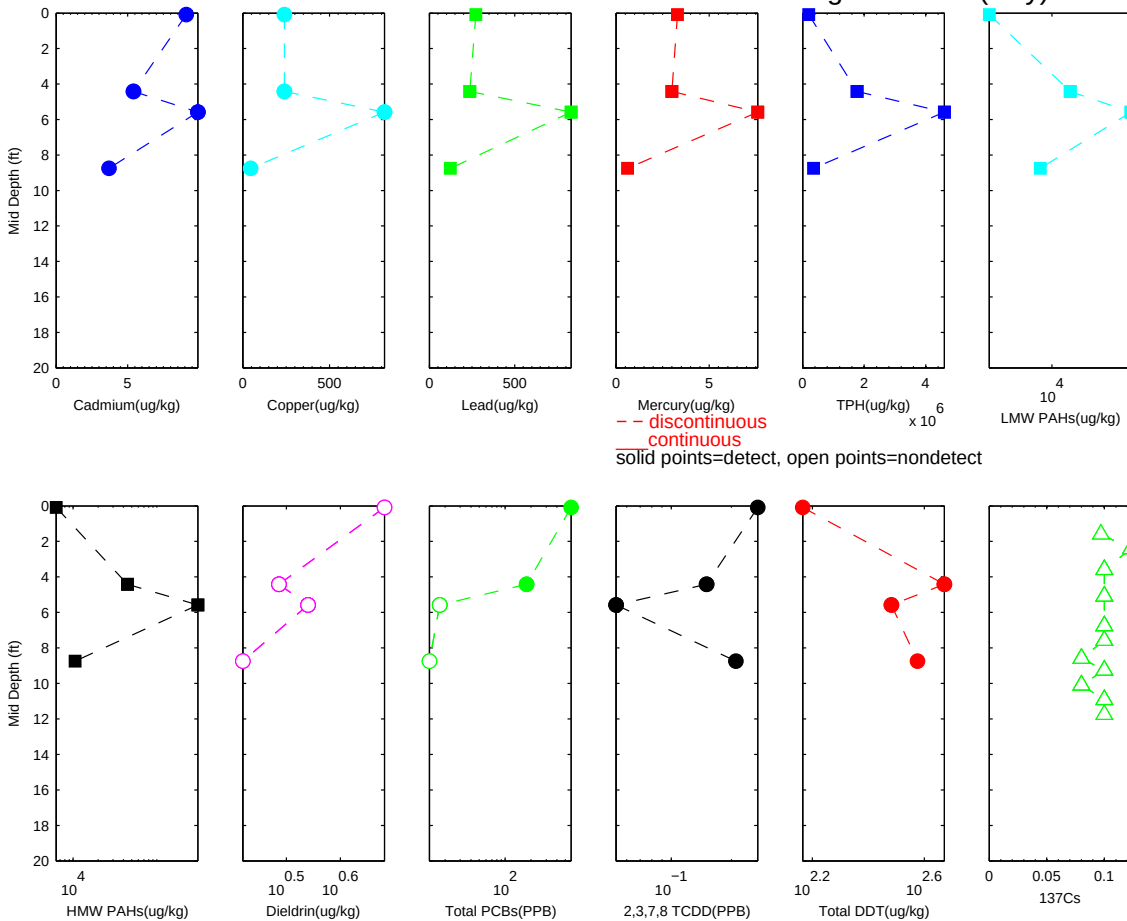
R2-0026972

Sample ID: 95A River Mile 2.3 PASSAIC 1993 Core Sediment Investigation − 02 (July)



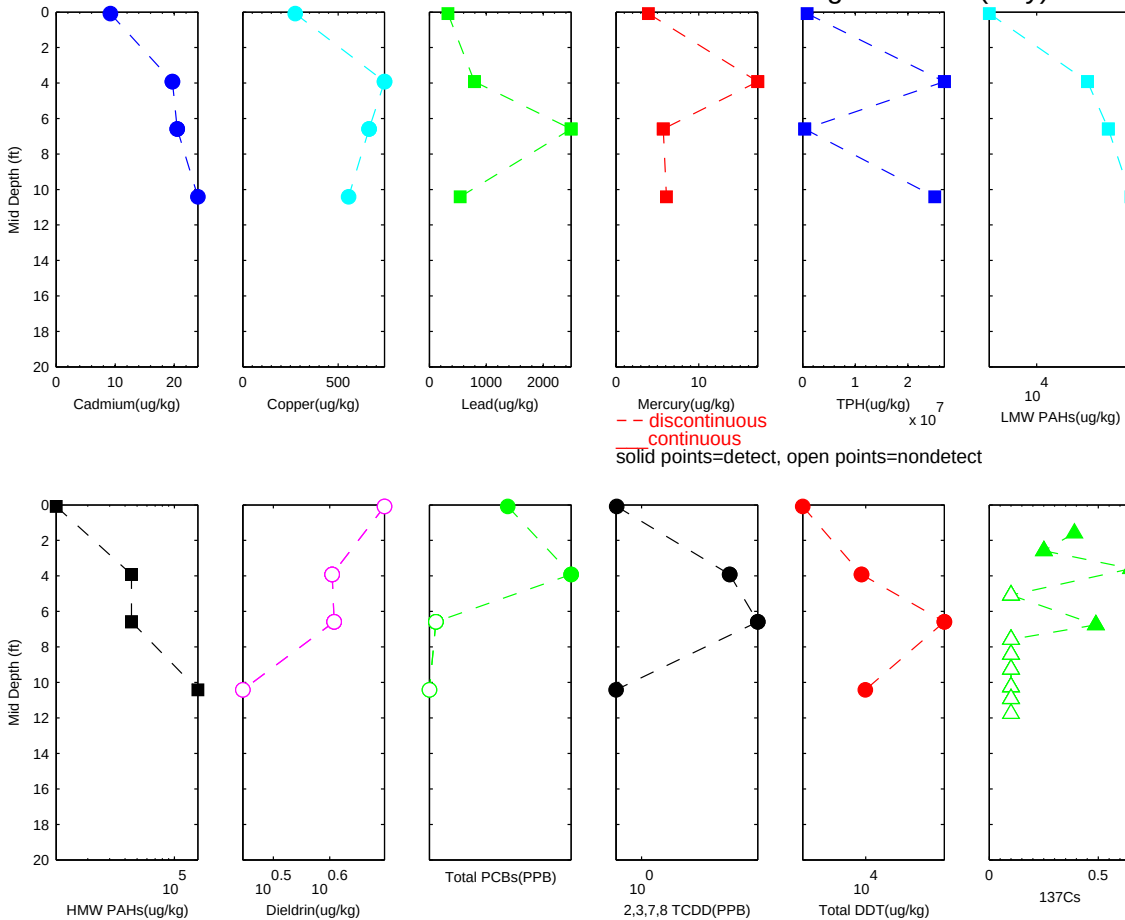
R2-0026973

Sample ID: 94A River Mile 2.91PASSAIC 1993 Core Sediment Investigation − 02 (July)



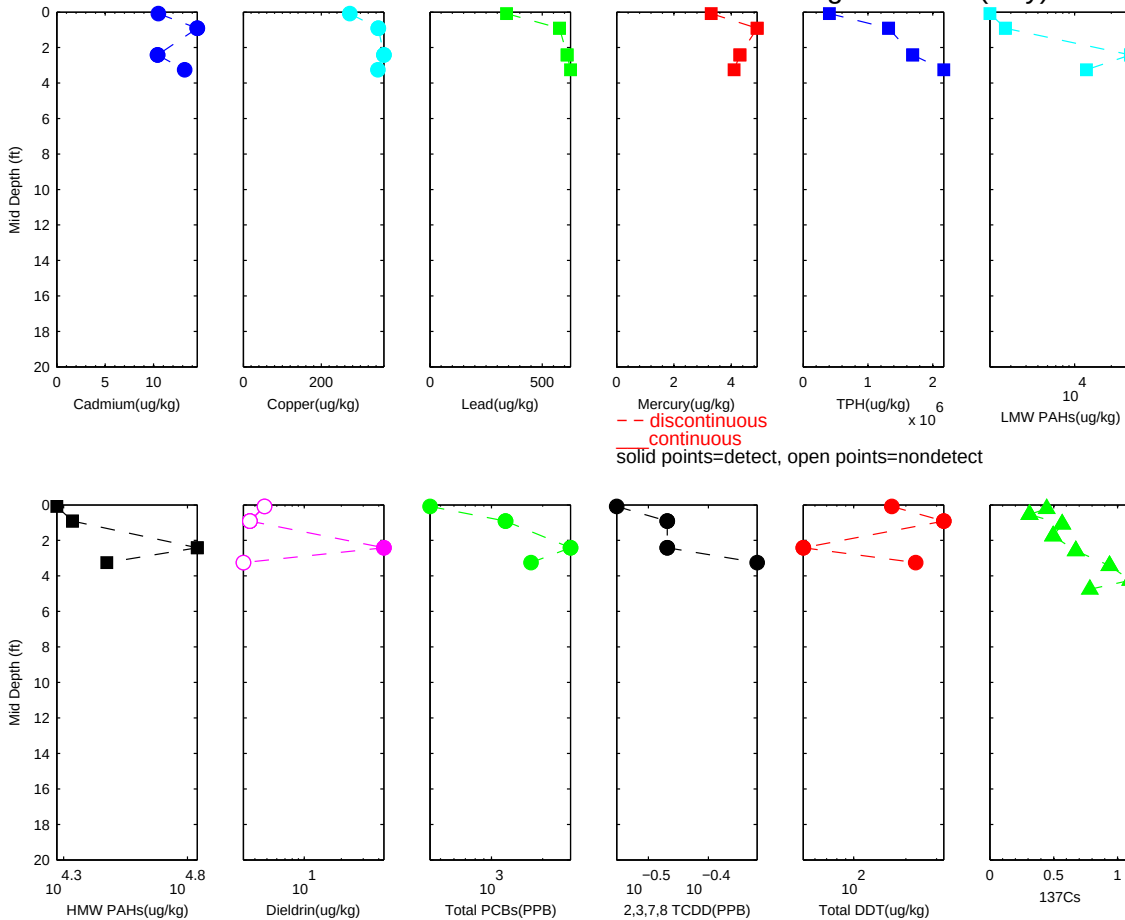
R2-0026974

Sample ID: 93A River Mile 2.86 PASSAIC 1993 Core Sediment Investigation − 02 (July)



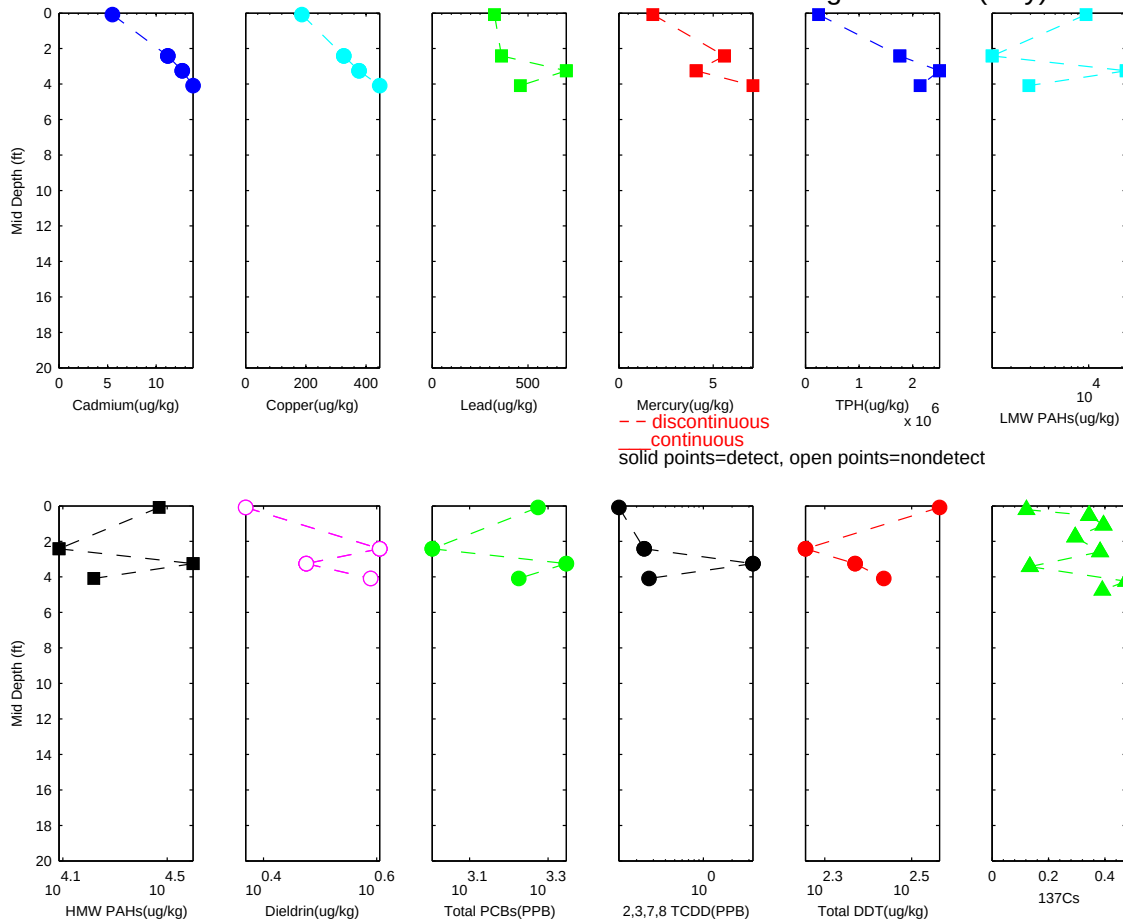
R2-0026975

Sample ID: 92A River Mile 1.66 PASSAIC 1993 Core Sediment Investigation − 02 (July)



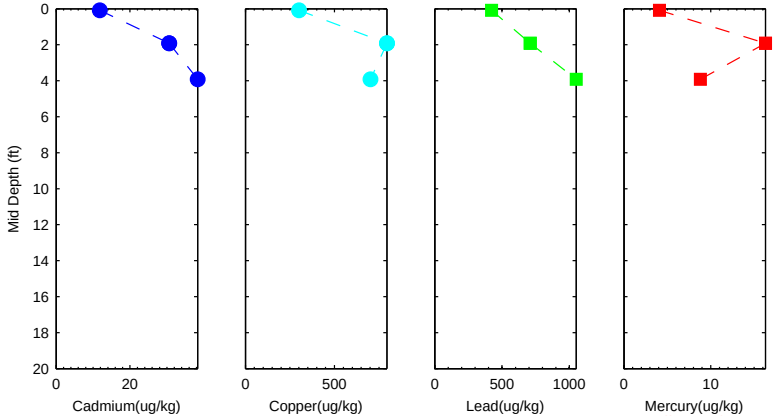
R2-0026976

Sample ID: 91A River Mile 1.89 PASSAIC 1993 Core Sediment Investigation − 02 (July)

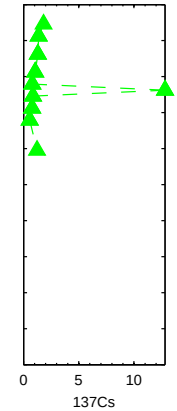


R2-0026977

Sample ID: 90A River Mile 6.94PASSAIC 1993 Core Sediment Investigation − 02 (July)



− − discontinuous
___ continuous
solid points=detect, open points=nondetect



R2-0026978

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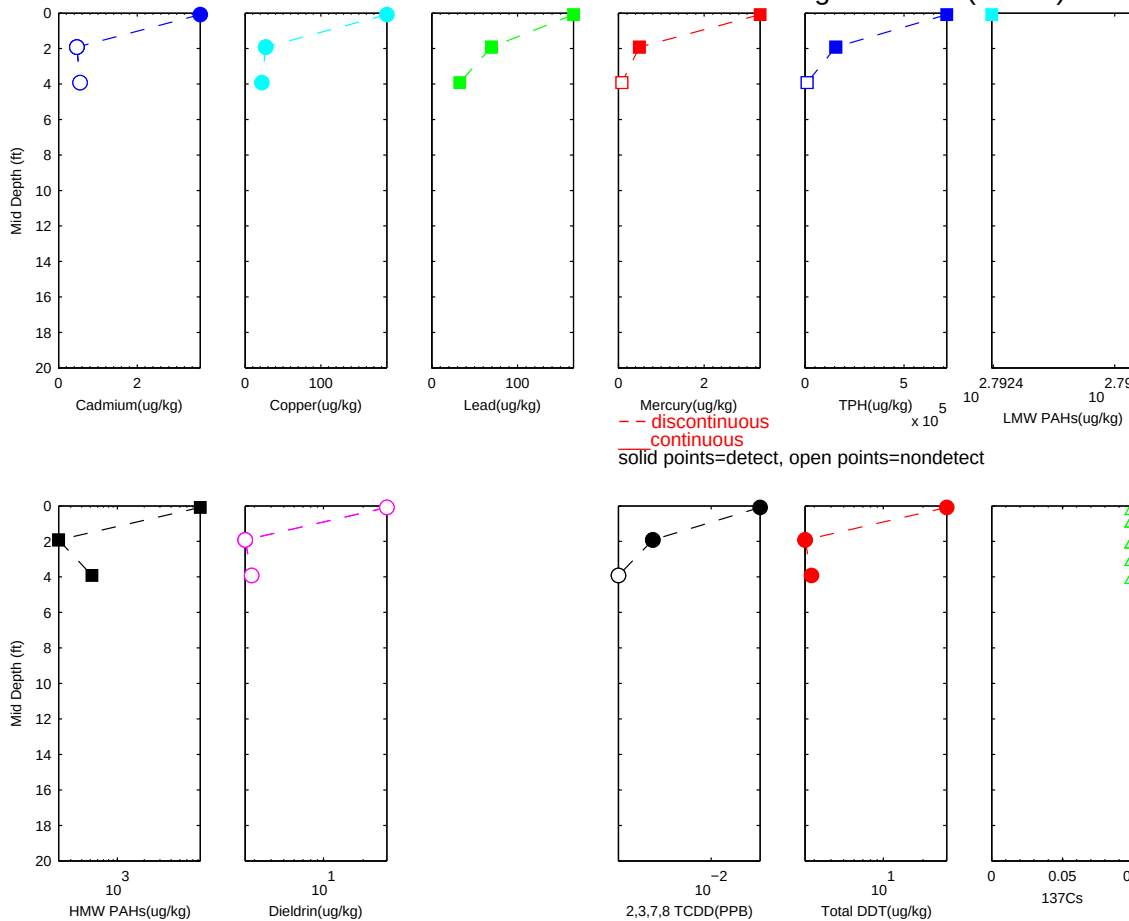
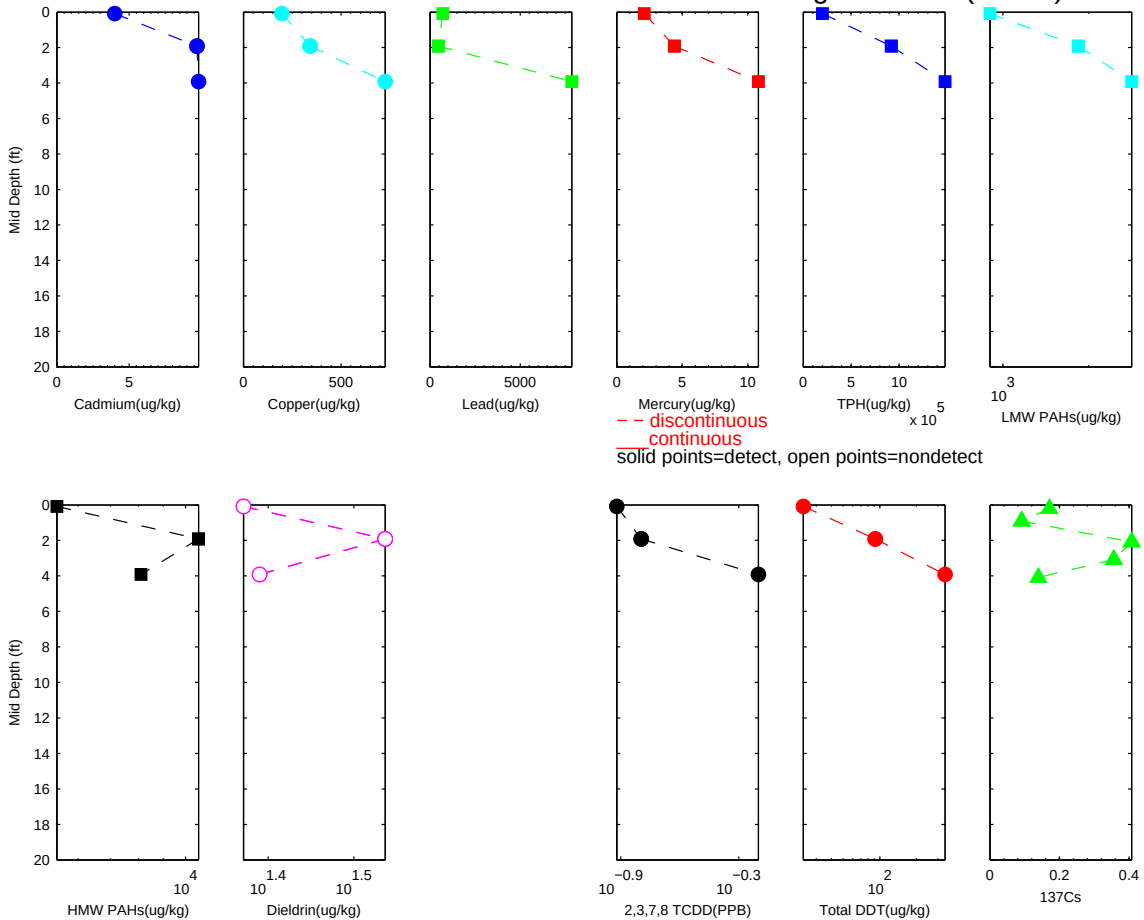


R2-0026979

Sample ID: 81A River Mile 0.3 PASSAIC 1993 Core Sediment Investigation − 01 (March)



R2-0026980

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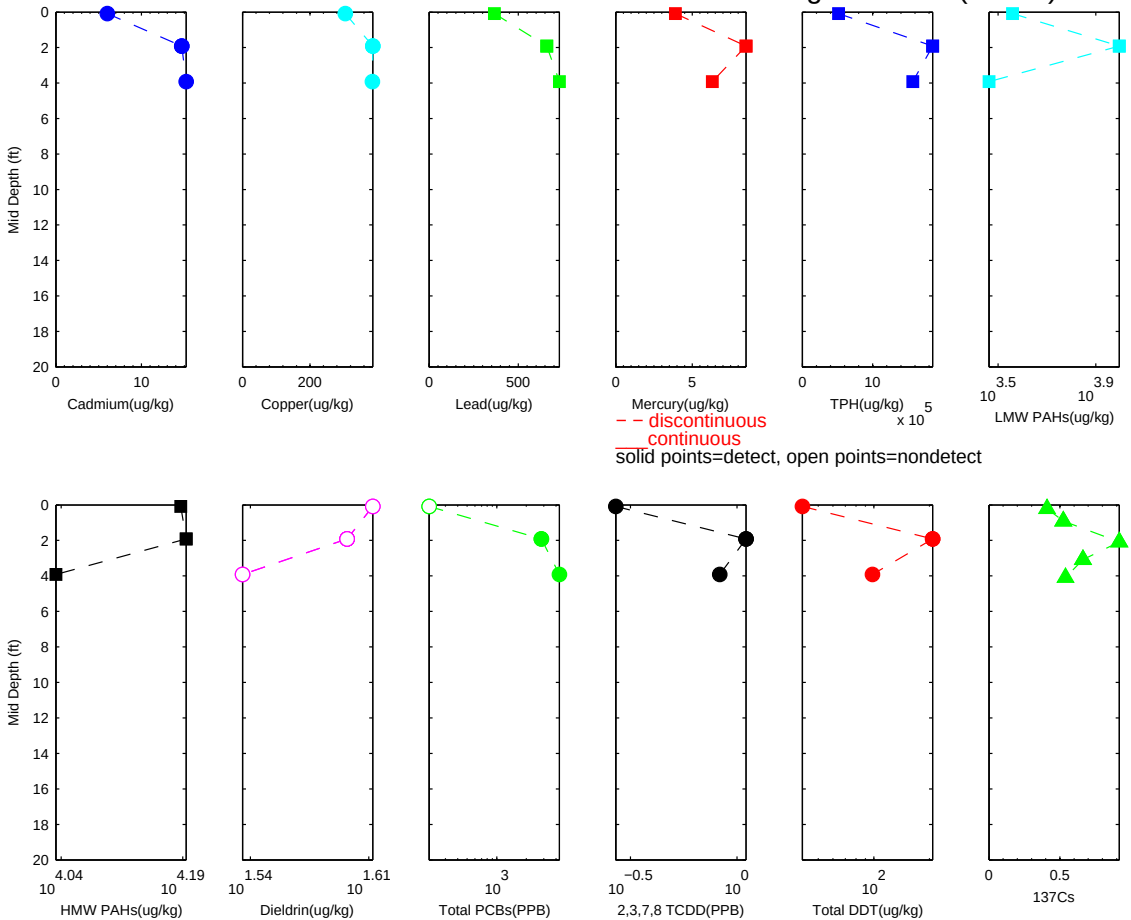
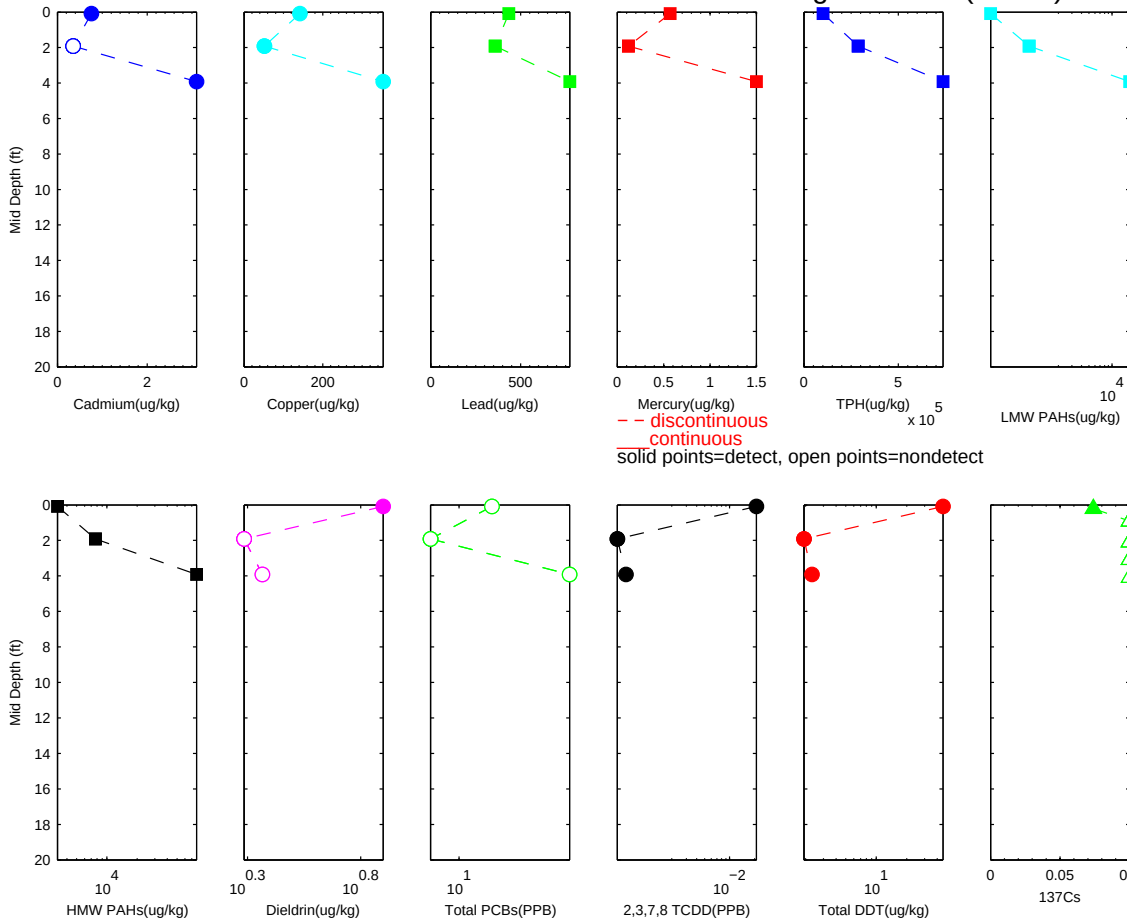


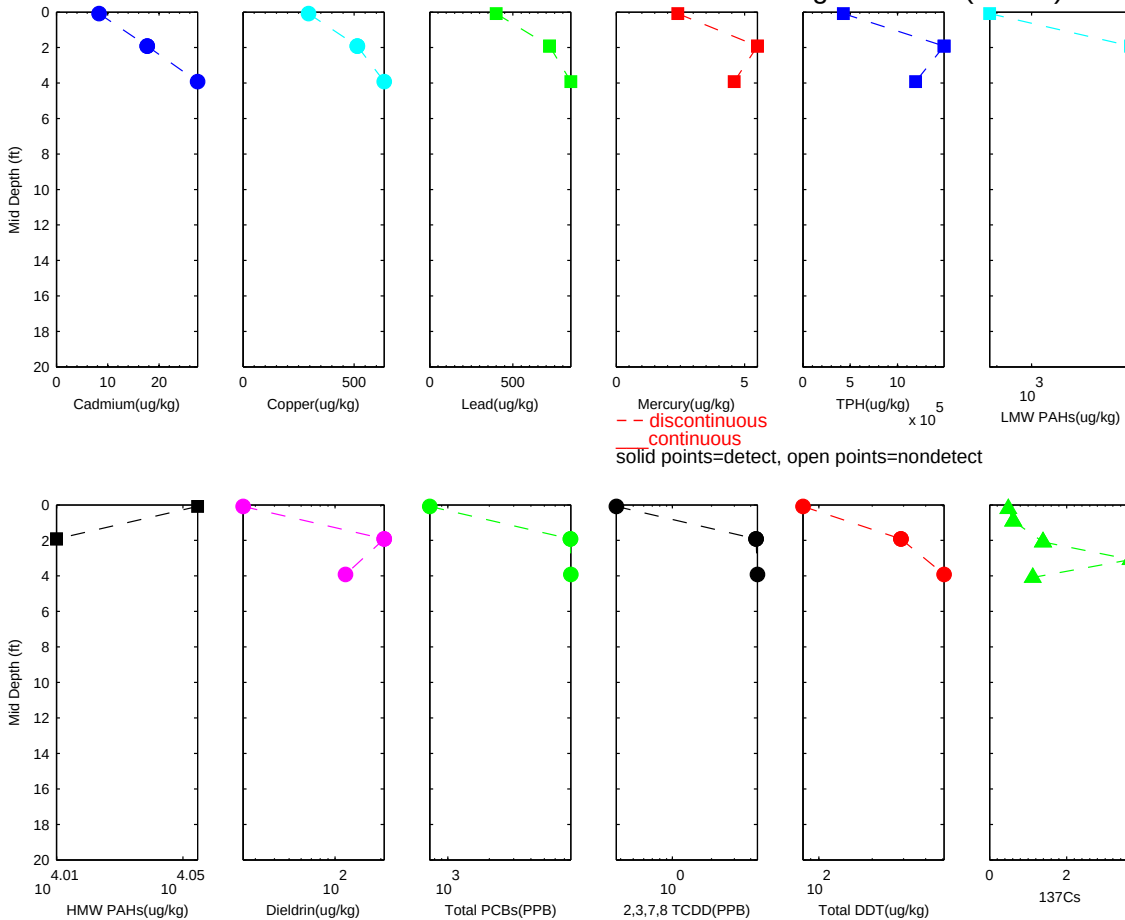
R2-0026981

Sample ID: 76A River Mile 6.92 PASSAIC 1993 Core Sediment Investigation − 01 (March)



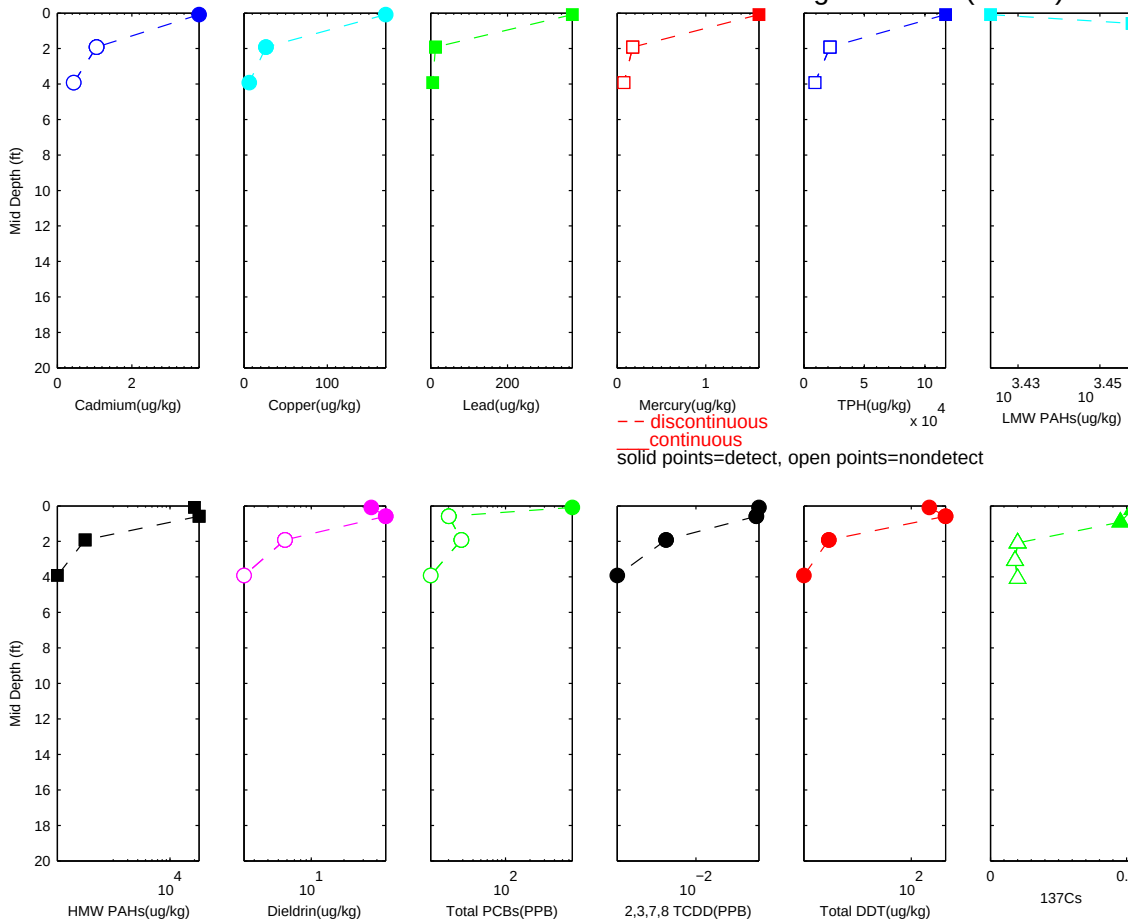
R2-0026982

Sample ID: 75A River Mile 6.94 PASSAIC 1993 Core Sediment Investigation − 01 (March)



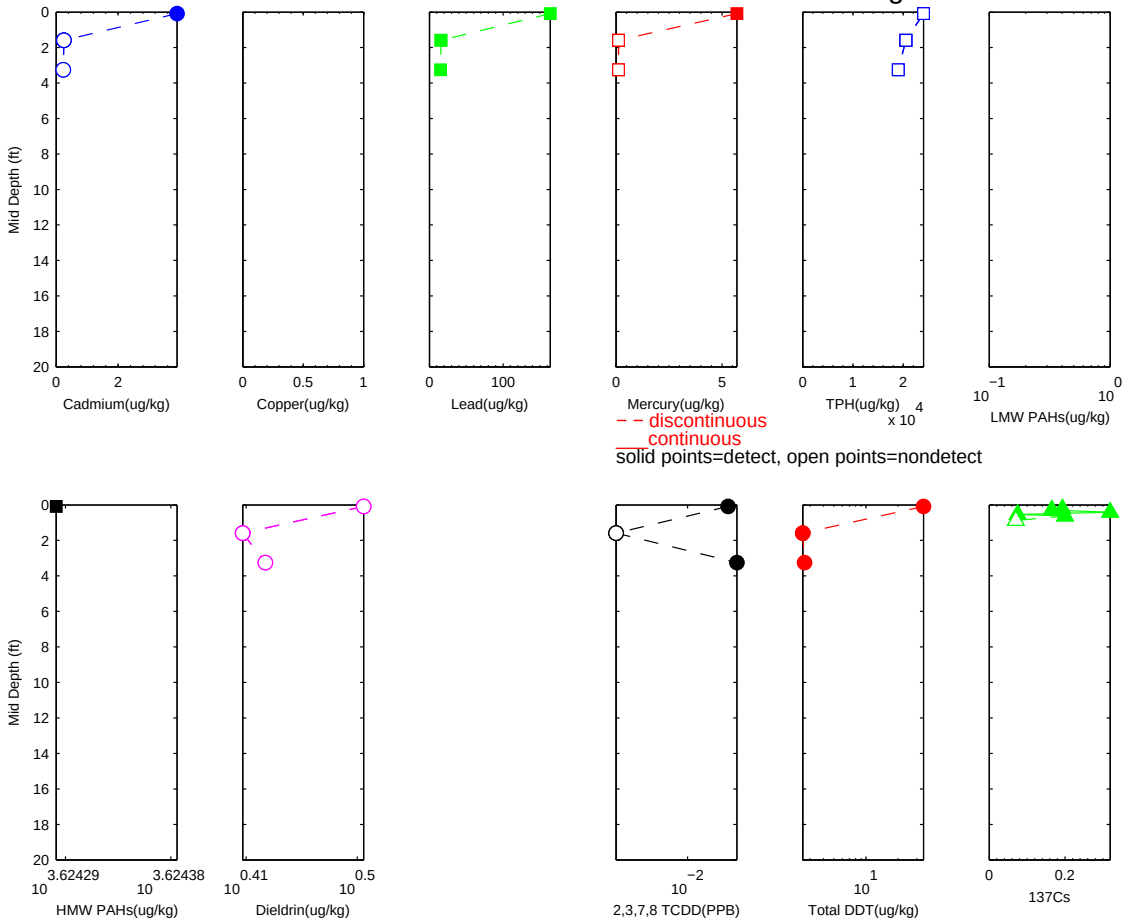
R2-0026983

Sample ID: 74A River Mile 11.16 PASSAIC 1993 Core Sediment Investigation − 01 (March)



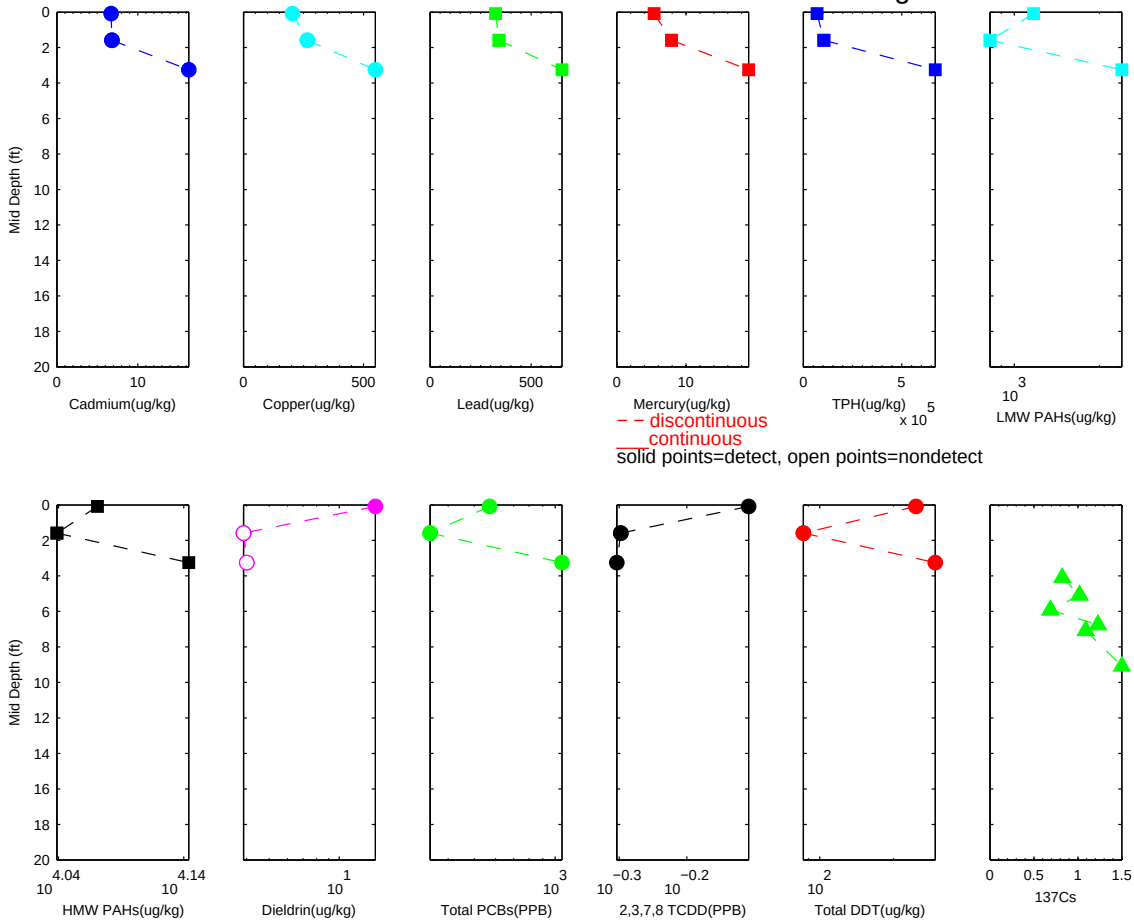
R2-0026984

Sample ID: 26A River Mile 0.21 PASSAIC 1991 Core Sediment Investigation



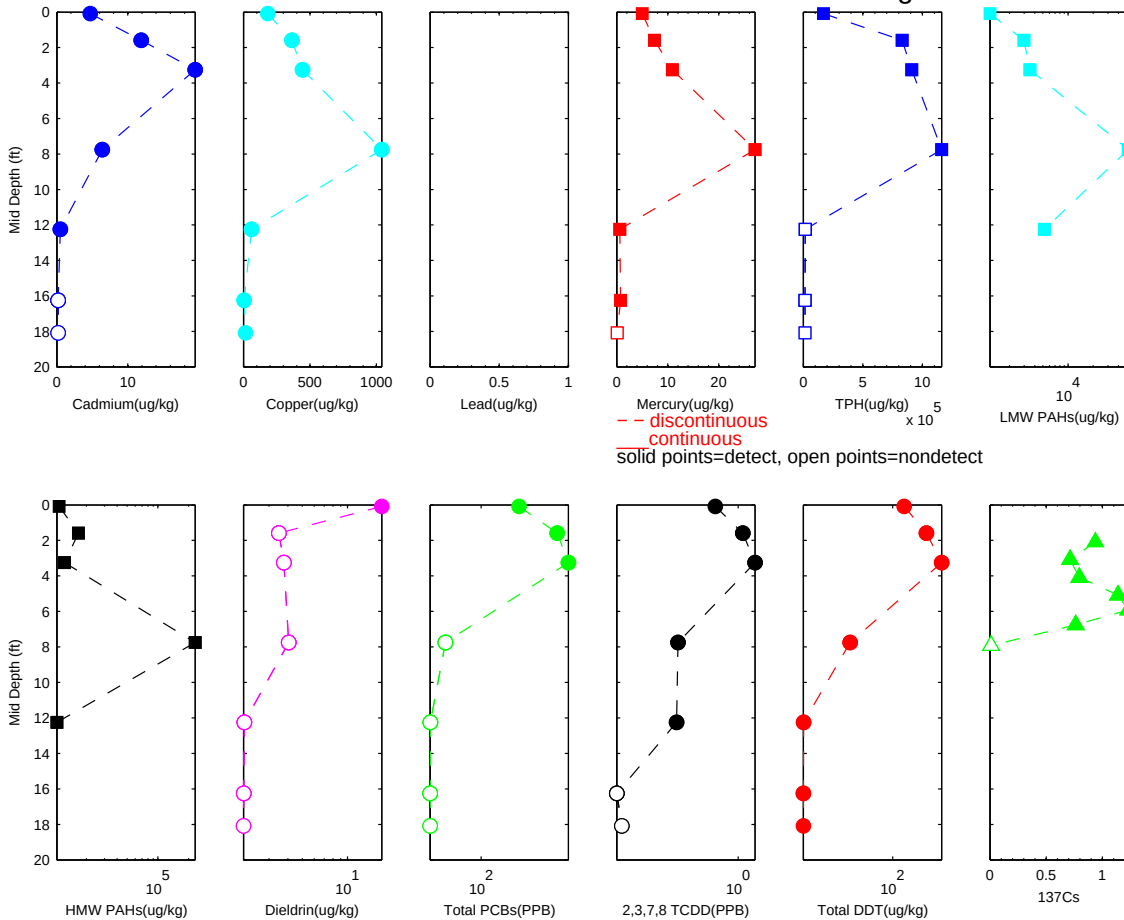
R2-0026985

Sample ID: 23A River Mile 2.02 PASSAIC 1991 Core Sediment Investigation



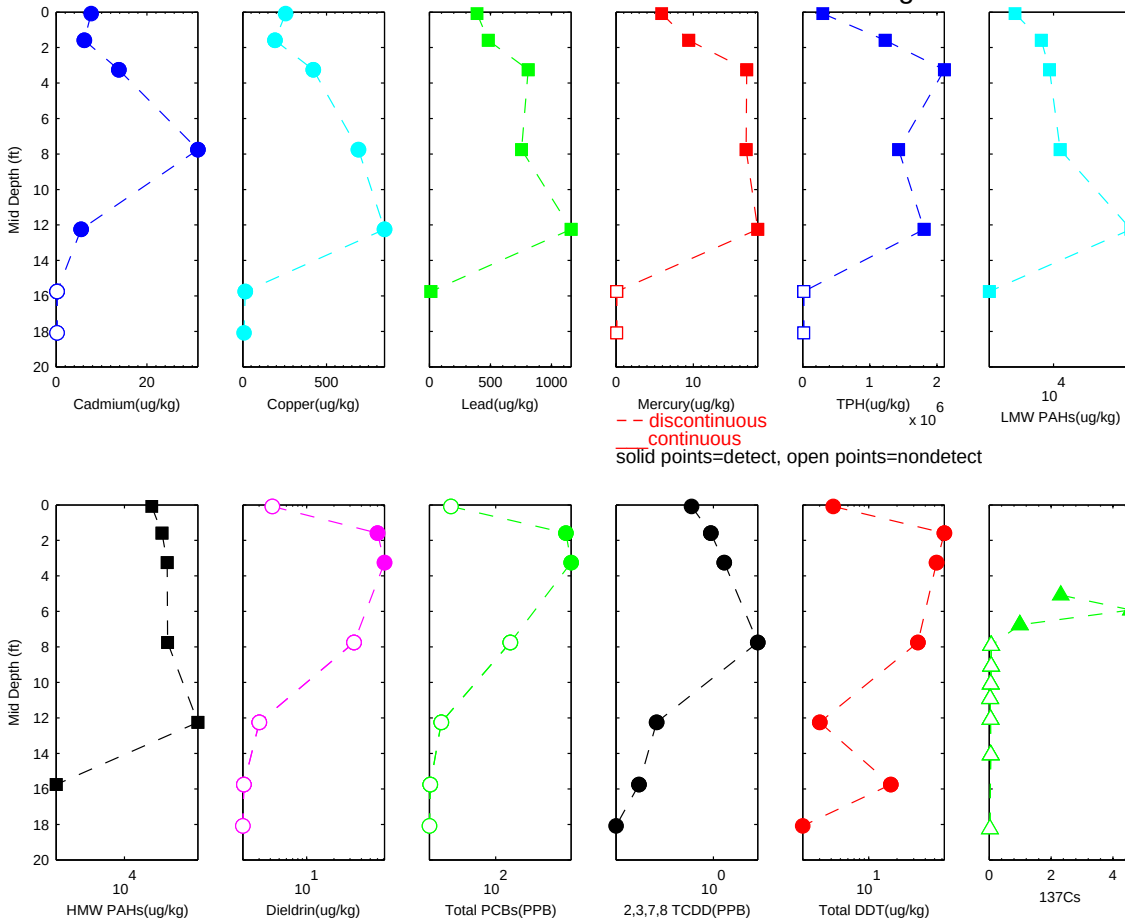
R2-0026986

Sample ID: 22A River Mile 2.39 PASSAIC 1991 Core Sediment Investigation



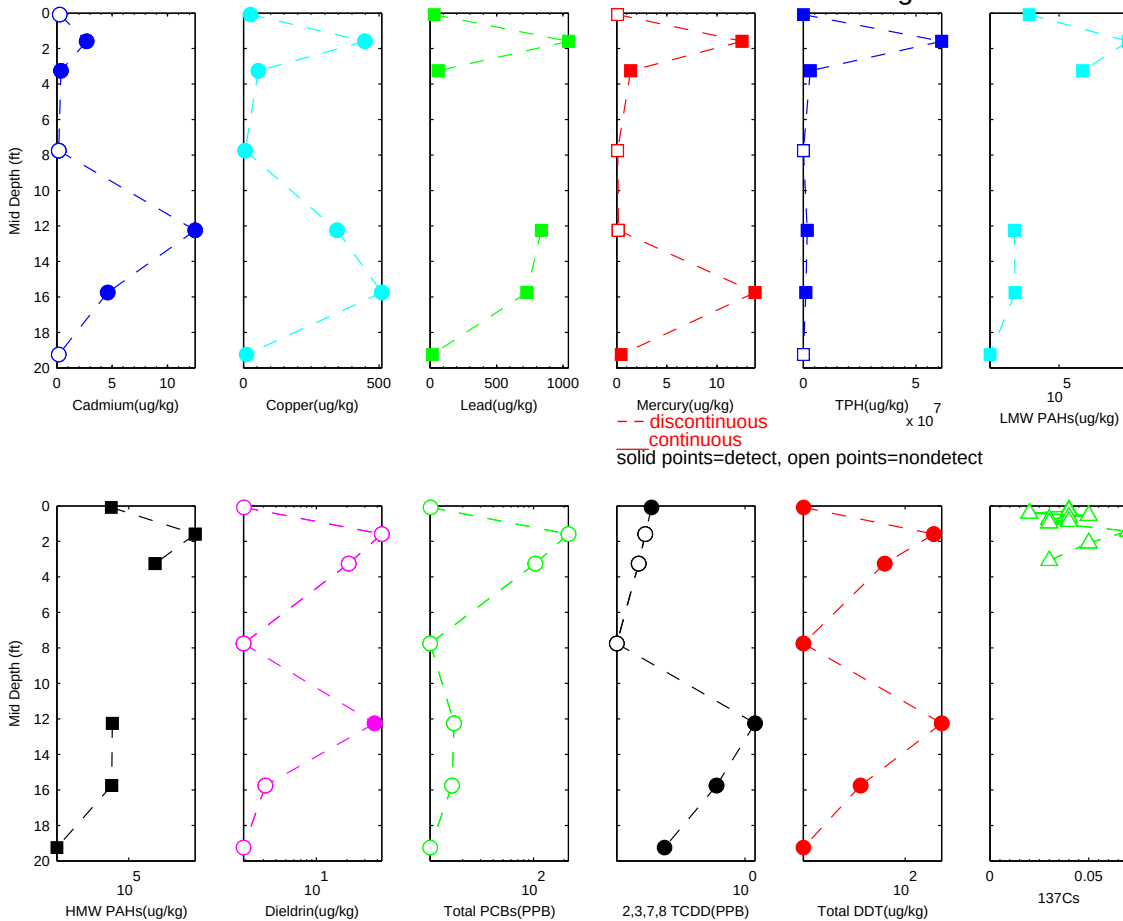
R2-0026987

Sample ID: 21A River Mile 3.01 PASSAIC 1991 Core Sediment Investigation



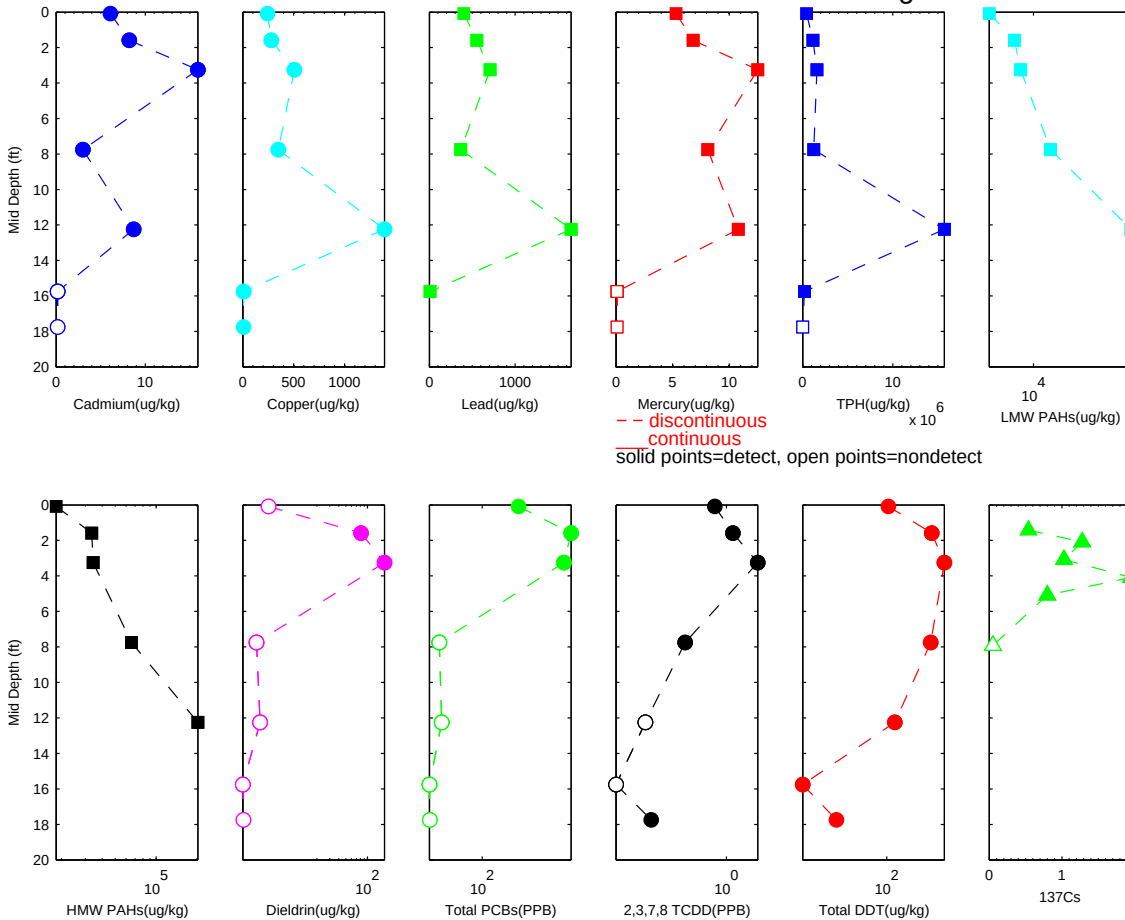
R2-0026988

Sample ID: 20A River Mile 3.05 PASSAIC 1991 Core Sediment Investigation



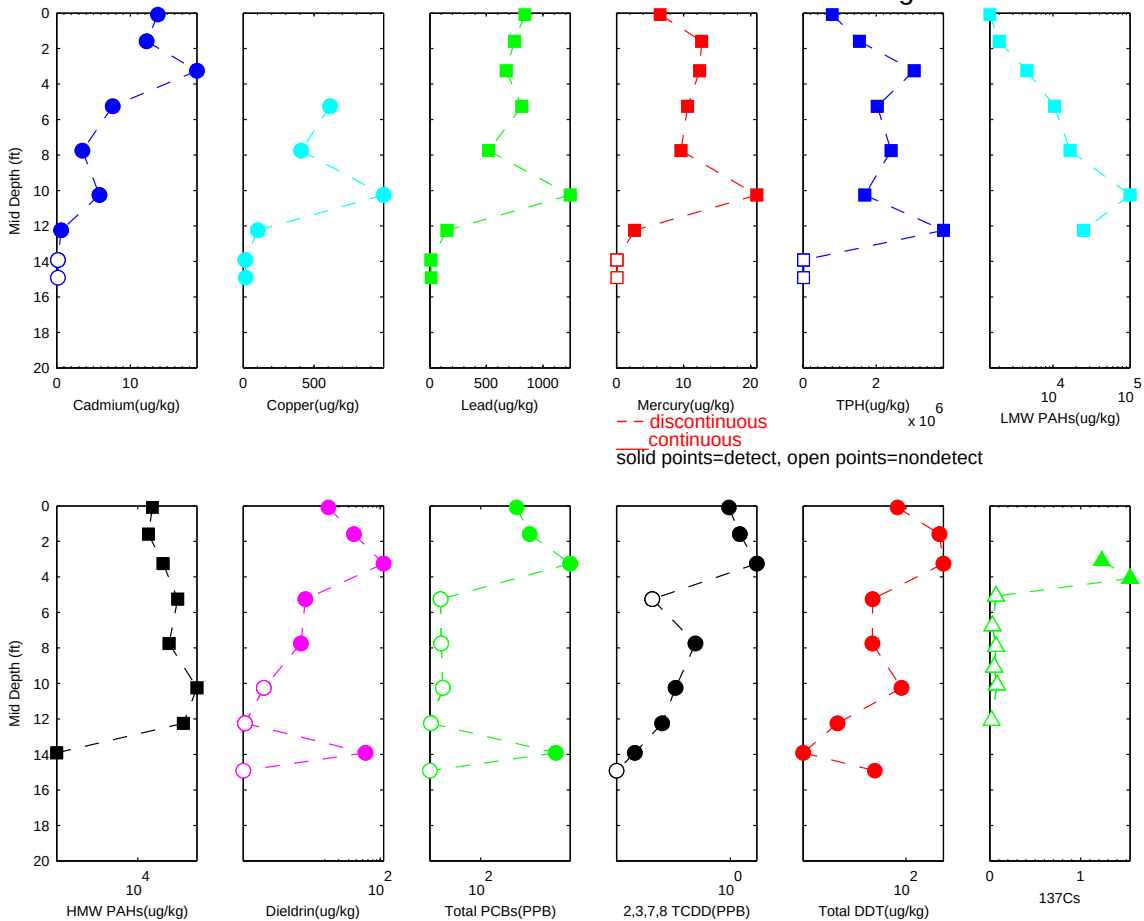
R2-0026989

Sample ID: 19A River Mile 3.09 PASSAIC 1991 Core Sediment Investigation



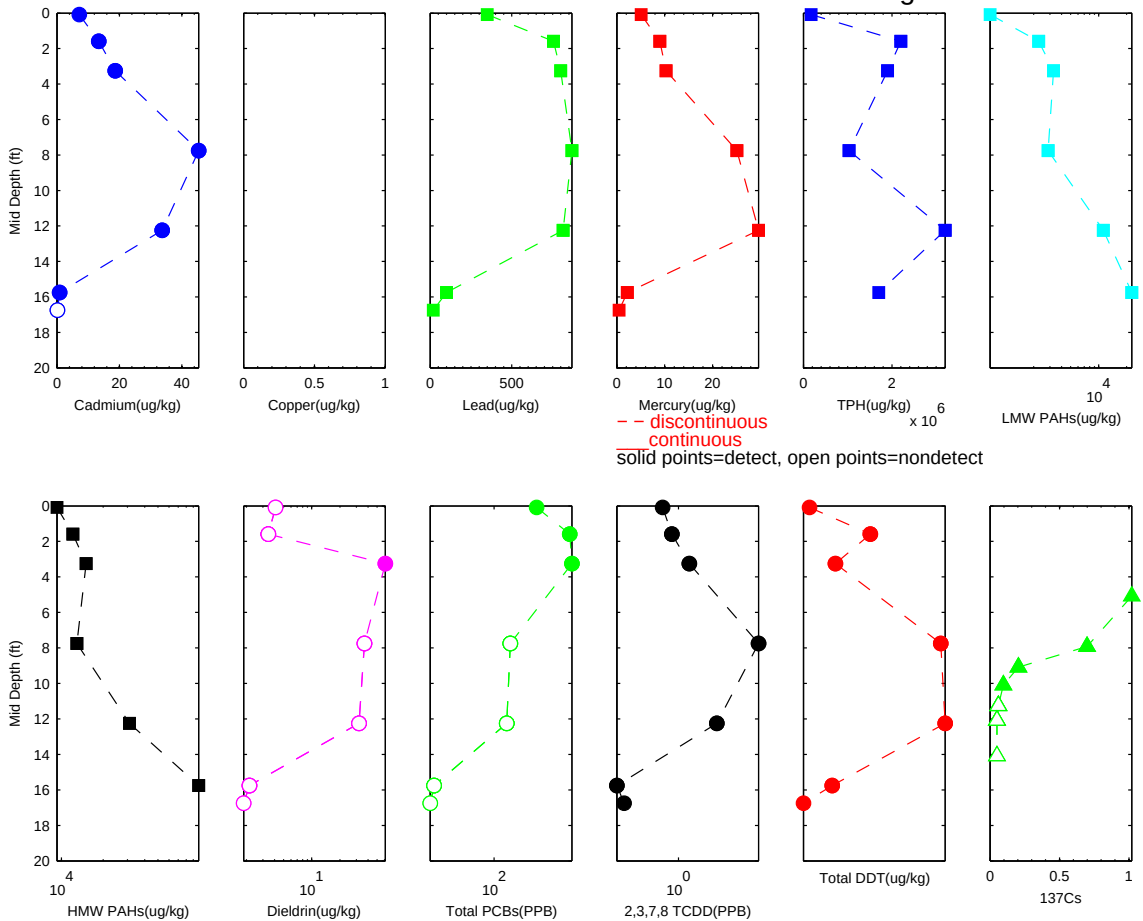
R2-0026990

Sample ID: 18A River Mile 3.14 PASSAIC 1991 Core Sediment Investigation



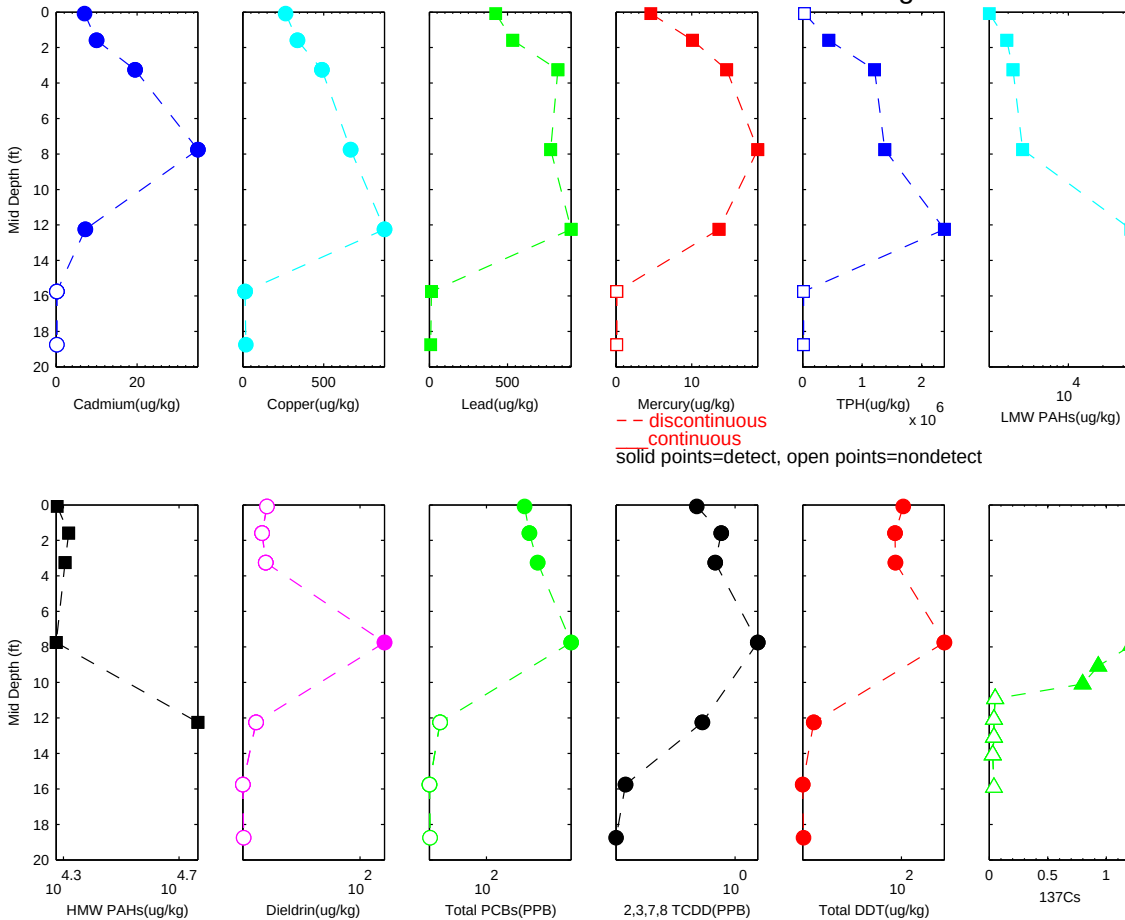
R2-0026991

Sample ID: 17A River Mile 3.25 PASSAIC 1991 Core Sediment Investigation



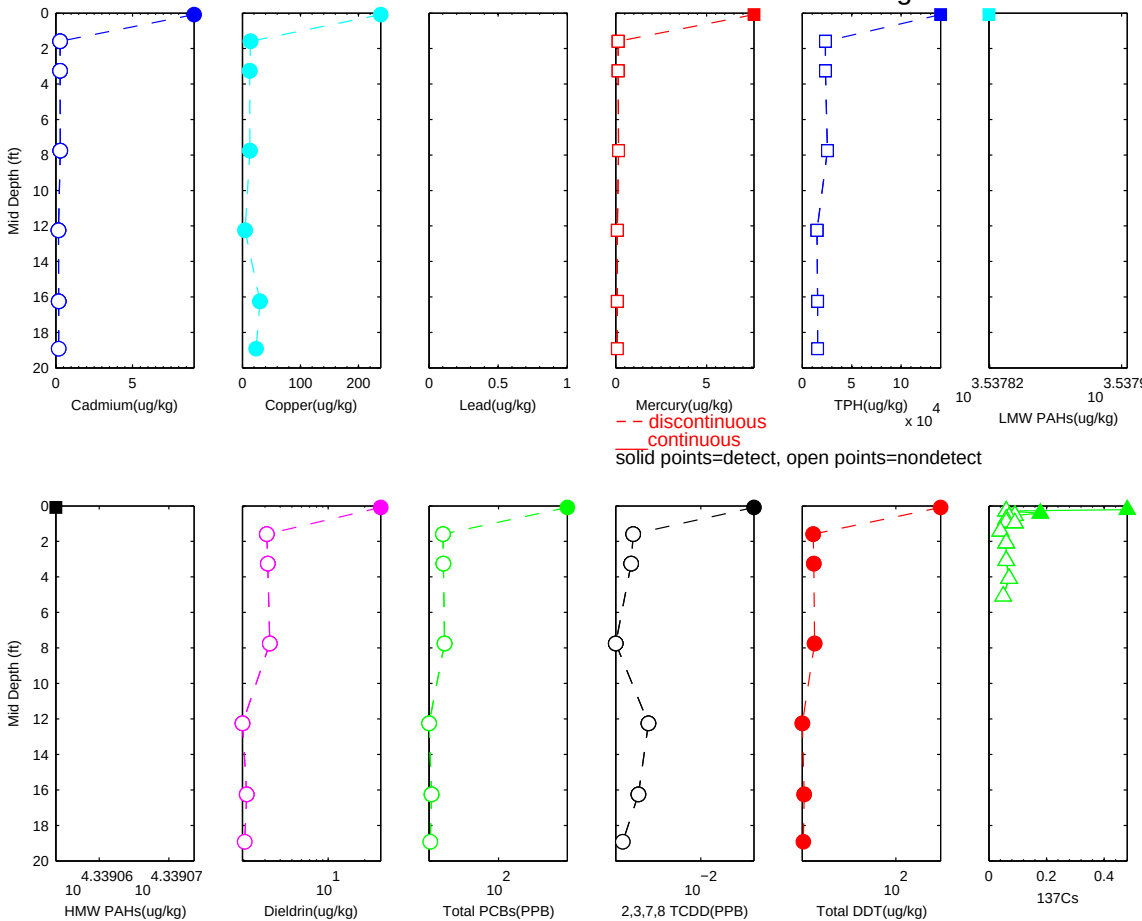
R2-0026992

Sample ID: 16A River Mile 3.36 PASSAIC 1991 Core Sediment Investigation



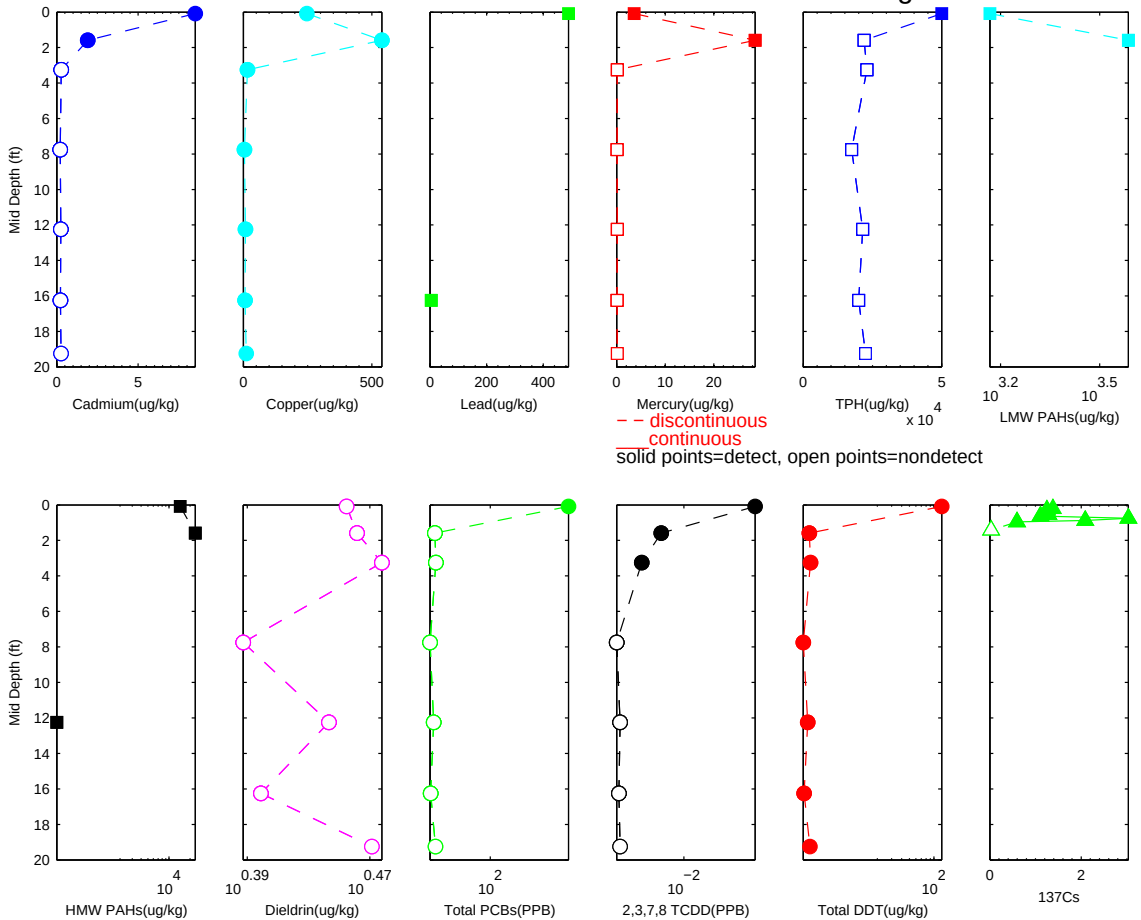
R2-0026993

Sample ID: 15A River Mile 3.55 PASSAIC 1991 Core Sediment Investigation



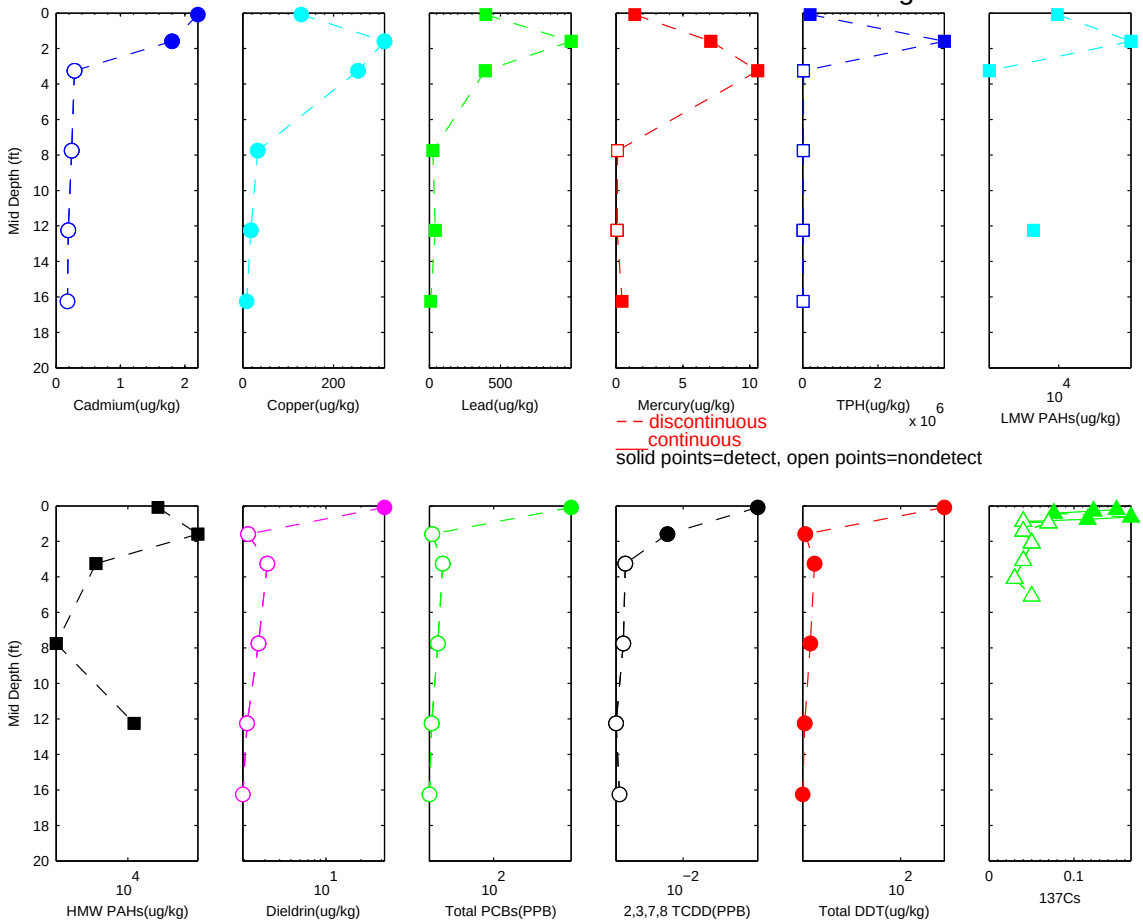
R2-0026994

Sample ID: 14A River Mile 4.2 PASSAIC 1991 Core Sediment Investigation



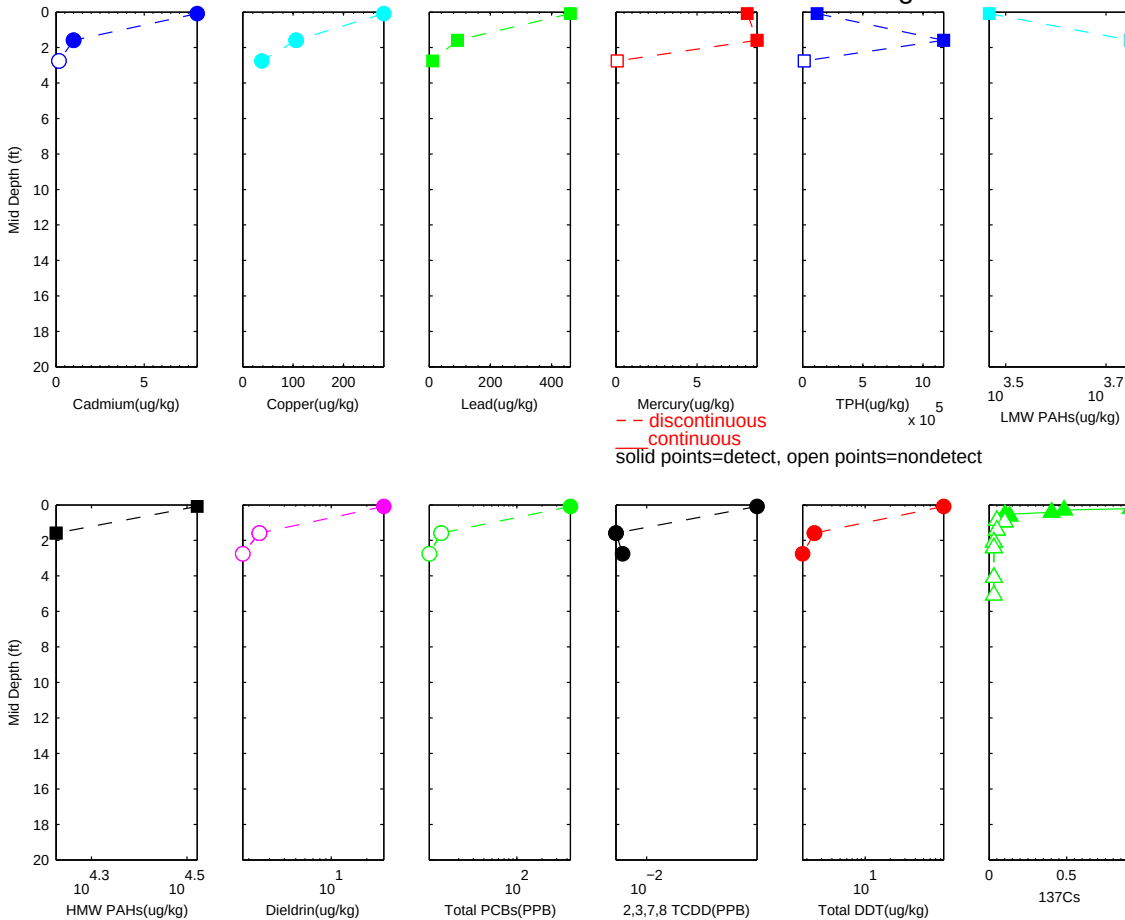
R2-0026995

Sample ID: 13A River Mile 3.97 PASSAIC 1991 Core Sediment Investigation



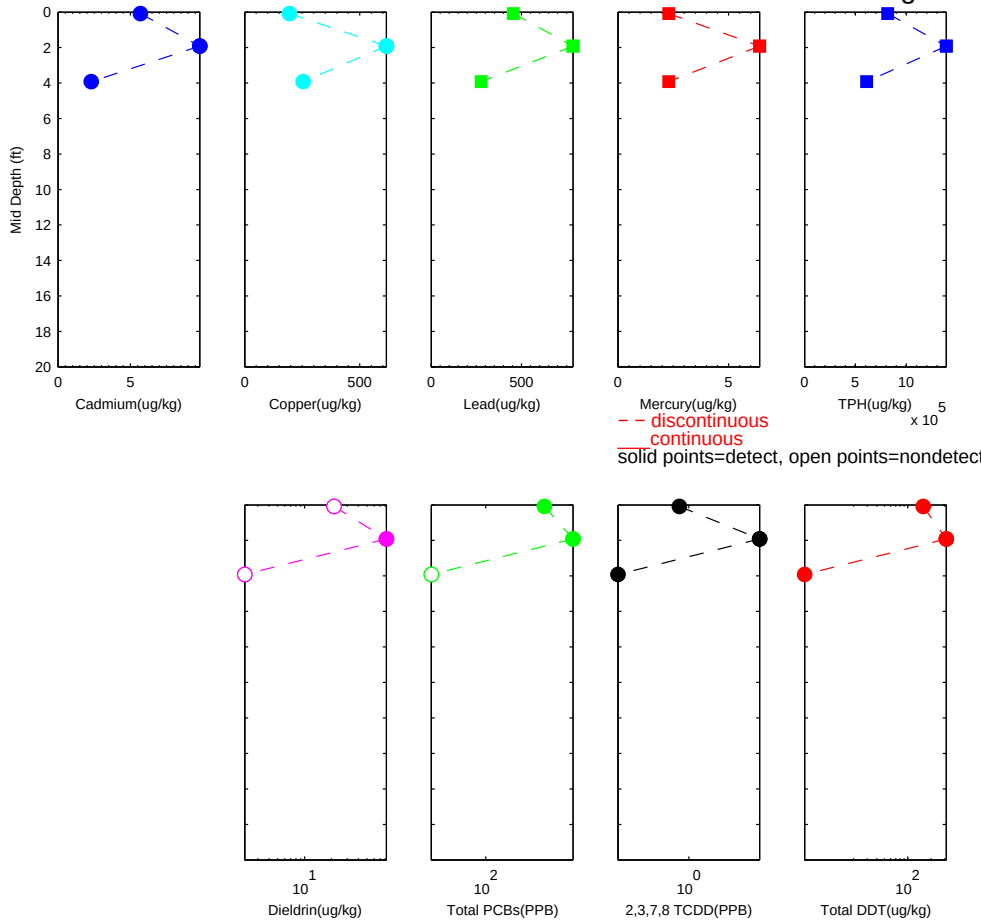
R2-0026996

Sample ID: 12A River Mile 4.87 PASSAIC 1991 Core Sediment Investigation



R2-0026997

Sample ID: 10A River Mile 6.91 PASSAIC 1991 Core Sediment Investigation



R2-0026998

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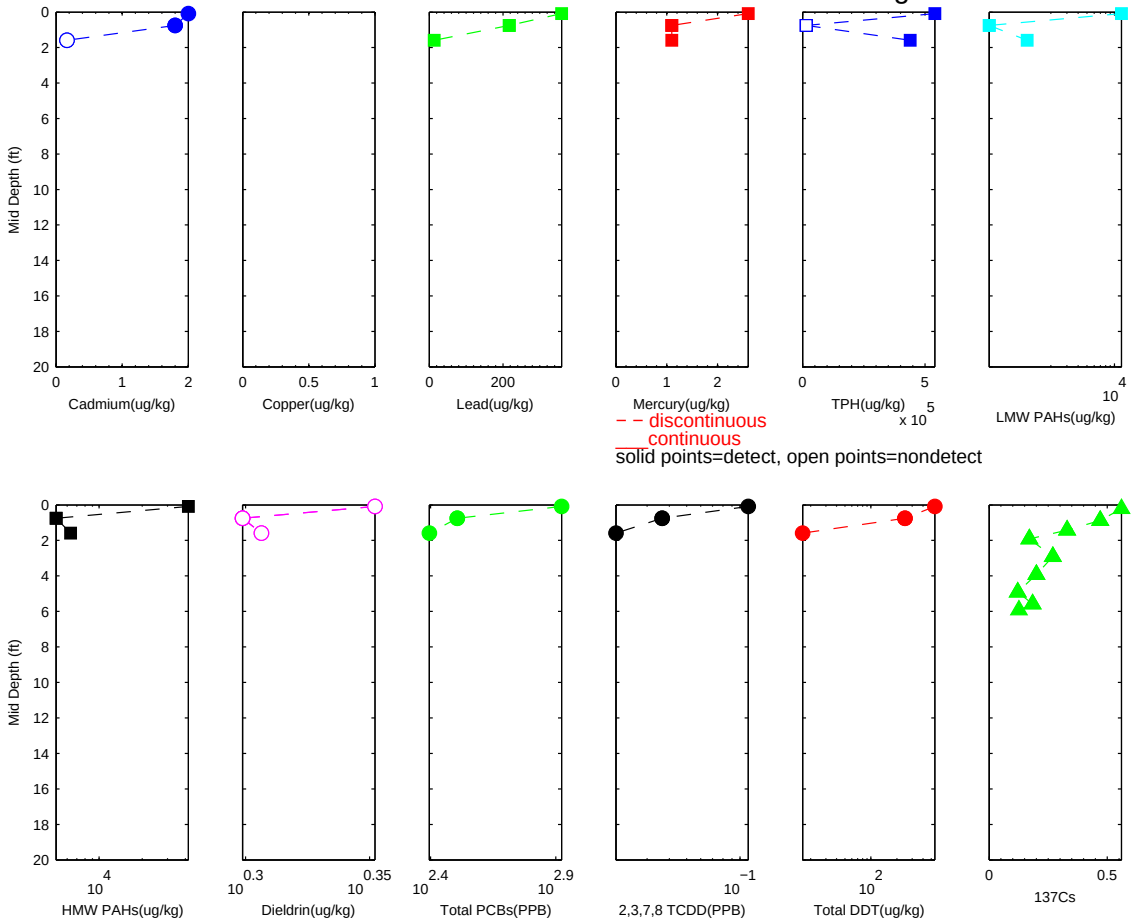

R2-0026999

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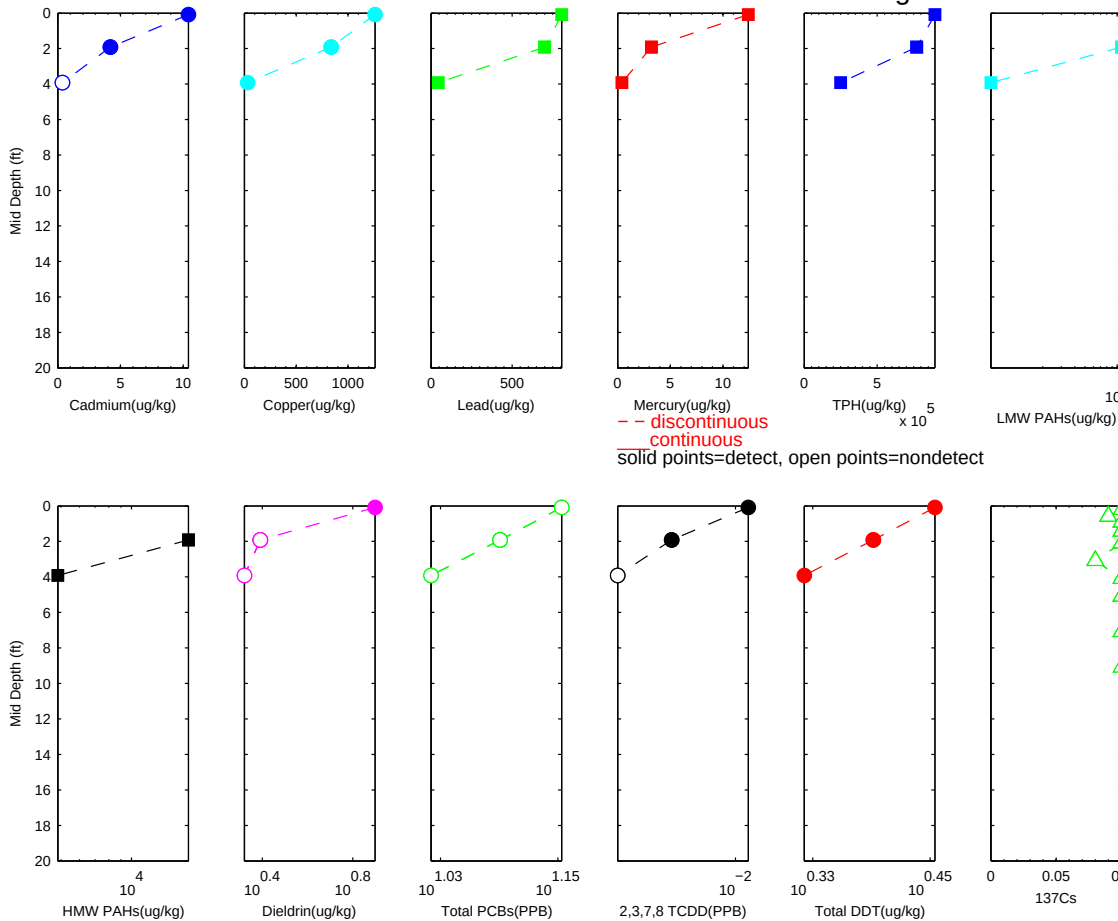

R2-0027000

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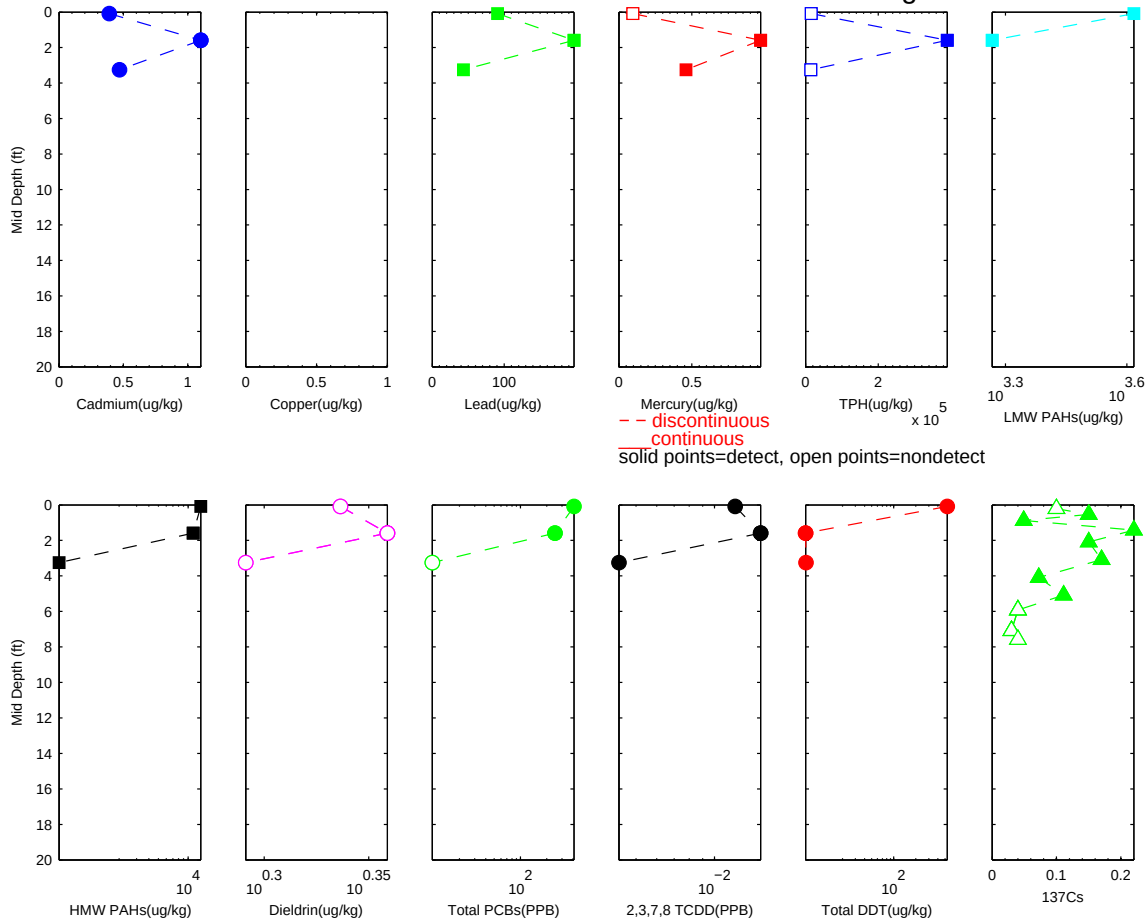
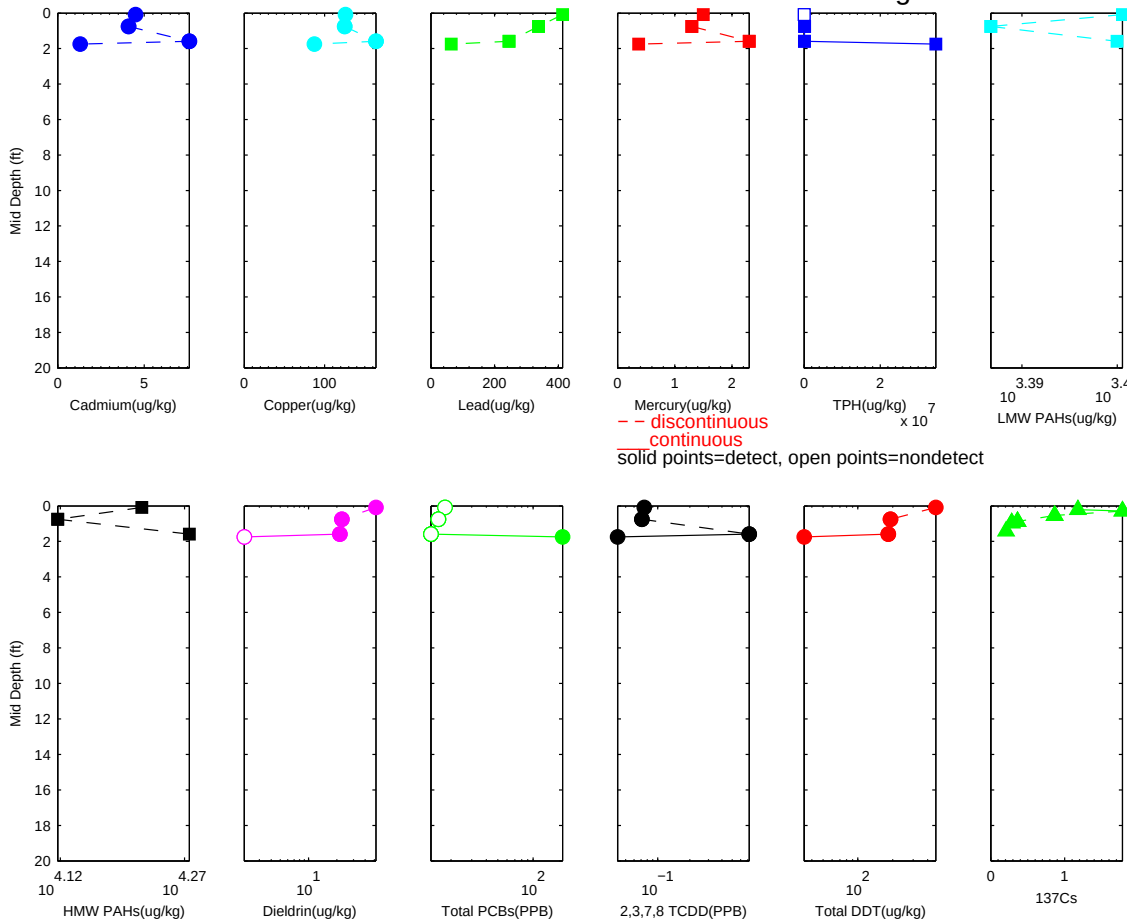


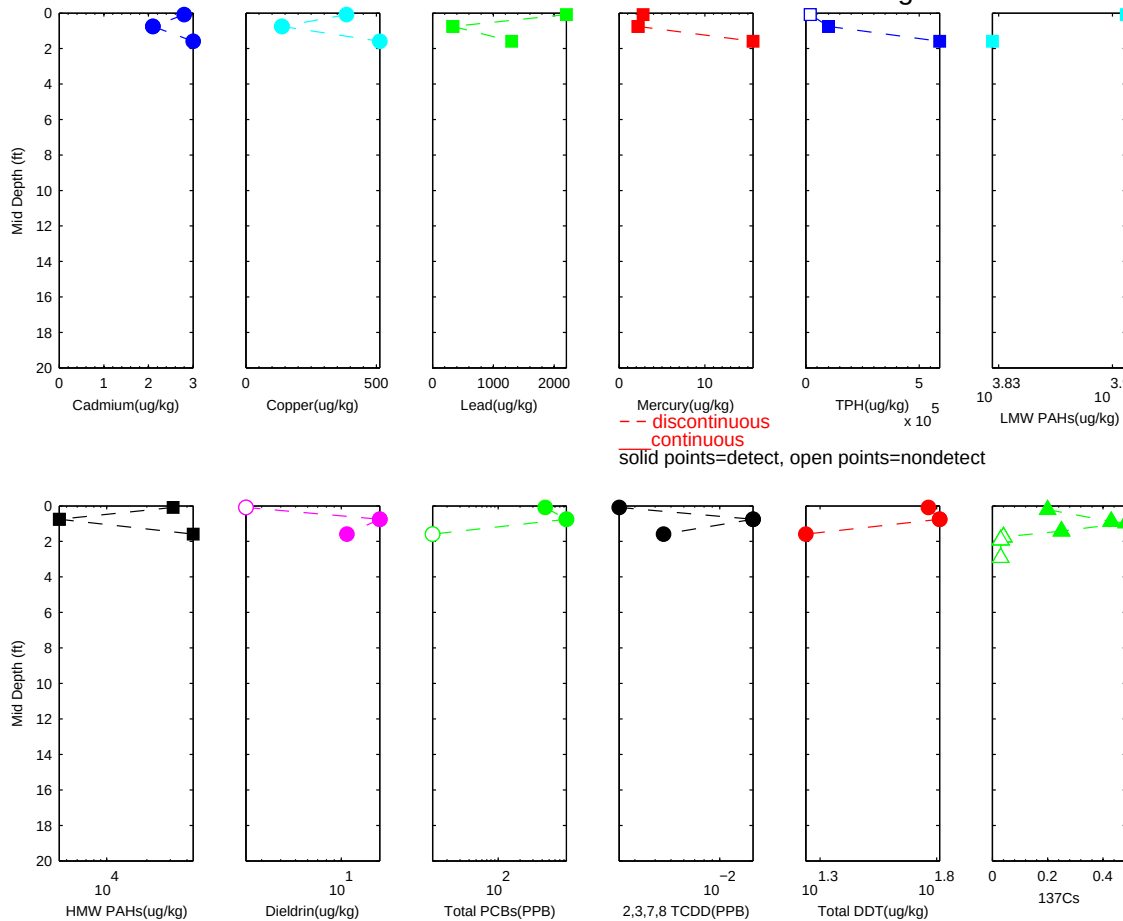
R2-0027001

Sample ID: 05B River Mile 11.19 PASSAIC 1991 Core Sediment Investigation



R2-0027002

Sample ID: 02A River Mile 16.95 PASSAIC 1991 Core Sediment Investigation



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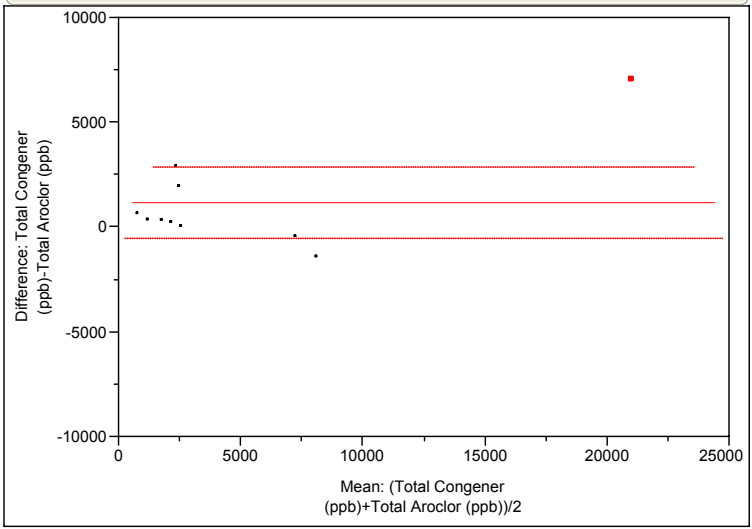
Attachment B

Statistical Analysis Relating Total PCB Concentrations by Aroclor and PCB Congener Methods

Aroclor-Congener Comparison

Matched Pairs 2008 Low Resolution Core Comparison: Aroclor vs Congener

Difference: Total Congener (ppb)-Total Aroclor (ppb)



Total Congener (ppb)	5521.3	t-Ratio	1.53572
Total Aroclor (ppb)	4366.4	DF	9
Mean Difference	1154.9	Prob > |t|	0.1590
Std Error	752.025	Prob > t	0.0795
Upper95%	2856.1	Prob < t	0.9205
Lower95%	-546.3		
N	10		
Correlation	0.95881		

Wilcoxon Sign-Rank

	Total Congener (ppb)-Total Aroclor (ppb)
Test Statistic	15.500
Prob > |z|	0.131
Prob > z	0.065
Prob < z	0.935

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Data Evaluation Report No. 4:

“Surface Sediment Contamination”

LOWER EIGHT MILES OF THE LOWER PASSAIC RIVER DATA EVALUTION REPORT NO. 4: SURFACE SEDIMENT CONTAMINATION

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DATA EVALUTION REPORT NO. 4: SURFACE SEDIMENT CONTAMINATION

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LOWER EIGHT MILES OF THE LOWER PASSAIC RIVER DATA EVALUTION REPORT NO. 4: SURFACE SEDIMENT CONTAMINATION

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Attachment A	Tukey-Kramer Honestly Significant Difference (HSD) Statistical Test for CSOs and SWOs Suspended Matter Concentrations for CARP and 2007-2008 USEPA Data

1 INTRODUCTION

This document is part of a series of data evaluation reports, which were prepared to support the Remedial Investigation (RI) and Focused Feasibility Study (FFS). Reports in this series describe different aspects of the Lower Passaic River. Where necessary, data evaluation reports are cross-referenced to direct the reader to another report that contains further explanation. Topics discussed in this series include major sediment and water investigations conducted in the river, boundary conditions on the river, historical sediment contamination, surface sediment contamination, contaminant inventory calculations, and biota analysis. The following data evaluation report summarizes the observations of surface sediment contamination within the FFS Study Area and portions of Newark Bay, and describes major sampling programs conducted on the river.

1.1 Overview of the FFS Study Area

The FFS Study Area is located within the Lower Passaic River Study Area (LPRSA), which is the 17-mile, tidal portion of the Passaic River from Dundee Dam [located at River Mile (RM[1]) 17.4] to the confluence with Newark Bay at RM0 and the watershed of this river portion, including the Saddle River (RM15.6), Third River (RM11.3) and Second River (RM8.1) [Figure 1-1]. During a comprehensive study of the Lower Passaic River, the sediments of the lower eight miles were found to be a major source of contamination to the rest of the river and Newark Bay. Therefore, the United States Environmental Protection Agency (USEPA) completed the FFS to evaluate alternatives to address those sediments in the lower eight-mile stretch from RM0 to RM8.3, near the border between the City of Newark and Belleville Township. The entire 17-mile Lower Passaic River is the subject of another Remedial Investigation/Feasibility Study (RI/FS) being implemented by the Cooperating Parties Group (CPG; a group of approximately 70

[1] The FFS uses the "River Mile" (RM) system developed by the United States Army Corps of Engineers (USACE), which follows the navigation channel of the Lower Passaic River. The Data Evaluation Reports (Appendix A), Empirical Mass Balance (Appendix C) and Lower Passaic River-Newark Bay model (Appendix B) were initially developed at the beginning of the 17-mile Remedial Investigation and Feasibility Study (RI/FS), and thus follow a RM system developed for that RI/FS, which follows the geographic centerline of the river. RM0 is defined by an imaginary line between two marker lighthouses at the confluence of the Lower Passaic River and Newark Bay: one in Essex County just offshore of Newark and the other in Hudson County just offshore of Kearny Point. River miles then continue upriver to the Dundee Dam (RM17.4). The two RM systems are about 0.2 miles apart.

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potentially responsible parties who signed an agreement with USEPA in 2007), under USEPA oversight. The Upper Passaic River watershed (the portion of the Passaic River located above the Dundee Dam) contributes solids, water, and contaminants that cross over the head-of-tide, which is represented by the Dundee Dam[2], into the Lower Passaic River.

1.2 Overview of Lower Passaic River Surface Sediment Contamination

Surface sediment data for the FFS Study Area were available from various studies conducted on the river between 1991 and 2012. The list of sampling programs included in this report is presented in Table 1-1. The objective of this data evaluation report is to describe the spatial and temporal characteristics of surface sediment contamination in the Lower Passaic River, while also noting conditions at the two main boundary areas, the Upper Passaic River and Newark Bay. A more detailed discussion of the relationship between Lower Passaic River surface sediment contamination and the various external sources of sediment can be found in Data Evaluation Report No. 2. The compounds considered in this data evaluation report are listed in Table 1-2. While surface sediments in this analysis constitute sediments within the top 6 inches of the sediment bed or less, there are differences in the age of the sediments contained within those samples, depending on the local rate of deposition. Given the broad range of deposition rates observed in the Lower Passaic River, a 6-inch sample may represent any of the following: i) prehistoric sediments (from a non-depositional area), ii) a few months of deposition (in a rapidly accumulating location), or iii) a few decades of deposition (in a slowly or irregularly accumulating location). To distinguish samples containing recently-deposited sediments, beryllium-7 (Be-7) was measured in the top 2 inches of a subset of the 0 to 6 inch samples. In all, four types of surface sediment samples are reviewed in this report:

[2] The Dundee Dam represents a hydraulic boundary separating the Upper and Lower Passaic River. The head-of-tide actual location is downstream of the dam because the Lower Passaic River rises above sea level close to the dam (refer to Lower Passaic River System Understanding of Sediment Transport [HQI and Sea Engineering Inc, 2011] for further details on the salt front migration).

- Surface sediment samples obtained from 0 to 1 inches with measureable levels of Be-7,
- Surface sediment samples obtained from 0 to 6 inches with measureable levels of Be-7 in the top 2 inches,
- Surface sediment samples obtained from 0 to 6 inches, and
- Surface sediment samples obtained from 0 to 2 inches.

The technical basis for the use of Be-7 in identifying recently-deposited sediments is discussed below in addition to a brief description of the sediment sample types listed above. This discussion is followed by a description of the use of Total Organic Carbon (TOC) and iron as normalizing factors in the examination of the surface sediment samples. In addition to the introduction, the remainder of this report describes the distribution of contaminants in the surface sediments of the Lower Passaic River and is organized around compound classes as follows:

- *Section 2.0,Temporal and Spatial Trends of 2,3,7,8-Tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) and Total Tetrachlorodibenzo-p-dioxin (Total TCDD)*: The section describes the concentrations of 2,3,7,8-TCDD and Total TCDD in surface sediment from the various historical studies from 1991 to 2012 and outlines the framework of the conceptual site model that explains the observations of dioxin contamination.
- *Section 3.0, Temporal and Spatial Trends for Other Contaminants*: provides temporal and spatial trends of concentrations of polychlorinated biphenyls (PCBs), pesticides, polycyclic aromatic hydrocarbons (PAHs) and metals in surface sediment from various historical studies from 1991 to 2012. This section focuses on differences in the spatial distribution of the other contaminants of potential concern (COPCs) and contaminants of potential ecological concern (COPECs) relative to that for 2,3,7,8-TCDD.
- *Section 4.0, Summary:* provides a summary of the surface sediment analyses.
- *Section 5.0, Acronyms*: defines the acronyms used in this report.
- *Section 6.0, References*: lists the references used in this report.

For each of the COPCs and COPECs, results are presented as follows:

- Maps of contaminant concentrations for 1991 to 2012 to present spatial and temporal distributions,
- Statistical comparisons of contaminant concentrations across sampling programs to examine temporal variation in concentrations,
- Plots of contaminant concentrations by river mile for 0 to 6 inch samples, 0 to 2 inch samples, and Be-7 bearing samples to further examine spatial trends, and
- Maps of contaminant concentrations by river mile, sediment texture, and location relative to the navigation channel to further explore the spatial variation of contamination.

1.2.1 Use of Beryllium-7 to Identify Recently-Deposited Sediments

Recently-deposited sediments can be distinguished from other surface sediments by the presence of Be-7 in the sediments. Be-7 is a naturally occurring radionuclide with a half-life of 53.4 days. This radionuclide is detectable in sediments within approximately 4 to 5 half-lives of deposition, or about 200 to 250 days (6-12 months). It is produced by the impact of cosmic rays on nitrogen and oxygen in the earth's atmosphere. Once produced, particle-reactive Be-7 rapidly becomes associated with aerosols in the atmosphere, and then deposited on the earth's surface, continuously and practically uniformly, primarily as a result of washout by precipitation. A thorough review of the geochemical application of Be-7 in evaluating sediment dynamics is provided by Kaste *et al.* (2002).

Once deposited in a river's watershed, the Be-7 partitions strongly to surface soils. Studies by Hawley *et al.* (1986) and You *et al.* (1989) calculate a soil/water partitioning coefficient, K_d, of 10^4 to 10^6. Other field and laboratory evidence has shown that on land, Be-7 is found solely within the first few millimeters of surface soil, and is not transported deeper into soils by infiltrating rainwater (Walling and Woodward, 1992; Blake *et al.*, 1999; Schuller *et al.*, 2006). The hydrophobic nature of Be-7 thus makes this radionuclide a useful tracer of short-term sediment dynamics (Kaste *et al.*, 2002).

As surface soils are eroded during rain storms, particles bearing Be-7 are washed from the watershed into the river, mixing with the suspended sediments in the water column (Kim *et al.*, 1999; Wallbrink and Murray, 1996). Given the much larger surface area of the watershed versus the surface area of the river, the vast majority of Be-7 that is in the water column has its genesis in watershed surface deposition and runoff, rather than in direct deposition of Be-7 from the atmosphere onto the river surface. With a high K_d, Be-7 remains sorbed to particles in the water column and does not readily partition to the dissolved phase. The presence of Be-7 in sediment can therefore be used to track sedimentation and resuspension regimes in aquatic environments such as lakes, lagoons, and estuaries (Fitzgerald, *et al*., 2001; Canuel *et al*., 1990; DeMaster *et al*., 1985).

Be-7 is determined by gamma spectroscopy, with the concentration of the isotope determined by the number of unique decays detected in a given mass of sediment over a standard counting time, typically 8 to 24 hours. For the purposes of the FFS, Be-7 is considered to be present when the detected level based on counting statistics exceeds zero by more than two standard deviations. With the sample sizes available, minimum Be-7 levels of 0.5 pCi/g were generally necessary to obtain positive detections and interpretable and consistent results. These levels were identified based on the sensitivity of the analytical method and prior work conducted in the New York metropolitan area (*e.g.*, USEPA, 1997).

As documented in several studies, the spatial and temporal distributions of Be-7 in sediments are commonly used to investigate particle cycling (Olsen *et al.*, 1986; Baskaran and Santschi, 1993; Feng, 1997), sediment deposition rates (Dibb and Rice, 1989; Canuel *et al.*, 1990), and biological mixing intensity (Krishnaswami *et al.*, 1980). Because fine particle deposition is the most important factor affecting the accumulation pattern and vertical distribution of Be-7 in estuarine systems (Olsen *et al.*, 1986), fine-grained sediment locations were targeted for sampling in the Lower Passaic River. These same particles are expected to carry many hydrophobic contaminants; thus the occurrence of both Be-7 and various hydrophobic contaminants in a sediment sample indicates that both were recently in the water column as suspended matter. In the Lower Passaic River

conceptual site model, the Be-7 bearing sediments are considered representative of recently deposited materials, allowing them to be compared with recent inputs from the watershed and Newark Bay to complete a solids and contaminant mass balance for the Lower Passaic River.

The level of Be-7 activities in the recently-deposited sediments collected in the Lower Passaic River is comparable to Be-7 activities in settling solids captured in sediment traps or recently-deposited sediments obtained by surface coring in the various tributaries to the Lower Passaic River. This is illustrated in Figure 1.2-1, which shows the Be-7 distribution in samples targeted for Be-7 in Lower Passaic River sediments and tributaries by river mile. Surface sediments and tributary solids all show Be-7 levels on the order of 10 pCi/g. Given the short half-life of this radionuclide, these observations suggest a close link between these solids. As will be illustrated later in this data evaluation report, the patterns of contamination can be used to link Be-7 bearing surface sediments and suspended matter of the Lower Passaic River.

1.2.2 Recently-Deposited Surface Sediments (0 to 1 inch)

Samples from Be-7 bearing locations represent the chemical characteristics of suspended sediments as they settle out of the water column, generally integrating the prior 6 to 12 months of deposition. Recently-deposited sediments used in sediment characterization include: 0 to 1 inch 2007-2008 Be-7 bearing sediments collected in the Lower Passaic River, tributaries and Upper Passaic River, and the 2005-2007 high resolution core tops in the Lower Passaic and Upper Passaic River. Tributary samples are discussed in Data Evaluation Report No. 2.

1.2.3 Surface Sediments (0 to 6 inches) at Depositional Locations

Tierra Solutions, Inc. (TSI) sampling programs for the Passaic River in 1995 and for Newark Bay in 2005 involved the collection of surface sediments in the top 6 inches of the sediment bed. At every location, a sample of the top 2 inches of sediment was tested for Be-7 activity. A separate core was obtained close to this location whose 0 to 6 inch

interval was analyzed for chemical parameters. Depending on the sedimentation rate at these locations, the 0 to 6 inch segment may integrate several years of deposited sediments. For example, if the sample was collected at a location with a constant sedimentation rate of 0.5 inch per year, then the top 6 inches will contain an average of 12 years of sediment contamination. If deposition has been interspersed with erosion at the location, this interval may include sediments that are decades old.

1.2.4 Surface Sediments (0 to 6 inches) at Non-Depositional Locations

Surface sediment samples where Be-7 was not detected are older than 6 months, either because they have been re-exposed through the erosion of overlying sediments or because they are from a location that is slowly (or not) depositional. Like the surface sediments at depositional locations, these samples may integrate sediments over multiple years or even decades, depending upon the deposition rate and the frequency and extent of erosion at the location.

In addition to the TSI and CPG samples where Be-7 was analyzed for but not detected, samples collected in 1999 and 2000 were obtained from 0 to 6 inches but without analysis of Be-7. These locations cannot be characterized concerning their time of deposition.

1.2.5 Surface Sediments (0 to 2 inches)

A subset of sediment samples was obtained from 0 to 2 inches but without any measurement of Be-7. As such, the age of the sediments in these samples cannot be surmised. These samples were primarily collected prior to 1995.

1.2.6 Comparison of Recently-Deposited Sediment to Suspended Solids

Daily tides mix, resuspend, and redeposit sediments, thereby reducing the variability in chemical concentrations in the recently-deposited surface sediments across the Lower Passaic River. Accordingly, suspended solids should possess the same contaminant pattern as the recently-deposited surface sediments. Suspended solids data from the

Infiltrex and Trace Organics Platform Sampler (TOPS) samples collected during the large volume water column sampling event in 2005 were converted from mass of contaminant per liter of water to mass of contaminant per mass of suspended solids by dividing the contaminant concentrations by the TSS concentration of the whole water sample. The United States Geological Survey (USGS) Water Monitoring Program data were used as reported to the New Jersey Department of Transportation as part of the Environmental Dredging Pilot Study. To compare the chemical concentrations of suspended solids to the corresponding value in recently-deposited sediments, the following evaluations were completed: 1) comparison of the PCB congener patterns, 2) comparison of the 2,3,7,8-TCDD/Total TCDD ratio, and 3) principal components analysis (PCA) of both sets of data. The results of these evaluations are discussed below.

To determine if the PCB congener patterns in suspended solids and recently-deposited sediments are similar, PCB congeners in both data sets were normalized to the PCB congener BZ52 (Ballschmiter and Zell, 1980) [3] and plotted with the lighter weight PCB compounds on the left and the heavier PCB compounds on the right. Figure 1.2-2 presents the normalized PCB congener pattern for suspended solids measured during the USGS monitoring program. This figure indicates similar PCB congener patterns in all water column samples from the different water column sample collections in December 5, 2005, December 6, 2005, and December 10, 2005. Comparison of average normalized PCB concentrations from the USGS data to normalized PCB concentrations collected by different techniques during the Lower Passaic Large Volume Filtration program also indicate a close agreement in the PCB congener pattern amongst the different programs/sampling techniques. These water column normalized PCB congener profiles (Figure 1.2-3) show that the same dominant PCB congeners (BZ20+28, BZ44+47+65, BZ61+70+74+76, BZ66, BZ90+101+113, BZ110+115, BZ129+138+160+163,

[3] Ballschmiter and Zell (1980) arranged the 209 PCB congeners in ascending numeric order and assigned what are commonly termed BZ number. The numbering system has been adopted by the International Union of Pure and Applied Chemists (IUPAC).

BZ147+149, and BZ153+168) were identified in the recently-deposited surface sediments of the Lower Passaic River (Figure 1.2-4).

The concentrations and ratio of 2,3,7,8-TCDD/Total TCDD in the suspended solids and the surface sediments were also examined. Similar to the PCB congener pattern, the same ratio observed in the surface sediments was reported in the suspended solids in two independent programs (Table 1-3). The average concentrations agreed within measurement error. Together, these results support the hypothesis that recently-deposited surface sediment and suspended solids are derived from the same pool of solids, tidally mixed, and distributed throughout the Lower Passaic River.

A PCA was performed to further examine the contaminant patterns of the recently-deposited sediment and the suspended solids. The recently collected Be-7 bearing surface sediment and suspended solids data (2007-2008) along with the USGS TOPS and 2005 high resolution core surface sediment data were used in the analysis. All classes of contaminants were included in the PCA analysis, and the analytes were as follows: chromium, copper, lead, mercury, 2,3,7,8-TCDD, Total-TCDD, PCB 24+27, PCB 31, PCB 50+53, PCB 52+69, PCB 61+70+74+76+66, PCB 90+101+113, PCB 180+193, PCB 196+203 and 4,4’-Dichlorodiphenyldichloroethylene (4,4'-DDE). Three principal components (PCs) that explain about 86 percent of the total variance were extracted. The first principal component (PC1) represented 54 percent, the second principal component (PC2) represented 21 percent, and the third principal component (PC3) contained about 11 percent of the total variance in the dataset.

A three-dimensional orthogonal plot of these three principal components (Figure 1.2-5) shows the sample points displayed by the principal components. Sample points are symbolized by different colors for different sources. The PCA result confirmed the hypothesis that the suspended solids possess the same contaminant pattern as the recently-deposited surface sediments (Figure 1.2-5), where the USGS TOPS suspended solids clustered together with the main stem of the Passaic River recently-deposited surface sediment. Another important observation from the PCA analysis is that the

suspended solids and recently-deposited surface sediments in the Lower Passaic River are different from the boundary conditions including: Newark Bay, the Upper Passaic River, and all the tributaries and combined sewer overflows / stormwater outfalls (CSOs/SWOs).

1.3 Consideration of TOC and Iron in Normalizing Surface Sediment Concentrations

Sediment concentrations are often normalized to TOC and iron in order to minimize differences between samples whose only real difference is the amount of coarser grained or non-absorbing sediment present in the samples. That is, within two samples, the fine-grained sediments may have the same chemical properties but the samples may vary in the fraction of sand and gravel, causing proportionate changes in overall sample concentration. Iron is used as a normalizing factor for metals contamination since it is generally associated with the binding sites on fine-grained particles that will absorb other metal species. TOC is used as a normalizing factor for organic contaminants since it expected to be present in proportion to the binding sites for organic contaminants such as pesticides and PCBs.

Prior to their use in normalizing, it is important to first examine the spatial distribution of these parameters themselves, since they may be influenced by factors other than fine-grained sediment content. This examination is presented below.

Total Organic Carbon

TOC is most useful as a normalizing factor when the sources of TOC are limited or are well known. In the Lower Passaic River, the sources are well known but they are not limited in number. There are a large number of CSOs, SWOs, and the tributaries to the Lower Passaic River, all of which contribute TOC to Lower Passaic River sediments. USEPA has amassed a large amount of data to characterize TOC in all of the major sources, facilitating its use as a normalizing factor in the Lower Passaic River.

An important concern in the application of TOC as a normalizing factor is the consistency in reported TOC levels for the same media by the various studies or sampling events conducted by different organizations. The distribution of TOC in the surface sediments of the Lower Passaic River as measured by the various studies is shown in Figure 1.3-1 for RM0 to RM2 and RM2 to RM8.[4] In general, for the six studies represented in the two diagrams, it was expected that each sampling event would have encompassed similar ranges of sediment properties in their samples. It was also anticipated that there might be analytical, year-to-year or seasonal variations that might affect the mean or median, causing differences in mean or median among the studies. Nonetheless, given sufficient data, the means and medians across studies would be expected to converge to an overall mean or median for surface sediment TOC. This was the case for five of the six studies wherein mean log concentrations (a statistical surrogate for the median) converged to a fairly narrow range, near 5 percent TOC ± 2-1/2 percent. Additionally, the overall range of values observed in five of the six studies is also fairly comparable, with extensive overlap across among the distributions. However, these diagrams also show markedly larger and statistically significant difference between the 1995 TOC measurements and several of the more recent studies (2008 and later). This is illustrated by the Tukey-Kramer circles shown at the right in the diagram. Circles represent the mean and its uncertainty for each of the sample groups examined. Circles that do not touch or intersect only slightly are indicative of sample groups that are statistically different from each other.[5] In each diagram, the highest circle represents the 1995 data set, which is statistically different from most of the other studies. While some of the more recent studies are also statistically different from each other, the differences are much smaller than the difference between the later studies and the 1995 study.

[4] The use of the log-transformed data in the figure is in response to the amount of variability and the somewhat skewed distribution of the data. Given the skewed nature of the data, the statistical test on the mean log of the data is a statistical surrogate for the median of the distribution. The median is considered the best estimate of the central tendencies of these distributions since it is not strongly affected by outliers, unlike a simple arithmetic mean.

[5] The size of the circle reflects the uncertainty in the mean log value, with larger circles reflecting larger uncertainty. Thus small sample sizes or highly variable data sets have larger circles than those of large data sets or low variability data sets. Circles for means that are significantly different either do not intersect, or intersect slightly, so that the outside angle of intersection is less than 90 degrees. If the circles intersect by an angle of more than 90 degrees, or if they are nested, the means are not considered significantly different at an alpha level of 0.05 (95 percent confidence level).

The differences between the 1995 study and later studies are likely to be due to analytical differences between the studies and not due to changes in TOC over time. Notably, the dated sediment cores from the Lower Passaic River, which include a record of TOC concentrations from 1995 to 2005 do not show large variations in TOC from year to year, generally less than 25 percent, more typical of the variations among the later studies. This is further illustrated in Figure 1.3-2, which shows the TOC concentrations as a function of river mile for the entire 17-mile Lower Passaic River Study Area. While there are trends with river mile within the data, most data sets scatter within the same range. The notable exception being the 1995 data set, which is clearly higher than the rest of the TOC data. The variability in TOC concentrations shown in Figures 1.3-1 and 1.3-2 limits the usefulness of TOC normalization between the 1995 study and subsequent studies, since variations in the absolute TOC level among programs may introduce variation in normalized concentrations that are due to analytical issues and not due to real changes. The application of TOC normalization within the same study or across the more recent studies, however, is still useful to minimize differences between samples whose only real difference is the amount of coarser grained or non-absorbing sediment present in the samples.

Iron

In contrast to TOC, iron presents a more internally consistent variable for normalization. This is illustrated in Figure 1.3-3, which shows the distribution of iron concentrations for the various sampling programs for RM0 to RM2 and RM2 to RM8. Below RM2, only the 2008 USEPA data set is different. This may be due to the sampling distribution of this data set, which was obtained exclusively between RM0 and RM1. For RM2 to RM8, no data set was statistically different but the 2010 CPG data may be slightly higher than the other sets. This likely reflects the near-exclusive focus on shoal samples for this program, with higher fine-grained sediment contents. Overall, these data sets present a generally consistent level of iron concentrations across the programs, suggesting this variable will be useful for normalization across all studies. This is further supported by Figure 1.3-4, which shows iron concentrations as a function of river mile. In this diagram, iron content

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increases gradually from Dundee Dam across the length of the Lower Passaic River and into Newark Bay, consistent with the anticipated increase in fine-grained sediment content. Note that the scatter in iron concentrations is greater above RM8, consistent with the higher frequency of coarse-grained samples and much greater extent of coarse-grained areas above this river mile.

2 TEMPORAL AND SPATIAL TRENDS FOR 2,3,7,8-TCDD AND TOTAL TCDD

This section describes the spatial and temporal variations in 2,3,7,8-TCDD, Total TCDD, and the ratio of these two parameters in the surface sediments of the Lower Passaic River. Because the concentrations of 2,3,7,8-TCDD and Total TCDD are quite elevated in the sediments of the Lower Passaic River relative to all external sources (see Data Evaluation Report No. 2), these contaminants may be used to trace the migration of contaminated sediments from the RM0 to RM12 region of the Lower Passaic River into Newark Bay and the upper portion of the Lower Passaic River above RM12.

2.1 Spatial Distribution of 2,3,7,8-TCDD Concentrations

The first set of figures in this section presents the historical record of surface sediment monitoring in map form, beginning in 1991 and extending to 2012. Figure 2.1-1 presents the surface sediment sampling results from 1991 to 2000, including the extensive 1995 sampling program conducted by TSI and the near shore sampling programs conducted by TSI and USACE in 1999 and 2000. The map presents the region of the Lower Passaic River between RM0 and RM8, since nearly all of the samples collected during this period were obtained below RM8. As a background on this and all subsequent maps presented in this data evaluation report, the results of a 2005 side-scan sonar survey are presented, which defined sediment texture throughout the river. The side-scan sonar data illustrate the extensive areas of fine-grained sediments found in this region of the Lower Passaic River, as indicated by the blue (silt areas) and green (silt and sand) areas. The coincidence of 2,3,7,8-TCDD contamination and various sediment textures can be used to infer contaminant levels in unsampled areas.

Notable in the map is the spatial extent of elevated sediment levels. The vast majority of sediment samples between RM0 to RM8 have levels above 100 pg/g (picograms per grams of sediment or parts per trillion), at least an order of magnitude above background levels of 2 pg/g observed in the sediments above Dundee Dam. Additionally, there are extreme values greater than 1,000 pg/g scattered throughout the eight-mile reach

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presented here. Symbols of yellow, orange and red indicating concentrations of 1,000 pg/g or higher occur within each river mile interval from RM2 to RM7. They occur in an apparent random fashion throughout the river, on both the inside and outside of river bends.

Figure 2.1-2 presents the results from 2005 to 2012, covering the entire length of the Lower Passaic River. Notable in the first map in the sequence (Figure 2.1-2a), representing the region above RM12, is the substantially lower levels of 2,3,7,8-TCDD contamination above RM13, as denoted by the extent of blue symbols. This region is also marked by extensive areas of coarse-grained sediments as compared to the region below RM8. The lack of 2,3,7,8-TCDD contamination above RM13 indicates that tidal circulation is limited in its ability to transport contamination from the lower portions of the Lower Passaic River much upstream of RM12. As will be shown later in the discussion, the influence of the tidal transport of contamination gradually declines from RM12 to RM15. Additionally, the lack of fine-grained sediments in this region would indicate that there are few areas for contaminant-bearing fine-grained sediments to accumulate.

Figure 2.1-2b represents the middle portion of the Lower Passaic River, RM8 to RM12. This region is more contaminated than the upstream area and more heterogeneous in both 2,3,7,8-TCDD concentrations and sediment texture than the downstream region (compare with Figures 2.1-1 and 2.1-2c). While this region also has extreme levels of 2,3,7,8-TCDD contamination, it also has a much higher frequency of samples with low levels of contamination. In both regions, *i.e.*, below RM8 and in RM8 to RM12, high concentrations of 2,3,7,8-TCDD occur within areas of fine-grained sediments. However, nearly all of the region below RM8 is fine-grained, resulting in relatively random locations with extreme values whereas, between RM8 and RM12, most of the bottom is coarse-grained and the extreme values are limited to very small portions of the river bottom where fine-grained sediments accumulate.

The last map in the sequence, Figure 2.1-2c, shows similar levels of contamination to those observed in 1995.The occurrence of extreme values can be found throughout the river on the inside and outside of river bends as well as in the channel. The impact of the navigation channel and its history on the distribution of surface sediment concentrations are further explored in Section 2.4

2.2 Spatial and Temporal Comparisons of 2,3,7,8-TCDD Concentrations

A quantitative analysis of surface concentrations of 2,3,7,8-TCDD shows that there is no trend in surface concentrations of 2,3,7,8-TCDD over time. Figure 2.2-1 presents the concentration distributions from 0 to 6 inch samples for the large 1995 sampling program, as well as the various post-2005 sampling programs, grouped by the river mile intervals 0 to 2, 2 to 8, 8 to 12 and 12 to 17.4. The break points recognize the various regions of the Lower Passaic River, with the RM0 to RM2 interval characterizing the most depositional region; RM2 to RM8 being the large, contaminated fine-grained region of the Lower Passaic River; RM8 to RM12 being the contaminated but predominantly coarse-grained region; and RM12 to RM17.4 being the least contaminated (with respect to 2,3,7,8-TCDD) coarse-grained region.

In each diagram, the distribution of 2,3,7,8-TCDD concentrations are shown for each data set available in the region. At the far right of each diagram is a set of circles representing the Tukey-Kramer test for statistically significant differences. The diagrams are plotted in log scale and the Tukey-Kramer tests are also done in log-scale to provide an analysis of the central tendency in each data set while minimizing the effects of extreme values, essentially a test of medians.

For both RM0 to RM2 and RM2 to RM8, there are no statistically significant differences in the data sets between 1995 and 2012. The median values (calculated for the period between 2008 and 2012) for RM0 to RM2 and RM2 to RM8 are 208 and 280 pg/g, respectively. These results indicate that since 1995 there has been no statistically significant change in the surface concentration of 2,3,7,8-TCDD below RM8. This is consistent with the dated sediment core results described in Data Evaluation Report No.

3, which concluded that only a very gradual decline was occurring. Given the variance in the surface sediment samples and their depth, such a gradual decline would be difficult to detect by measurements of surface sediments alone.

In Figure 2.2-1b, the distributions for RM8 to RM12 and RM12 to RM17.4 are shown. In these areas, there are no data sets prior to 2008 of the 0 to 6 inch interval of sufficient size to provide a useful statistical test. The diagrams compare the results among the most recent studies. For RM8 to RM12, the four CPG studies have essentially the same median. The USEPA study, which sampled silt areas exclusively, has a somewhat higher value than the surveys but the difference is statistically significant only when the 2008 USEPA study is compared against all other CPG studies treated as a single group. The CPG studies were not limited to silt areas, but also incorporated samples from the less contaminated coarse-grained areas, resulting lower medians relative to the silt-only 2008 USEPA study. The simple median value for the entire set of samples for RM8 to RM12 (294 pg/g), which represents a combination of coarse- and fine-grained material, is very similar to that of RM2 to RM8 (280 pg/g), which represents fine-grained material only. However, the sampling locations above RM8 preferentially sampled silts rather than coarse-grained sediments. Coarse-grained sediments are spatially much more extensive above RM8. An area weighted geometric mean concentration (based on the mean of the logs of the concentrations) for the RM8 to RM12 region is only 200 pg/g, reflecting the generally lower concentrations observed in the coarse-grained areas.

Above RM12, concentrations drop off rapidly, as shown in the lower diagram in Figure 2.2-1b. The overall median value is only 3.3 pg/g. While all five data sets agree statistically, the USEPA samples are visibly higher than nearly all other measurements. However, these samples were obtained just upstream of RM12 in a fine-grained sediment deposit and cannot be considered spatially representative of the entire region above RM12. The 2010 and 2012 CPG data have the same caveat.

Figure 2.2-2 represents a similar sequence of results for Total TCDD. Given that 2,3,7,8-TCDD typically represents about 70 percent of the Total TCDD mass, these results

should and do repeat the patterns seen in the 2,3,7,8-TCDD concentrations. Note that there are no results shown for Total TCDD for the 2008 CPG data set. This is due to analytical issues that prevented the calculation of a comparable Total TCDD value for these samples (see CSC and Interface, Inc., 2010 and 2011for a more detailed discussion). For this reason, there are also no results for the 2,3,7,8-TCDD to Total TCDD ratio for the 2008 CPG data as discussed below.

Figure 2.2-3 represents a similar sequence of results for the 2,3,7,8-TCDD to Total TCDD ratio. While there are some minor differences in the ratio for the 1995 and 2012 datasets relative to the 2008-2010 datasets, all sample results below RM12 yield values close to 0.7, which is the characteristic dioxin ratio of the Lower Passaic River. RM2 to RM8 and RM8 to RM12 have medians that are within error of this value, whereas RM0 to RM2 has values slightly lower, around 0.6, likely due to the influence of solids from Newark Bay.[6]

Above RM12, the distribution of this ratio becomes more variable, reflecting the mixing of sediment from above Dundee Dam with those of the Lower Passaic River. Thus the range extends from background values (about 0.05) to that of the highly contaminated areas of the Lower Passaic River (0.7). The variation of this ratio with river mile in the consistent manner just described is an important line of evidence supporting the conceptual site model and the premise that the sediments of the Lower Passaic River present a unique ratio signature easily identified against possible external sources.

2.3 Variation of Dioxin Concentrations with River Mile

After confirming the comparability of the various Lower Passaic River data sets in the previous discussion, it is then useful to combine them and examine the trends in dioxin contamination with river mile. As will be shown below, the 2,3,7,8-TCDD concentrations show less than a factor of 2 change in the median concentration between RM2 and RM12

[6] Also notable on the figure are the occurrence of values greater than 1. While this is theoretically impossible based on the definition of the 2,3,7,8-TCDD to Total TCDD ratio, in reality, these quantities are actually determined separately. As a result, analytical variability can result in values slightly greater than 1.

when normalized to TOC. In contrast, 2,3,7,8-TCDD concentrations increase by more than 2 orders of magnitude between RM17.4 and RM12 as relatively clean Upper Passaic River solids are mixed with the highly contaminated solids of the Lower Passaic River. A similar but less steep gradient occurs below RM2, as less contaminated solids from Upper New York Bay are mixed with Lower Passaic River solids across Newark Bay and the lower 2 miles of the Lower Passaic River. The relative lack of a trend in concentrations with river mile in RM2 to RM12 indicates the effects of tidal mixing. The observation that this same stretch is 1 to 2 orders of magnitude more contaminated than the regions upstream and downstream indicates that a very large source of dioxin exists in this region. As shown elsewhere (*e.g.*, the Empirical Mass Balance in Appendix C), this source is the legacy[7] sediments of the Lower Passaic River.

Figure 2.3-1 presents the results for 2,3,7,8-TCDD for 0 to 6 inch samples for the Lower Passaic River as well as Newark Bay and the Upper Passaic River. Note the vertical scale: in order to represent the full range of concentrations observed in this 30 mile portion of the Passaic River and Newark Bay, the diagram spans 7 orders of magnitude.

It is evident from Figure 2.3-1 that the various data sets are similar in range and central tendency. Presented in this fashion, the surface concentrations describe several domains:

- The Upper Passaic River, with its extremely low 2,3,7,8-TCDD concentrations (less than 3 pg/g),
- RM12 to RM17.4 region, characterized by a two-order of magnitude gradient in the median 2,3,7,8-TCDD concentration, the result of the mixing of Upper Passaic solids with resuspended solids originating in the Lower Passaic River,
- RM8 to RM12 region, characterized by highly variable concentrations of 2,3,7,8-TCDD, ranging from about 5 to 23,000 pg/g but with relatively few samples around the median concentration of 294 pg/g.

[7] The term "legacy sediments" is used to refer to contaminated sediments deposited in the river during the period that it was filling in, and that are the legacy of the long history of industrial and municipal discharges to the river.

- RM2 to RM8 region, characterized by a similar range in the 2,3,7,8-TCDD concentration (1 to 34,000 pg/g) but a stronger central tendency to the distribution, with many samples close to the median of 280 pg/g.
- RM0 to RM2 region, characterized by a shallower gradient than that observed at RM12 to RM17.4, declining from about 280 to 100 pg/g, as solids from Newark Bay are mixed into the Lower Passaic River.
- Newark Bay, where the gradient that begins at RM2 extends through the bay, as less contaminated solids from Upper New York Bay are mixed with solids from the Lower Passaic River.

Also shown on the diagram are samples from the tributaries to the Lower Passaic River, but below the head of tide. Because they were obtained below the head of tide, they may be impacted by solids transported from the Lower Passaic River during hide tide periods. Nonetheless, they are much lower than samples from the main stem of the river (less than 10 pg/g), consistent with the lack of 2,3,7,8-TCDD contamination in these water bodies, as concluded in Data Evaluation Report No.2.

Of particular note in Figure 2.3-1 is the lack of a concentration gradient in the RM2 to RM12 portion of the river. While surface sediments exhibit a large degree of variability, the central tendency remains the same, unlike the regions outside these river miles. This observation is strong evidence of the extent and intensity of tidal mixing. In this portion of the Lower Passaic River, gradients along the axis of the river are minimized and surface concentrations are the result of both recent deposition as well as the erosion of the legacy sediments.

Figure 2.3-2 presents the data available for samples 2 inches or less in thickness from the historical record for the Passaic River only. Samples for this interval were obtained only from 1991 to 1993 (0 to 2 inches) and in the 2007-2008 (0 to 1 inch) USEPA studies. While these data are much more limited, they still describe the same trends in concentration evident in Figure 2.3-1 while also exhibiting less variability at any given river mile interval. This is partially attributable to the sampling programs involved. The

2007-2008 USEPA programs specifically targeted recently-deposited Be-7 bearing sediment (discussed further below). This targeting produced the observations of low contaminant concentration variability in recently-deposited sediments. The objectives of the 1991 to 1993 programs were not as focused on Be-7 bearing sediments but were concentrated at the downstream end of the Lower Passaic River where sediment concentration variance tends to be reduced (see Figure 2.3-1). Nonetheless, the observation of greatly reduced variability in the 0 to 2 inch samples indicates that the 0 to 6 inch samples include more highly contaminated sediments, either as samples from highly contaminated areas or as samples from locations where highly contaminated sediments underlie more recently deposited sediments. Data Evaluation Report No. 3 provides evidence that highly contaminated sediments equate to older sediments. Thus, the presence of more contaminated sediments in the 0 to 6 inch samples also means that much older sediments, deposited in the 1950s and 1960s, lie at or very close to the sediment-water interface.

Figure 2.3-3 presents the results for recently-deposited sediments in the Lower Passaic River (0 to 1 inch, Be-7-bearing samples) as well as for samples from depositional locations (0 to 6 inch samples at locations with Be-7 present in the 0 to 2 inch interval). As noted previously, in the Lower Passaic River, the latter samples are not considered recently-deposited, but rather represent a mixture of recent deposition and older (pre-1990s), underlying sediments. The Newark Bay samples were collected in the same manner, also representing 0 to 6 in sediment intervals. However, the Newark Bay samples presented here were further restricted to channel areas, which are generally subject to frequent dredging. As such, much of the sediment in these samples is likely to be deposited since the last dredging event. As a result, these samples are expected to consist of sediments no more than 3 to 5 years old (the typical interval between dredging events). The reduced level of variation in these samples relative to similar samples obtained by the CPG in the Lower Passaic River suggests that the Newark Bay samples selected in this manner do avoid inclusion of older (pre-1990s), more contaminated sediments.

The recently-deposited sediments presented in Figure 2.3-3 describe a tightly defined function, with little variance between RM0 and RM12. The absolute concentration varies only about 2.5-fold over this interval (*i.e.*, from 250 to 550 pg/g), but variation between neighboring points (separated by 0.5 to 1 mile) is generally less than 25 percent. This is a dramatic reduction in the nearly 4 orders-of-magnitude variability (3 to 15,000 pg/g) observed in the 0 to 6 inch samples from this portion of the Lower Passaic River, as exhibited in Figure 2.3-1. The concentration gradients at RM0 to RM2 and RM12 to RM17.4, which became apparent only after the collection of many hundreds of 0 to 6 inch samples, are apparent here with just a few samples.

In the lower diagram of Figure 2.3-3, the 2,3,7,8-TCDD concentrations have been normalized to TOC in the samples. This normalization further reduces the gradient in the recently-deposited samples from RM2 to RM12 to about 2 fold, indicating that some of the gradient in the absolute 2,3,7,8-TCDD concentration is simply due to higher organic content in the Be-7 bearing samples upstream. Notably the normalization does little for the variability observed in the 0 to 6 inch samples obtained from depositional zones, further supporting the assertion that these samples do not represent recently-deposited sediments alone but incorporate a significant fraction of older, more contaminated sediments.

Figures 2.3-4 to 2.3-6 present the same sequence of results for Total TCDD. As expected, the distribution of this parameter closely mimics that of 2,3,7,8-TCDD, given the high percentage of 2,3,7,8-TCDD in the Total TCDD. Note that there are no Total TCDD results for the 2008 samples obtained by the CPG due to analytical issues as discussed above.

Figures 2.3-7 to 2.3-9 present the same sequence for the 2,3,7,8-TCDD to Total TCDD ratio. This ratio behaves somewhat differently from the concentration data, showing an even steeper gradient in the RM12 to RM17.4 portion of the river. This is expected since the ratio will remain fairly constant as Lower Passaic River solids are diluted with the much less contaminated Upper Passaic solids. Only when the mass contributions to a

sediment sample from the Upper Passaic River and Lower Passaic River are comparable (*i.e.*, concentrations of 2,3,7,8-TCDD are less than 10 pg/g) will the ratio deviate from that observed in the main portion of the Lower Passaic River. The same arithmetic applies across Newark Bay. Thus with the elevated dioxin ratios observed in the Bay, it can be concluded that the vast majority of the 2,3,7,8-TCDD burden in Newark Bay sediments is due to loads delivered by the Lower Passaic River.

2.4 Influence of the Navigational Channel and Sediment Texture

The next sequence of figures considers the influence of the navigation channel and sediment texture on the concentrations of 2,3,7,8-TCDD. In Section 2.1, the examination of 2,3,7,8-TCDD concentrations and sediment textures on a map basis suggested that the region above RM8 was different than that below RM8. In this section, the distribution of concentrations from RM0 to RM12 is examined more closely to further explore these observations.

In Figure 2.4-1, 2,3,7,8-TCDD concentrations from RM8 to RM12 are contrasted with those observed from RM1 to RM7 based on 0 to 6 inch samples. In this comparison, the interval from RM1 to RM7 was used since it was extensively sampled in both 1995 and 2008. Notable in the figure for the RM1 to RM7 interval is the close agreement of the median values for 1995, the 2008 to 2010, and the 2012 samples, as represented by the horizontal lines. In this region, both coarse and fine-grained sediment samples from the 2008 to 2010 sampling programs have comparable median concentrations. The median values for the 2012 fine-grained sediment from RM1 to RM7 are almost the same as the median values for the 1995 and 2008 to 2010 samples. No median is represented for the 2012 coarse-grained sediment since the data are too limited in number. Note that the coarse and fine-grained sediment assignments for 2008 to 2012 are based on a 2005 side-scan sonar survey and not the individual sample descriptions. 1995 samples were not sorted in this manner since grain-size distribution data were not obtained for these samples and the 2005 side scan sonar survey was not considered representative of 1995 conditions due to the passage of time.

Above RM8, concentrations for coarse and fine-grained sediments for the 2008 to 2010 dataset as defined by side scan sonar differ by a factor of 3, with coarse-grained sediment concentrations (140 pg/g) about 3 times lower than fine-grained sediments concentrations (370 pg/g). Fine-grained sediments above RM8 are comparable in concentration to samples below RM8 (370 *vs.* 294 pg/g, respectively). For the limited 2012 dataset, the median values of the concentrations for fine-grained sediment are about 80 percent higher than the corresponding median values for the 2008 to 2010 dataset (578 *vs.* 370 pg/g, respectively). While the difference between the 2008 to 2010 and the 2012 datasets appear relatively large, similar median values are also observed for subsets for the 2008-2010 dataset, such as the 2008 USEPA dataset for RM8 to RM12 (median value 538 pg/g). In contrast, the median values of the concentrations for coarse grain sediments for 2012 dataset are 5 times lower than the corresponding median values for the 2008 to 2010 dataset (18 *vs.* 140 pg/g, respectively). The reason for the difference is not known but may be due to effects due to Hurricane Irene, which preceded the 2012 sampling event, or due to the limited sample size for 2012 (8 samples), among other possible causes.

The general consistency in the mean 2,3,7,8-TCDD concentrations in fine grained sediments throughout RM2 to RM12 is taken as further evidence for the dynamic and extensive nature of tidal mixing in the Lower Passaic River, generating comparable levels of fine-grained sediment concentration throughout the lower 12 miles of the estuary, particularly between RM2 and RM12. Given that the majority of fine-grained sediment areas are located below RM8.3, this observation also provides direct support for the focus of the FFS on the lower eight miles.

The Lower Passaic River has a navigation channel from RM0 to RM15. Maintenance dredging of this channel ceased in the 1950s to 1980s (depending on river mile). The coincidence of chemical disposal in the river prior to restrictions arising from the Clean Water Act, along with the construction and subsequent limited maintenance of the navigation channel, created an ideal situation for contaminated sediments to accumulate in the Lower Passaic River. The deepest portions of the channel were constructed below

RM8, with minimum channel depths of 16 ft or greater. This has led to the accumulation of thick beds of contaminated sediment both in the channel as well as in the shoals below RM8 (see Chapter 4 of the RI).

The region below RM8 was further examined, taking into account the navigation channel. Specifically, samples were assigned as in the navigational channel or in the shoals based on the USACE channel boundaries. These two populations of samples were then examined to see if concentrations in the navigational channel were in reality lower than those in the shoals, akin to the observations above RM8. To make the comparisons robust, all of the available 0 to 6 samples obtained in this portion of the Lower Passaic River were used in the analysis.

To make this comparison, log-transformed concentrations were compiled for channel and shoal areas for RM0 to RM2 and RM2 to RM8, reflecting the observed change in the 2,3,7,8-TCDD concentration trend with river mile that occurs around RM2, with the intention of maximizing the probability that a statistically significant difference would be observed if present. The results of these calculations are shown on an absolute concentration basis in Figure 2.4-2a and on a TOC-normalized basis in Figure 2.4-2b. In both river mile intervals, the results indicate no statistically significant differences between channel and shoal areas on an absolute basis. On a TOC-normalized basis, shoal and channel concentrations agree with uncertainty from RM0 to RM2 and channel concentrations are about 50 percent lower than the shoal concentrations from RM2 to RM8. The difference in channel and shoal is considered minor in comparison with the four order of magnitude variation in 2,3,7,8-TCDD concentrations observed in each of these areas. The channel and shoal areas equally show local variations but no systematic trends with river mile, consistent with expectations given the history of the channel dredging as described above.

The analyses presented in Figures 2.4-1 and 2.4-2 were repeated for Total TCDD but are not shown here since the results were essentially the same as those of 2,3,7,8-TCDD. A parallel analysis was conducted for the 2,3,7,8-TCDD to Total TCDD ratio, replicating

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the presentations in Figures 2.4-1 and 2.4-2. These results are shown in Figures 2.4-3 and 2.4-4. In Figure 2.4-3, it is evident that, unlike the 2,3,7,8-TCDD concentration results, the 2,3,7,8-TCDD to Total TCDD ratio shows little difference among sediments types or with river mile between RM2 and RM12 for the 2009 to 2010 data. The median values of the ratio for coarse-grained sediments between RM8 and RM12 for the 2012 dataset are the same as the corresponding the median values of the ratio for the 2009 to 2010 dataset (approximately 0.7), but the median values of the ratio for fine-grained sediments between RM8 and RM12 are slightly higher (0.8). The close agreement of the ratio across sediment texture and river mile reflects the fact that all of the 2,3,7,8-TCDD contamination in this portion of the Lower Passaic River is derived from the same industrial source or sources and bears the same 2,3,7,8-TCDD to Total TCDD ratio fingerprint. The slightly higher ratio and higher concentrations in the fine-grained sediments above RM8 for the 2012 data may identify these samples as older sediments present at the river bed surface. Dated sediment core results from this river section show higher 2,3,7,8-TCDD concentrations and higher 2,3,7,8-TCDD to Total TCDD ratios for older sediments. The differences in concentration in the RM0 to RM12 region are largely due to variations in fine-grained sediment content or TOC, variations that will not change the characteristic ratio. The 1995 results did yield a slightly higher 2,3,7,8-TCDD to Total TCDD ratio than the 2008 to 2012 results for RM0-8; however, these differences are minor in comparison to typical baseline ratios of 0.04 to 0.06. The reason for the difference between 1995 and subsequent studies is unknown but may be due minor analytical differences between 1995 and 2009 to 2012 studies in the Total TCDD sum (particularly since the median concentrations of 2,3,7,8-TCDD agree closely between the two periods[8]).

[8] The lack of change in the median concentrations of 2,3,7,8-TCDD accompanied by the small decline in the ratio between the two studies indicates an increase in the reported Total TCDD values between the two periods. While the reason for the increase in Total TCDD is not known, a slight difference in analytical techniques is likely. The observation of a 0.07 decline in the value of the ratio needs only a 10 percent increase in the average Total TCDD value. This deviation is well within the likely accuracies of the studies involved.

The comparison of channel and shoal areas yielded no difference in ratio for the RM0 to RM2 portion but did show a statistically significant but substantively unimportant difference in the 2,3,7,8-TCDD to Total TCDD ratio (a difference of 0.04 on a mean value of 0.7). This difference parallels the difference between the 1995 results and those of the 2009 to 2012 dataset, illustrated by the horizontal median lines seen in Figure 2.4-3. The reason for this small difference is not known but it is similar in size to the small differences observed among analytical programs. Figure 2.4-5 contrasts the distribution of the ratio for the two study periods for the RM0 to RM2 and the RM2 to RM8 portions of the Lower Passaic River.

While these observations identify minor differences in the dioxin ratio among programs, the main conclusion to be drawn from the ratio analysis is that the ratio is nominally 0.7 with minor variations everywhere the same, regardless of sediment texture (note the small variability in linear scale in Figures 2.4-3, 2.4-4, and 2.4-5), and markedly different from all known external sources of 2,3,7,8-TCDD. This observation is a major supporting line of evidence to the conclusion that estuarine circulation in the Lower Passaic River mixes fine-grained sediment over its entire length, particularly from RM2 to RM12. Further, these observation are important evidence for the absence of external sources of 2,3,7,8-TCDD of any consequence.

2.5 Summary of Dioxin-Related Observations

Taken together, these quantitative analyses confirm the lack of change in surface sediment concentrations of 2,3,7,8-TCDD over time, as well as confirming the unique 2,3,7,8-TCDD to Total TCDD ratio first observed by Chaky (2003). The 2,3,7,8-TCDD concentrations in the top 6 inches of sediment show nearly 4 orders of magnitude variation within 1 mile intervals between RM2 and RM12, but less than a factor of 2 change in the median concentration over the same distance when normalized to TOC. An essentially identical trend is observed in recently-deposited Be-7 bearing sediments when normalized to TOC. In contrast, 2,3,7,8-TCDD concentrations increase by more than 2 orders of magnitude between RM17.4 and RM12 as Upper Passaic River solids are mixed with the highly contaminated solids of the Lower Passaic River. A similar but less steep

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gradient occurs below RM2, as less contaminated solids from Upper New York Bay are mixed with Lower Passaic River solids across Newark Bay and the lower 2 miles of the Lower Passaic River. The observations regarding the 2,3,7,8-TCDD to Total TCDD ratio further support these observations, as the ratio varies little between RM2 and RM12 and then declines across the concentration gradients at either end of the Lower Passaic River. Surface concentrations within RM2 to RM12 are affected by spatial variations in fine-grained sediment content, which occur primarily above RM8. Below RM8, the channel and shoal areas are comparably contaminated, with local variations but no systematic trends with river mile. While the variations in fine-grained sediments affect the distribution of 2,3,7,8-TCDD concentrations, they do not affect the 2,3,7,8-TCDD to Total TCDD ratio. In total, these observations are well explained by the historical industrial discharges of 2,3,7,8-TCDD and the occurrence of extensive tidal mixing and reworking of the sediment bed, generating locally variable concentrations as legacy sediments are exposed while recent deposition is evenly contaminated over intervals of several miles, yielding the observations seen in 0 to 6 inch samples and in recently-deposited Be-7 bearing sediments.

3 TEMPORAL AND SPATIAL TRENDS FOR OTHER CONTAMINANTS

This section describes the temporal and spatial distribution of the other COPCs and COPECs for the Lower Passaic River, constructed along the same analyses performed in Section 2. The other contaminants of the Lower Passaic River often follow the spatial and temporal trends observed in the 2,3,7,8-TCDD results, but there are occasional differences. Many times these differences are due to more significant external sources relative to those for 2,3,7,8-TCDD. In the following discussions, only the differences between the distributions of the various compounds of concern and the distribution of 2,3,7,8-TCDD are noted. The compounds of concern are addressed by compound class since trends are often similar within the class. The discussions are organized in this manner to keep the narrative text brief and focused on the important issues. However, the attached figures parallel the analyses completed for 2,3,7,8-TCDD.

For each compound examined, 1995 sampling results are contrasted with more recent measurements. While statistically significant differences are often seen in these comparisons, there are analytical issues due to changes in analytical techniques during the intervening years. For this reason, changes in surface sediment concentrations are noted but not considered definitive of the rate or even the direction of change. The dated sediment cores described in Data Evaluation Report No. 3 are used to estimate long term trends in surface sediment concentrations.

The following observations made for 2,3,7,8-TCDD were also confirmed by all other COPCs and COPECs:

- Surface concentrations are locally variable but largely without trend in river mile from RM2 to RM12.
- When upstream contamination is less than that of the Lower Passaic River, a decreasing concentration gradient occurs from RM12 to RM17.4.

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- When downstream contamination is less than that of the Lower Passaic River, a decreasing concentration gradient occurs from RM2 to RM0 and sometimes extends to the southern end of Newark Bay.
- For organic contaminants, normalization to TOC reduces the longitudinal variation within the Lower Passaic River for Be-7 bearing sediments but does little to reduce local variability in 0 to 6 inch samples from depositional locations. Additionally, with the exception of PAHs, normalization to TOC reduces the concentration gradients observed above RM12 and below RM2. A similar statement for metals normalized to iron is made in the next set of bullet points below.
- Surface concentrations within RM2 to RM12 are affected by variations in fine-grained sediment content, which occur primarily above RM8. From RM2 to RM8, where the river bottom is dominated by fine-grained sediment, bank to bank, each contaminant showed comparable median concentrations in channel and shoal areas, with local variations. No contaminant showed a systematic trend with river mile between RM2 and RM8.
- The spatial distribution of the other COPCs and COPECs in the Lower Passaic River are well explained by the occurrence of extensive tidal mixing and reworking of the sediment bed, generating locally variable concentrations as legacy sediments are exposed while recent deposition is evenly contaminated over distances of several miles.

The following observations were made from several of the other contaminants, and add to the list above:

- Some component of the gradient above RM12 is due to the greatly reduced presence of fine-grained sediment above this river mile. In some instances, normalization to TOC or iron largely eliminates the gradient, indicating that the Upper Passaic River is contributing contaminant concentrations on a fine-grained particle basis that are comparable to those observed in the Lower Passaic River.
- Extreme values of many other compounds of concern do not always coincide with extreme 2,3,7,8-TCDD surface concentrations. This is likely to stem from

extensive tidal mixing and reworking of the sediment bed and from differences in release history relative to 2,3,7,8-TCDD, respectively.

- For metal contaminants, normalization to iron reduces sample-to-sample variability across sampling event, often fairly substantially, and typically more than TOC normalization does for organic contaminants, indicating that fine-grained sediment content, which parallels iron levels in the sediment, may control metal contamination levels more closely than organic contamination levels.
- Some compounds appear to have lower surface concentrations in the 2008-2012 sampling period than in 1995, unlike 2,3,7,8-TCDD. These observations are inconsistent with those from the dated sediment cores (see Data Evaluation Report No. 3) and probably result from analytical differences among sampling programs, an issue that is not a concern for the dated sediment cores since they were all analyzed over a six month period by the same laboratories and analytical techniques.

Because of the apparent variations in surface sediment concentrations over time for some contaminants [mercury, DDT and its metabolites (noted as Total DDx), and dieldrin in particular] and the associated analytical issues, summary statistics of surface sediment concentrations were compiled based on the 2008 to 2012 data alone. This summary is based on 0 to 6 inch samples only and includes both CPG and USEPA sampling efforts from this period. The summary statistics are provided in Table 3-1. The compiled values in the table are considered estimates of current surface sediment conditions.

3.1 Temporal and Spatial Trends of PCBs in Surface Sediments

In general, the observations of PCBs concentrations in the surface sediments of the Lower Passaic River are very consistent with the observations of 2,3,7,8-TCDD concentration trends. The primary analysis of PCBs was done as the sum of PCBs, or "Total PCBs", rather than individual congeners, homologues, or Aroclors. Not all data sets quantified PCBs in the same manner. Both the 1995 TSI data set and the 2008 USEPA data estimated Total PCBs as the sum of Aroclors, while all other recent sampling efforts collected PCB congener data. In order to reconcile the two PCB metrics,

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an adjustment factor was developed from a subset of the 2008 USEPA and CPG data in which both Total PCBs by congener and Total PCBs by Aroclor were developed (see Attachment B of Data Evaluation Report No 3). Based on matched pairs of congener analysis and Aroclor analysis, the congener sum was found to be, on average, 1.25 times higher than the Aroclor sum. On this finding, the 1995 TSI and 2008 USEPA Aroclor data were multiplied by a factor of 1.25 to make the measurements equivalent to the 2008-2010 CPG results and enables a much more extensive and robust series of analyses.

Unlike the 1995 TSI and 2008 USEPA data for PCBs, there were no matched pairings of PCB Aroclor and PCB congener analytical results made as part of the 1999-2000 surface sediment study by TSI and the Minish Park Study. To create a rough basis for comparison and enable some mapping of the 1999-2000 shoreline data in Figure 3.1-1, the 1999-2000 Total PCB concentration was estimated based on the sum of the reported 10 congeners multiplied by 17.8. This factor was based on the ratio between the average 1999-2000 surface sediment concentration and the average Total PCB concentration in the 1999-2000 horizons of the dated high-resolution sediment cores collected in 2005. Because of the uncertain nature of this factor, the 1999-2000 data are presented only in Figure 3.1-1 and were not used in any of the subsequent statistical analyses for PCBs presented later in this data evaluation report.

Figures 3.1-1 to 3.1-9 present a set of analyses that parallels the analyses done for 2,3,7,8-TCDD. Additionally, Figure 3.1-7 presents the results for three PCB congener peaks for the 2005 to 2008 Be-7 bearing samples and CPG samples containing Be-7. (Note that the 2012 CPG samples were not analyzed for Be-7 and so are not represented here.) The three PCB congeners were plotted to represent a range of PCB molecular weights, from light (BZ52+69), medium (BZ90+101+113), and heavy (BZ180+193). These diagrams represent the results of congener-specific analyses and were plotted to confirm that the trends seen in the Total PCB analyses are also observed on a congener level. In addition to confirming many of the 2,3,7,8-TCDD observations discussed above, the PCB analyses also yield the following observations:

- Surface sediment concentrations of Total PCBs appear unchanged over time, with some allowance for the difficulties in comparing the two analytical methods used. No statistically significant differences were observed. This is consistent with the very gradual decline in concentration observed in the dated sediment cores. A similar comparison of the two periods is made in Figure 3.1-8, but for RM1 to RM7 as opposed to the intervals used in Figure 3.1-3a. In this instance, the median value for the adjusted Total PCB concentrations in 1995 is within 10 percent of the 2008-2010 value for RM1 to RM7. Given the assumptions and uncertainties involved in applying the adjustment factor, any real change in the surface sediment concentration is too small to be distinguishable from the uncertainties and variability in the data sets.
- Relatively minor concentration gradients are observed above RM12 and below RM2, especially after TOC normalization of the Be-7 bearing sediment samples (Figure 3.1-6). Specifically, the RM2 to Newark Bay gradient for TOC-normalized PCB concentrations is reduced to a factor of 2 over its length and the Upper Passaic River to RM12 gradient is essentially eliminated. This indicates that surface sediment concentrations of Total PCBs in the Lower Passaic River are more similar to those found in the Upper Passaic River and Newark Bay as compared to the very large (2 orders of magnitude) gradients observed for 2,3,7,8-TCDD concentrations in these areas.
- The Total PCBs concentrations in Be-7 bearing sediments in the Upper Passaic River are very similar in concentration to concentrations in Be-7 bearing sediments in the Lower Passaic River, especially when TOC-normalized. This suggests that the load of PCBs from the Upper Passaic River is a significant portion of the Total PCB budget for the Lower Passaic River. This indication is confirmed by the Empirical Mass Balance Analysis (see Appendix C).
- Similar to 2,3,7,8-TCDD, Total PCB concentrations above RM8 are about twice as high in fine-grained sediments as compared to coarse-grained sediments, but show no difference in time (1995-2010) or river mile (RM1 to RM13, comparing fine sediments). Total PCBs concentrations also and show no significant difference between channel and shoal sediments below RM8.

3.2 Temporal and Spatial Trends of Pesticides in Surface Sediments

The three pesticides identified as COPC and COPECs in the risk assessment were analyzed for surface sediment concentration trends: Total 4,4'-DDT, including all 3 forms (4,4'- Dichlorodiphenyltrichloroethane (4,4'-DDT) and its metabolites 4,4'-Dichlorodiphenyldichloroethane (4,4'-DDD) and 4,4'- Dichlorodiphenyldichloroethylene (4,4'-DDE); abbreviated here as Total DDx), dieldrin, and total chlordane. Pesticides generally confirmed the observations obtained from the analysis of 2,3,7,8-TCDD. In particular, the observations relating to the current distribution of contamination along the main axis of the river, where the 0 to 6 inch surface concentrations are highly variable but show no trend with river mile from RM2 to RM12. Like 2,3,7,8-TCDD, the pesticides show decreasing concentration gradients with river mile above RM12 and below RM2. However, there are apparent differences in surface concentrations over time for two of the pesticides. Changes in analytical techniques during this period make it difficult to determine if these differences are real. Among other concerns, 4,4'-DDT quantitation in 1995 was relatively poor due to the presence of significant interference, resulting in many rejected and nondetect analyses. Note that gas chromatography/electron capture detector (GC/ECD) SW-846 Method 8081A used in 1995 was rejected in favor of high resolution gas chromatography/high resolution mass spectrometry (HRGC/HRMS) USEPA Method 1699 and NYSEC HRMS-2, WS-ID-0014 in the later studies. For this reason, comparisons involving the 1995 data set are done on the basis of 4,4'-DDE alone (this compound was fairly frequently detected in surface sediment samples) while later comparisons use the sum of the 3 DDT forms (4,4'-DDE, 4,4'-DDD, and 4,4'-DDT). Figures 3.2-1 to 3.2-25 present the sequence of analysis for these pesticides, paralleling the 2,3,7,8-TCDD analyses. Following are the additional observations from the analysis of the pesticide results, including differences from the 2,3,7,8-TCDD observations:

- 4,4'-DDE, dieldrin, and total chlordane did exhibit higher concentrations in fine-grained sediments versus coarse-grained sediments above RM8 (2-3 times), as was observed for 2,3,7,8-TCDD. However, the concentrations in the fine-grained sediments above RM8 were notably higher than those below RM8 (about 1.5 to 2.0

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times as high). This is different from the behavior for 2,3,7,8-TCDD, wherein fine-grained sediment concentrations were the same upstream and downstream of RM8.

- Both Total DDx and dieldrin exhibited little difference between shoal and channel areas for RM2 to RM8, as was observed for 2,3,7,8-TCDD. However, median channel and shoal concentrations for the two pesticides were different in RM0 to RM2, with shoal concentrations about 25 and 45 percent lower than channel, respectively for Total DDx and dieldrin. Total chlordane exhibited lower concentrations in the shoals than in the channel everywhere below RM8: about 25 percent lower for RM2 to RM8 and 45 percent lower for RM0 to RM2. The reason for the channel-shoal differences in pesticides that were not evident in 2,3,7,8-TCDD and PCBs is unknown. Nonetheless, while these differences are significant based on statistical considerations, they do not represent substantive differences between channel and shoal in the level of risk posed by these compounds. Specifically, risks to biota and humans are linearly related to environmental concentrations (see Data Evaluation Report No. 6). As a result, only order of magnitude changes yield substantive changes in risk. Therefore, the channel and shoal sediments would be expected to yield comparable risk levels for the same exposure scenarios since the concentration differences between channel and shoal sediments are a factor of 2 or less (*i.e.*, less than 50 percent).
- The concentration gradients with river mile above RM12 and below RM2 are substantially shallower than those observed for 2,3,7,8-TCDD. The Be-7 bearing sediments and TOC normalized data reduces the concentration gradients with river mile for pesticides even further. This observation highlights the greater importance of the Upper Passaic River in the mass budgets for these compounds in the Lower Passaic River. The substantive reduction of the gradient above RM12 by controlling for time (Be-7 bearing) and TOC content indicates that the Upper Passaic River is currently delivering solids with concentrations for these three pesticides that are comparable to Lower Passaic River concentrations on a TOC basis. Variations in absolute concentrations for these compounds between RM12 and RM17.4 are largely a factor of the organic carbon content and by inference, the coarse-grain sediment fraction. In a similar construct, the shallowness of the concentration gradient to

Newark Bay highlights the presence of substantive levels of these compounds on NY/NJ harbor suspended matter. In total, these observations indicate that these compounds are more strongly influenced by external solids loads to the Lower Passaic River, unlike 2,3,7,8-TCDD. The relative importance of external sources and resuspension of legacy sediment is quantitatively estimated in the Empirical Mass Balance Analysis (see Appendix C).

- The concentrations observed for 4,4',-DDE and dieldrin in the 1995 TSI study mimic the spatial distribution of these contaminants in 2008 to 2012 (*i.e.*, highly variable but with little to no trend with river mile). However, the absolute concentrations of these two pesticides are 2 to 5 times higher in 1995 than in 2008 to 2012 period for DDE and dieldrin, respectively. This observation is not borne out by other lines of evidence, such as the dated sediment cores (see Figures 3.2-26 and 3.2-27 and Data Evaluation Report No. 3) and fish body burdens (see Data Evaluation Report No. 6). For 4,4'-DDE, the decline in surface sediment concentrations appears much more rapid than the dated sediment cores or the fish tissue. Figure 3.2-26 shows the very slowly declining concentrations of 4,4'-DDE across all five dated sediment cores. For dieldrin, the dated sediment core evidence from both the Upper and Lower Passaic River indicates that concentrations for this compound are increasing over time at all dated sediment locations (see Figure 3.2-26), whereas the 1995 to 2008- 2012 trend for the surface sediments indicates a decline in concentration.
- Comparisons involving the 1995 data set for DDT were done on the basis of 4,4'-DDE alone, because of analytical concerns for 4,4'-DDT and its other metabolite in the 1995 data set. Specifically, the 1995 results were obtained using SW-846 Method 8081A, which involves GC/ECD. Quantitation by this method was relatively poor due to the presence of many interferences, resulting in many rejected and non-detect results. Comparisons among the later data sets are able to use the sum of the three DDT forms (4,4'-DDE, 4,4'-DDD, and 4,4'-DDT) to represent Total DDx concentration trends, because quantitation was improved through the use of a HRGC/HRMS (USEPA Method 1699 and NYSDEC HRMS-2, WS-ID-0014). In 2008, the CPG analyzed chlorinated pesticides by both the HRGC/HRMS method and the standard SW-846 GC/ECD method. The results show that the HRGC/HRMS

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procedures offer greater sensitivity, improved accuracy, and enhanced compound identification.

- Given these concerns and observations, the calculated decline in concentrations from 1995 to 2012 suggested by the 0 to 6 inch samples for these compounds is unlikely to have actually occurred. Rather, the declines described by the dated sediment cores are considered more reflective of the true changes in these compounds over time.

3.3 Temporal and Spatial Trends of PAHs in Surface Sediments

Recognizing the close correlations among individual PAH compounds, PAHs were treated in three groups rather than as individual compounds for this analysis. Parallel analyses were conducted for high molecular weight (HMW) PAHs (4 or more rings per molecule), low molecular weight (LMW) PAHs (2 to 3 rings per molecule), and Total PAHs. The analyses are presented in Figures 3.3-1 to 3.3-24. In general, PAH compounds closely replicated the trends for 2,3,7,8-TCDD in nearly all aspects below RM8 and had no trend with river mile to RM12. The notable differences involved the following observations:

- The PAH concentration trend above RM12 lacked a downward gradient toward RM17.4,
- The correlation between PAHs and sediment characteristics above RM8 differed from the 2,3,7,8-TCDD spatial trends, and
- A comparison of the 1995 to the later studies suggested an apparent increase in PAH concentrations to the present (*i.e.*, 1995 sediments were statistically lower than more recent samples).

The last observation is attributed to analytical differences between programs and is not considered accurate since the high resolution cores do not support increasing surface sediment PAH concentrations over time, indicating instead that PAH concentrations in surface sediments have remained nearly constant since about 1975 (see Data Evaluation Report No. 3). The following are the main observations derived from the PAH results:

- The trends with river mile for the three PAH sums are similar to each other and to observations from 2,3,7,8-TCDD concentrations, indicating the mixing ability of tidal transport, scour, and deposition.

- PAH concentrations do not decline appreciably above RM12, unlike 2,3,7,8-TCDD and to a lesser extent, 4,4'-DDE. If concentrations are normalized to TOC, they actually increase above RM12 for both coarse and fine-grained sediments.
- PAH concentrations in the Upper Passaic are comparable or higher than those observed in the Lower Passaic River. This is most easily evident when Be-7 bearing sediments are normalized to TOC; Upper Passaic River sediments are clearly higher in PAH concentrations. This difference indicates an on-going source of PAHs to the Lower Passaic River from the Upper Passaic River, given the magnitude of flow and solids that enter the Lower Passaic River from the Upper Passaic River. This data-based observation is confirmed by the Empirical Mass Balance analysis (see Appendix C), which finds the Upper Passaic River to be the most significant PAH source of benzo(a)pyrene and fluoranthene to the Lower Passaic River.
- A comparison of the PAH concentrations in fine-grained and coarse-grained sediments above RM8 yielded the smallest differential between the two sediment types for any of the organic compounds examined. Median concentrations on coarse-grained sediments were only 25 percent lower than the concentrations on fine-grained sediments. By contrast, most other organic compounds were at least 40 percent lower on coarse-grained sediments.

3.4 Temporal and Spatial Trends of Metals in Surface Sediments

The last compound class considered in this analysis of surface sediment contamination is the metals. In this analysis, cadmium, chromium, copper, lead, and mercury are examined for their spatial and temporal trends. Of these, copper, lead, and mercury are COPCs or COPECs. The other two metals were examined here due to their potential usefulness in geochemical data interpretation and the Empirical Mass Balance (see Appendix C). Figures 3.4-1 to 3.4-40 present the various analyses conducted for these five metals.

All five metals examined closely follow the spatial distribution pattern described by 2,3,7,8-TCDD, the main difference being the steepness of the concentration trend with river mile below RM2. In general, Newark Bay metal concentrations on solids are not

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very different from those observed in the Lower Passaic River so the concentration gradient below RM2 is rather shallow. The trend of metal concentrations with river mile above RM12 is more pronounced and more closely mimics the shape of the 2,3,7,8-TCDD trend. Overall, the spatial trends in metal concentrations confirm the observations based 2,3,7,8-TCDD. The important additional observations are noted below:

- Iron normalization significantly reduces the variability in concentrations in most metals for both Be-7 bearing samples as well as 0 to 6 inch samples obtained from depositional locations. As noted previously, this reduction in variance reflects the geochemistry of iron in that it is generally associated with the binding sites on fine-grained particles that will also absorb other metal species. Thus, increased iron levels indicate increased binding sites and increased fine-grained particle content in the sample. Iron normalization typically exhibited a greater effect reducing sample-to-sample variability for metal contaminants than TOC normalization did for organic contaminants, indicating that fine-grained sediment content may control metal contamination levels more closely than it controls organic contamination levels.
- Iron normalized data in RM2 to RM12 exhibit significantly reduced variability for four of the five metals (variability among Be-7 bearing mercury analyses did not decline as a result of normalization to iron). Sample to sample variability for three of the four remaining metals was $\pm$ 15 percent of the value or less. For lead, the variability was reduced to $\pm$ 20 percent.
- Based on the low degree of variability in recently-deposited sediments from RM2 to RM12, it can be inferred that variations in water column fine-grained suspended matter contaminant burdens (*i.e.*, the particles that are the source of these recently-deposited sediments) are reduced to the same degree or less on the scale of 6 months to 1 year. That is, water column concentrations of metals on suspended matter vary less than $\pm$20 percent between RM2 and RM12 when averaged over a 6 to 12 month period. It is likely that water column concentrations of organic contaminants have a similar level of agreement over this portion of the Lower Passaic River, based on the similarly low variability noted in TOC-normalized samples. The distribution of metal concentrations is considered further evidence for the dynamic and extensive nature of tidal mixing in the Lower Passaic River.

- Metals contamination in 0 to 6 inch surface sediments exhibit the same spatial variation patterns as 2,3,7,8-TCDD, *i.e.*, surface sediments exhibit a large degree of variability but the central tendency remains the same from RM2 to RM12. The central tendency in the 0 to 6 inch samples is generally coincident with the mean value of the Be-7 bearing samples.
- Overall metal variability is less than that observed for the organic contaminants. This is most easily noted by comparing the number of log cycles on the organic sample presentations (typically 6 cycles) with those for the metal sample presentations (typically 4 cycles).
- For cadmium, chromium, copper, and lead, shoal and channel samples were within statistical agreement below RM8, while for mercury the data suggest some differences in channel and shoal although the differences were not statistically significant. All metals results showed reduced concentrations for coarse-grained sediment samples upstream of RM8 relative to fine-grained sediment samples.
- All five metals showed a decline in 0 to 6 inch sediment concentrations from 1995 to 2008-2012 for RM2 to RM8, with the greatest decline observed for mercury. While a decline in these concentrations is expected given the results of the dated sediment cores, the magnitude of the change obtained by comparing surface concentrations is much greater than predicted by other lines of evidence and suggests there may be analytical issues across the 0 to 6 inch sediment sampling programs leading to this observation. Notably, fish tissue concentrations in the Lower Passaic River for several of these metals have not declined consistently over this period, varying in trend from study to study and among species (see Data Evaluation Report No. 6). The dated sediment cores indicate much slower rates of decline across the entire river post-1995, but these rates appear consistent with the dated core-based rates of decline estimated for the post-1980 period. Because of the continuous nature of the records, their internal analytical consistency and their agreement across 12 miles of the Lower Passaic River, the rate of decline in metals concentrations from the dated sediment cores is considered the best estimate of the actual rate of decline in metal concentrations.

4 SUMMARY OF DATA EVALUATION REPORT NO. 4

The analysis of surface sediment contamination in the Lower Passaic River has provided a series of observations that form much of the basis for the conceptual site model. These observations provide insight into the processes at work in the Lower Passaic River that govern the fate and transport of the contaminants found there. In conducting the analysis, 2,3,7,8-TCDD was used to glean many of the original insights due to the scale of the differences between Lower Passaic River sediment concentrations and those of the external sources of solids. The analysis of the other 13 compounds, representing the compound classes PCBs, pesticides, PAHs and metals, confirmed the insights in nearly every instance, providing an extensive series of observations to support the construction of the conceptual site model. In a limited number of instances, the interpretation of the other compounds provided a more nuanced understanding of the processes involved, but did not change the main conclusions drawn from the 2,3,7,8-TCDD-based observations. This analysis and the conclusions that follow are based on a review of data from 16 different studies of sediment contamination in the Lower Passaic River, involving sampling intervals from 0 to 1 to 0 to 6 inches thick.

Listed below are the main conclusions of this data evaluation report:

- Surface concentrations are locally variable but largely without trend in river mile from RM2 to RM12. Of note, concentrations of 2,3,7,8-TCDD in 0 to 6 inch samples can vary over 4 orders of magnitude within a single river mile interval. However, 2,3,7,8-TCDD concentrations in recently-deposited sediments vary less than a factor of 3 from RM2 to RM12, slowly and regularly increasing in value moving upstream. This gradual increase is further reduced when concentrations are normalized to TOC. Other compounds show a similar distribution, with highly variable local concentrations but little variation in the concentrations measured in recently-deposited sediments from RM2 to RM12.
- When Upper Passaic River contamination on recently-deposited sediments is less than that of the Lower Passaic River, an increasing concentration gradient occurs from RM17.4 to RM12.

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- When downstream contamination is less than that of the Lower Passaic River, a decreasing concentration gradient occurs from RM2 to RM0 and sometimes extends to the southern end of Newark Bay.
- For organic contaminants, normalization to TOC further reduces concentration variation within the Lower Passaic River for Be-7 bearing (*i.e.*, recently-deposited) sediments but does little to reduce variability in 0 to 6 inch results from samples in depositional locations. This is because 0 to 6 inch samples tend to incorporate much older materials (pre-1990s), which are generally more contaminated, thus reducing the interpretative value of normalization.
- Some component of the concentration gradient above RM12 is due to the greatly reduced presence of fine-grained sediment in this region. In some instances, normalization to TOC or iron largely eliminates the gradient for recently-deposited sediments, indicating that the Upper Passaic River is contributing contaminant concentrations on a fine-grained particle basis that are comparable to those observed in the Lower Passaic River for contaminants such as PAHs, dieldrin and Total Chlordane.
- For metal contaminants, normalization to iron reduces sample-to-sample variability, often fairly substantially, and typically more than TOC normalization does for organic contaminants, indicating that fine-grained sediment content may control metal contamination levels more closely than organic contamination levels.
- Iron-normalized data in RM2 to RM12 exhibit significantly reduced variability for cadmium, chromium, copper, and lead. Sample to sample variability for cadmium, chromium, and copper was $\pm$ 15 percent or less of the mean value for RM2 to RM12. For lead, the variability was reduced to $\pm$ 20 percent. Variation in mercury concentrations is larger (roughly $\pm$45 percent) and was not reduced by normalization to iron. The reason for the lack of improvement in mercury variation has not been explored.
- The low variability in recently-deposited sediments indicates that tidal mixing homogenizes water column fine-grained suspended matter contaminant burdens (*i.e.*, the particles that are the source of these recently-deposited sediments). That

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is, water column concentrations of metals on fine-grained suspended matter vary less than ± 20 percent between RM2 and RM12 (when averaged over a 6 to 12 month period, which is the measurement period of Be-7). It is likely that water column concentrations of organic contaminants have a similarly low range of variability over this region, based on the similarly low variability noted in TOC-normalized samples.

- Surface concentrations within RM2 to RM12 are affected by variations in fine-grained sediment content (*i.e.*, percent fines). Most variation in fine-grained sediment content in surface sediments occurs above RM8, where most of the river bottom is characterized as sands and coarser sediment with pockets of fine-grained sediments. In RM2 to RM8, each contaminant showed comparable concentrations in channel and shoal areas, with local variations. No contaminant showed a systematic trend with river mile in RM2 to RM8.
- Extreme values of the COPCs and COPECs occurred somewhat randomly across the river bottom and do not always coincide with extreme values of other COPCs or COPECs. These observations occurred in the 0 to 6 inch and 0 to 2 inch non-Be-7 bearing samples. The randomness of these values indicates that care is necessary in estimating local concentration averages. These extreme values are likely the result of differences in release history for the various compounds such that different compounds reach maximum values at different horizons with the sediment bed. Their presence at the riverbed surface is evidence for reworking of the sediment bed after initial deposition and burial. Alternatively, and probably less likely in the channel and deeper shoals, their presence at the riverbed surface may be evidence for lack of burial subsequent to deposition 30 to 40 years ago.
- Samples obtained from 0 to 6 inches integrate sediments over highly variable time scales, whereas Be-7 bearing samples represent just the last year of deposition or less. As a result, 0 to 6 inch samples have inherently more variable concentrations, incorporating deeper, more contaminated sediments.
- The observations of parallel trends in median contaminant concentrations across the Lower Passaic River from both 0 to 6 inch samples and the Be-7 bearing sediments is the result of the estuarine processes at work in the river. The spatial

distribution of the COPCs and COPECs in the Lower Passaic River is well explained by the occurrence of extensive tidal mixing and reworking of the sediment bed, generating locally variable concentrations as legacy sediments are exposed and reworked, while recent deposition is evenly contaminated over distances of several miles.

- Some compounds such as DDT, mercury and dieldrin appear to have lower surface concentrations in the 2008 to 2012 sampling period than in 1995, unlike 2,3,7,8-TCDD. The comparison of 0 to 6 inch samples indicated higher PAH concentrations in 2008 to 2012 relative to 1995. These observations are inconsistent with those from the dated sediment cores (see Data Evaluation Report No. 3) and probably result from analytical differences among sampling programs and over time. Analytical differences are not an issue for the dated sediment cores since a single analytical technique was used across all cores for all core layers for any given analyte. Thus, the magnitude of the differences suggested by comparison across the various surface sediment sampling programs may not be real.

Based on these observations, the Lower Passaic River Study area can be divided into the following regions for the purposes of the conceptual site model of contaminant transport:

- The Upper Passaic River exhibits a generally low level of contamination relative to the Lower Passaic River when viewed on a simple concentrations basis; the exception is PAHs. Normalized concentrations further reduce the differences between the Upper Passaic sediments for PCBs, dieldrin, and chlordane, which appear comparable to or higher than normalized levels in the Lower Passaic River. This indicates that the level of contamination in Upper Passaic River fine-grained sediment is comparable to levels found in recently-deposited Lower Passaic River sediments for PAHs, PCBs, dieldrin, and chlordane. Irrespective of normalization, however, the Upper Passaic River is still orders of magnitude lower in 2,3,7,8-TCDD concentrations relative to the Lower Passaic River.

- The RM12 to RM17.4 region is characterized by an increasing concentration gradient with decreasing river mile (a two-order of magnitude gradient in 2,3,7,8-TCDD concentration). This is the result of the mixing of cleaner Upper Passaic solids with more contaminated resuspended solids originating in the Lower Passaic River,
- The RM8 to RM12 region is characterized by highly variable contaminant concentrations but little-to-no trend in concentration with river mile. Some of the concentration variability can be explained by variations in fine-grained sediment content. In particular, the RM8 to RM12 region has wide areas of coarse-grained sediments and relatively few areas of fine-grained sediments. Higher contaminant concentrations occur primarily in fine-grained sediments in this region.
- The RM2 to RM8 region is also characterized by highly variable contaminant concentrations but has a stronger central tendency to the distribution compared to the RM8 to RM12 region, with many samples close to the median concentration for each contaminant. This is attributed in part to the more spatially extensive fine-grained sediment texture that is characteristic of this region. There is little area characterized as coarse-grained in RM2 to RM8.
- The RM0 to RM2 region is characterized by a shallow concentration gradient for most contaminants. This gradient is still substantively steeper than any trend observed from RM2 to RM12. For 2,3,7,8-TCDD, the gradient in this region is much shallower than that observed in the RM12 to RM17.4 region. The gradient in the RM0 to RM2 region is attributed to the mixing of solids from Newark Bay into the Lower Passaic River as the result of tidal exchange.

5 ACRONYMS

2,3,7,8-TCDD	2,3,7,8-Tetrachlorodibenzo-p-dioxin
Be-7	Beryllium-7
BZ	Ballschmiter and Zell
COPC	Contaminants of Potential Concern
COPEC	Contaminants of Potential Ecological Concern
CPG	Cooperating Parties Groups
CSO	Combined Sewer Overflow
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
FFS	Focused Feasibility Study
GC/ECD	Gas Chromatography/Electron Capture Detector
HMW	High Molecular Weight
HRGC/HRMS	High Resolution Gas Chromatography/High Resolution Mass Spectrometry
K_d	partitioning coefficient
LMW	Low Molecular Weight
LPRSA	Lower Passaic River Study Area
NYSDEC	New York State Department of Environmental Conservation
pg/g	picograms per grams of sediment
PAH	Polycyclic Aromatic Hydrocarbon
PCA	Principal Components Analysis
PC1	First principal component
PC2	Second principal component
PC3	Third principal component
PCB	Polychlorinated Biphenyl
RI	Remedial Investigation
RM	River Mile
SWO	Stormwater Outfall

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TOC	Total Organic Carbon
TOPS	Trace Organics Platform Sampler
Total DDx	Sum of the three DDT metabolites (4,4'-DDE, 4,4'-DDD and 4,4'-DDT
Total TCDD	Total Tetrachlorodibenzo-p-dioxin
TSI	Tierra Solutions, Inc.
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey

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TABLES

Table 1-1: Surface Sediment Sampling Programs Used in Data Evaluation Report No. 4

Year	Study Name	Analytical Methods
1991	USEPA Core Sediment Investigation	Not Available
1991	NOAA NS&T Hudson-Raritan Phase I	Analytical Methods of the National Status and Trends Program Benthic Surveillance and Mussel Watch Projects 1984-1992 (Peven and Uhler, 1993)
1993	NOAA NS&T Hudson Raritan Phase 2	Analytical Methods of the National Status and Trends Program Benthic Surveillance and Mussel Watch Projects 1984-1992 (Peven and Uhler, 1993)
1993	USEPA Passaic Core Sediment Investigation	Not Available
1993	REMAP 1993	PAHs: Methylene chloride extraction; determination by GC/MSC. TSB SOP C-48 (USEPA Region 2, 1994a) PCB/Pesticides: Methylene chloride extraction; determination by HRGC/ECD; GERG SOPs-ST02, ST04 Total Metals: HNO3 and HF acid digestion; GERG SOPs ST08, ST09, ST10, ST11 Total recoverable metals: HNO3/H2O2 or microwave digestion; TSB SOPs C-5, C-8, C-72, C-73 C-74 (USEPA Region 2, 1994b-f) Hexavalent Chromium: Chelation with APDC, extraction with MIBK, determination by FAAS; MCAWW 218.4 (USEPA, 1983) Dioxins and Furans: Method 1613A AVS/SEM: GERG SOPs-9130, ST11, ST09, ST10 Butyltins: Tropolone extraction, determination by HRGC/FPD or HRGC/MS (GERG SOP-9013) TOC: Acidification with H3PO4, determination using CO2 analyzer; MCAWW 415.1 (USEPA 1983) Grain size: sieving and pipette analysis (USEPA, 1993)
1995	Passaic RI Sampling Program	Pesticide/PCBs: 3550/8081 Chlorinated Herbicides: INC/8150A PCDDs/PCDFs: INC/1613A Metals: 3050A/6010A Lead: 3050A/7421 Mercury: INC/7471 TOC: INC / Lloyd Kahn
1995	USACE Minish Park Investigation	Not Available
1999	1999 Sediment Sampling Program	Semi-VOAs (excluding PAHs): 3540C/8270C (biological) & 3550B/8270C (sediment) Percent Lipid: NOAA, 1993 PAHs: HRCG/LRMS/SIM (GERG, 1998) Pesticides: 8081A PCB Aroclors: 8082 PCB Congeners and Homologues: 1668M PCDD/PCDFs: 1613A Inorganics including Mercury: 3010A/3050B/3052/6010B/7470A/7471A Cyanide: 9010B/9012A/9013/9014 TOC: 9060 Lloyd Kahn DOC: 9060 TSS: 160.2 Ammonia: 350.3 Acid Volatile Sulfide/Simulataneously Extracted Metals (Allen et al., 1991) Sediment Toxicity Testing for Marine and Estuarine Amphipods: ASTM E1367 Sediment Toxicity Testing for Polychaetes (ASTM E1611)

Table 1-1: Surface Sediment Sampling Programs Used in Data Evaluation Report No. 4

Year	Study Name	Analytical Methods
1999	1999 Late Summer/ Early Fall Environmental Sampling Program	Semi-VOAs (excluding PAHs): 3540C/8270C (biological) & 3550B/8270C (sediment) Percent Lipid: NOAA, 1993 PAHs: HRCG/LRMS/SIM (GERG, 1998) Pesticides: 8081A PCB Aroclors: 8082 PCB Congeners and Homologues: 1668M PCDD/PCDFs: 1613A Inorganics including Mercury: 3010A/3050B/3052/6010B/7470A/7471A Cyanide: 9010B/9012A/9013/9014 TOC: 9060 Lloyd Kahn DOC: 9060 TSS: 160.2 Ammonia: 350.3 Acid Volatile Sulfide/Simulataneously Extracted Metals (Allen *et al.* , 1991) Sediment Toxicity Testing for Marine and Estuarine Amphipods: ASTM E1367 Sediment Toxicity Testing for Polychaetes (ASTM E1611)
1999-2000	USACE Minish Park Monitoring Program	Not Available
2000	2000 Spring Environmental Sampling Program	Semi-VOAs (excluding PAHs): 3540C/8270C (biological) & 3550B/8270C (sediment) Percent Lipid: NOAA, 1993 PAHs: HRCG/LRMS/SIM (GERG, 1998) Pesticides: 8081A PCB Aroclors: 8082 PCB Congeners and Homologues: 1668M PCDD/PCDFs: 1613A Inorganics including Mercury: 3010A/3050B/3052/6010B/7470A/7471A Cyanide: 9010B/9012A/9013/9014 TOC: 9060 Lloyd Kahn DOC: 9060 TSS: 160.2 Ammonia: 350.3 Acid Volatile Sulfide/Simulataneously Extracted Metals (Allen et al., 1991) Sediment Toxicity Testing for Marine and Estuarine Amphipods: ASTM E1367 Sediment Toxicity Testing for Polychaetes (ASTM E1611)
2005	USACE Sedflume Testing	Total Mercury: EPA-CLP (ILM0.5.3) with flex clause Trace Mercury:EPA 1631 plus modifications for extraction of sediment Methyl Mercury: EPA 1630 EPA 1630 plus modifications for extraction of sediment Chromium,Hexavalent: 7199/3060A SEM Metals (Cd, Pb, Hg, Ni and Zn): SW-846 methods or other approved USEPA methods for metals SVOCs including PAHs and PCB Aroclors: EPA-CLP SOM1.0, with flex cause options to achieve requested RLs PAHs: 8270 (modified) Pesticides: 8081 (modified) PCB congeners: EPA 1668A Dioxins/furans: EPA 1613B Screening for $Dioxin_{TEQ}$ and PCB_{TEQ}: 4025 (modifiedd) Chlorinated Herbicides: 8151A TOC Combustion: Lloyd Kahne Be-7, Cs-137, Pb-210: HASL-300 EML and USEPA-600

Table 1-1: Surface Sediment Sampling Programs Used in Data Evaluation Report No. 4

Year	Study Name	Analytical Methods
2005	USEPA Gust Microcosm Testing	Total Mercury: EPA-CLP (ILM0.5.3) with flex clause Trace Mercury:EPA 1631 plus modifications for extraction of sediment Methyl Mercury: EPA 1630 EPA 1630 plus modifications for extraction of sediment Chromium,Hexavalent: 7199/3060A SEM Metals (Cd, Pb, Hg, Ni and Zn): SW-846 methods or other approved USEPA methods for metals SVOCs including PAHs and PCB Aroclors: EPA-CLP SOM1.0, with flex cause options to achieve requested RLs PAHs: 8270 (modified) Pesticides: 8081 (modified) PCB congeners: EPA 1668A Dioxins/furans: EPA 1613B Screening for $Dioxin_{TEQ}$ and PCB_{TEQ}: 4025 (modifiedd) Chlorinated Herbicides: 8151A TOC Combustion: Lloyd Kahne Be-7, Cs-137, Pb-210: HASL-300 EML and USEPA-600
2005	USEPA High Resolution Sediment Coring	Total Mercury: EPA-CLP (ILM0.5.3) with flex clause Trace Mercury:EPA 1631 plus modifications for extraction of sediment Methyl Mercury: EPA 1630 EPA 1630 plus modifications for extraction of sediment Chromium,Hexavalent: 7199/3060A SEM Metals (Cd, Pb, Hg, Ni and Zn): SW-846 methods or other approved USEPA methods for metals SVOCs including PAHs and PCB Aroclors: EPA-CLP SOM1.0, with flex cause options to achieve requested RLs PAHs: 8270 (modified) Pesticides: 8081 (modified) PCB congeners: EPA 1668A Dioxins/furans: EPA 1613B Screening for $Dioxin_{TEQ}$ and PCB_{TEQ}: 4025 (modifiedd) Chlorinated Herbicides: 8151A TOC Combustion: Lloyd Kahne Be-7, Cs-137, Pb-210: HASL-300 EML and USEPA-600
2005	Polytechnic Institute (RPI) and Lamont-Doherty Earth Observatory (L-DEO) Upper Passaic High Resolution Sediment Cores	Radionuclide measurements were carried out using a gamma counter with an intrinsic germanium detector (ORTEC GWL-120)
2005	Newark Bay Study Phase I Remedial Investigation	Cadmium: USEPA 6010B Mercury: USEPA 7471A PAHs: USEPA 8270C 4,4'-DDD, DDE & DDT: USEPA 8081 Dieldrin: USEPA 8081 Aroclor PCBs: USEPA 3550/8082 Congener PCBs: USEPA 1668A PCDDs/PCDFs: USEPA 1613B Total Organic Carbon: Lloyd Kahn

Table 1-1: Surface Sediment Sampling Programs Used in Data Evaluation Report No. 4

Year	Study Name	Analytical Methods
2006	USEPA Low Resolution Sediment Coring	Total Mercury: EPA-CLP (ILM0.5.3) with flex clause Trace Mercury:EPA 1631 plus modifications for extraction of sediment Methyl Mercury: EPA 1630 EPA 1630 plus modifications for extraction of sediment Chromium,Hexavalent: 7199/3060A SEM Metals (Cd, Pb, Hg, Ni and Zn): SW-846 methods or other approved USEPA methods for metals SVOCs including PAHs and PCB Aroclors: EPA-CLP SOM1.0, with flex cause options to achieve requested RLs PAHs: 8270 (modified) Pesticides: 8081 (modified) PCB congeners: EPA 1668A Dioxins/furans: EPA 1613B Screening for $Dioxin_{TEQ}$ and PCB_{TEQ}: 4025 (modifiedd) Chlorinated Herbicides: 8151A TOC Combustion: Lloyd Kahne Be-7, Cs-137, Pb-210: HASL-300 EML and USEPA-600
2007	Newark Bay Study Phase II Remedial Investigation	Cadmium: USEPA CLP, ILM06.X-Met Mercury: USEPA CLP, ILM06.X-Met PAHs: USEPA CLP, SOM01.2 4,4'-DDD, DDE & DDT: USEPA CLP, SOM01.2 Dieldrin: USEPA CLP, SOM01.2 Aroclor PCBs: USEPA CLP, SOM01.2 Congener PCBs: USEPA 1668A PCDDs/PCDFs: USEPA 1613B Total Organic Carbon: Lloyd Kahn
2007	USEPA Upper Passaic High Resolution Sediment Coring	Total Mercury: EPA-CLP (ILM0.5.3) with flex clause Trace Mercury:EPA 1631 plus modifications for extraction of sediment Methyl Mercury: EPA 1630 EPA 1630 plus modifications for extraction of sediment Chromium,Hexavalent: 7199/3060A SEM Metals (Cd, Pb, Hg, Ni and Zn): SW-846 methods or other approved USEPA methods for metals SVOCs including PAHs and PCB Aroclors: EPA-CLP SOM1.0, with flex cause options to achieve requested RLs PAHs: 8270 (modified) Pesticides: 8081 (modified) PCB congeners: EPA 1668A Dioxins/furans: EPA 1613B Screening for $Dioxin_{TEQ}$ and PCB_{TEQ}: 4025 (modifiedd) Chlorinated Herbicides: 8151A TOC Combustion: Lloyd Kahne Be-7, Cs-137, Pb-210: HASL-300 EML and USEPA-600
2007-2008	USEPA Supplemental Sediment Programs	Congener PCBs: USEPA Method 1668A PCDDs /PCDFs: USEPA Method 1613B Pesticides: Axys Method MLA-028 (HRGC/HRMS similar to 1613B) PAHs: Axys Method MLA-021 (similar to SW846-8270) PCB Aroclors: SW846-8082 TOC: USEPA Lloyd Kahn Method TAL Metals plus Titanium and Mercury: SW-846-6010B and 6020/7470A (The lab used ICP-AES and if necessary ICP-MS, which ever given the better detection limits) Radiochemistry Be-7, Cs-137 and K-40: HASL-300 EML or USEPA Method 4 80-032

Table 1-1: Surface Sediment Sampling Programs Used in Data Evaluation Report No. 4

Year	Study Name	Analytical Methods
2008	USEPA Suspended-Phase High Flow Storm Event Sampling	Congener PCBs: USEPA Method 1668A PCDDs /PCDFs: USEPA Method 1613B Pesticides: Axys Method MLA-028 (HRGC/HRMS similar to 1613B) PAHs: Axys Method MLA-021 (similar to SW846-8270) PCB Aroclors: SW846-8082 TOC: USEPA Lloyd Kahn Method TAL Metals plus Titanium and Mercury: SW-846-6010B and 6020/7470A (The lab used ICP-AES and if necessary ICP-MS, which ever given the better detection limits) Radiochemistry Be-7, Cs-137 and K-40: HASL-300 EML or USEPA Method 4 80-032
2008	USEPA Sedflume Consolidation Testing	Total Mercury: EPA-CLP (ILM0.5.3) with flex clause Trace Mercury:EPA 1631 plus modifications for extraction of sediment Methyl Mercury: EPA 1630 EPA 1630 plus modifications for extraction of sediment Chromium,Hexavalent: 7199/3060A SEM Metals (Cd, Pb, Hg, Ni and Zn): SW-846 methods or other approved USEPA methods for metals SVOCs including PAHs and PCB Aroclors: EPA-CLP SOM1.0, with flex cause options to achieve requested RLs PAHs: 8270 (modified) Pesticides: 8081 (modified) PCB congeners: EPA 1668A Dioxins/furans: EPA 1613B Screening for $Dioxin_{TEQ}$ and PCB_{TEQ}: 4025 (modifiedd) Chlorinated Herbicides: 8151A TOC Combustion: Lloyd Kahne Be-7, Cs-137, Pb-210: HASL-300 EML and USEPA-600
2008	2008 CPG Low Resolution Sediment Coring	Cadmium: USEPA 6020 Chromium (total): USEPA 6020 Chromium (hexavalent): USEPA 7199/3060A Copper: USEPA 6020 Lead: USEPA 6020 Mercury, low level: USEPA 1631 Methyl Mercury: USEPA 1630 modified TOC: Lloyd Kahn Method PCBs, Aroclors: Method 8082 PCBs – Homologs and Congeners: Method 1668A Dioxin/Furan: Method 1613B Organochlorine Pesticides: Method 8081A Organochlorine Pesticides; HRGC/HRMS Method (based on USEPA Methods 1613B, 1668, 8081A and New York State Department of Environmental C20Conservation [NYSDEC] HRMS-2 PAHs and Alkyl PAHs: Method KNOX-ID-0016, HRGC/LRMS-SIM
2009-2010	2009-2010 CPG Benthic and Surface Sediment Program	PCBs – Congeners: USEPA 1668A PCBs – Aroclors: USEPA SW-846 8082 PCDDs/PCDFs: USEPA 1613B PAHs: CARB 429 Modified Alkylated PAHs: USEPA SW-846 8270D Organochlorine Pesticides: USEPA 1699 Modified (NYSDEC HRMS-2) Metals (ICP/MS): USEPA SW-846 6020 Metals (ICP): USEPA SW-846 6010B Methylmercury: USEPA 1630 Total Mercury: USEPA 1631

Table 1-1: Surface Sediment Sampling Programs Used in Data Evaluation Report No. 4

Year	Study Name	Analytical Methods
2012	2012 CPG Low Resolution Coring Supplemental Sampling Program	SVOCs: Method 8270C PCDD/PCDFs: EPA 1613B PCB Congeners: EPA 1668A PAHs: NOAA 130 Pesticides: EPA 3640A, EPA 1699, NYSDEC HRMS-2 Grain Size: ASTM D422 or D4464 Specific Gravity: ASTM D854 Atterberg Limits: ASTM D4318 TPH: NJ Method OQA-QAM-025-10/91 Butyltins,:SOP based on Krone, 1988, SOC-BUTYL, Rev. 9 Metals: USEPA 6010/6010B/6020 Mercury: USEPA 1631 AVS/SEM: USEPA Methods 821-R-91-100, 6010C/6020 SEM Mercury: EPA 7470A Radionuclides: HASL-300/USEPA 901.1 Total Sulfides EPA 9030B TOC: Llyod Kahn Amonia: EPA 350.1 Total Cyanides and Cyanides: EPA 335.2 Phosphorus: EPA 365.3 Nitrogen, Total and Soluble Kjeldahl: ASTM D3590-89A, ASTM D1426-93B Percent solids, Total Solids, Percent Moisture: EPA 160.3

Table 1-2: Compounds Evaluated in Data Evaluation Report No. 4

Chemical	Human Health COPC	Ecological COPEC	Considered in Geochemical Analyses
Cadmium			X
Chromium			X
Copper		X	X
Lead		X	X
Mercury	X	X	X
Total PAHs			X
High Molecular Weight PAHs		X	X
Low Molecular Weight PAHs		X	X
Chlordane	X		X
Dieldrin	X	X	X
Total DDT		X	X
DDD, DDE & DDT	X		
Total PCBs	X	X	X
2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD)	X	X	X
Total TCDD	X	X	X

Notes:
COPC = Contaminants of Potential Concern
COPEC = Contaminants of Potential Ecological Concern

Table 1-3: Ratio of 2,3,7,8-TCDD/Total TCDD Measured on Surface Sediment and Suspended Solids

Analyte[a]	Average Surface Sediment	Average USGS TOPS	Infiltrex Program	TOPS Laboratory
2,3,7,8-TCDD (µg/kg)	0.28 ±0.079 (N = 3)	0.57 ±0.57 (N = 18)	0.22 (N = 1)	0.17 (N = 1)
Total TCDD (µg/kg)	0.42 ±0.11 (N = 3)	0.78 ±0.62 (N = 18)	0.32 (N = 1)	0.25 (N = 1)
Ratio 2,3,7,8-TCDD/Total TCDD	0.65 ±0.024 (N = 3)	0.72 ±0.15 (N = 18)	0.69 (N = 1)	0.68 (N = 1)

a: Arithmetic average and standard deviation (± 1 sigma) based on a normal distribution of sample size.
N = sample size

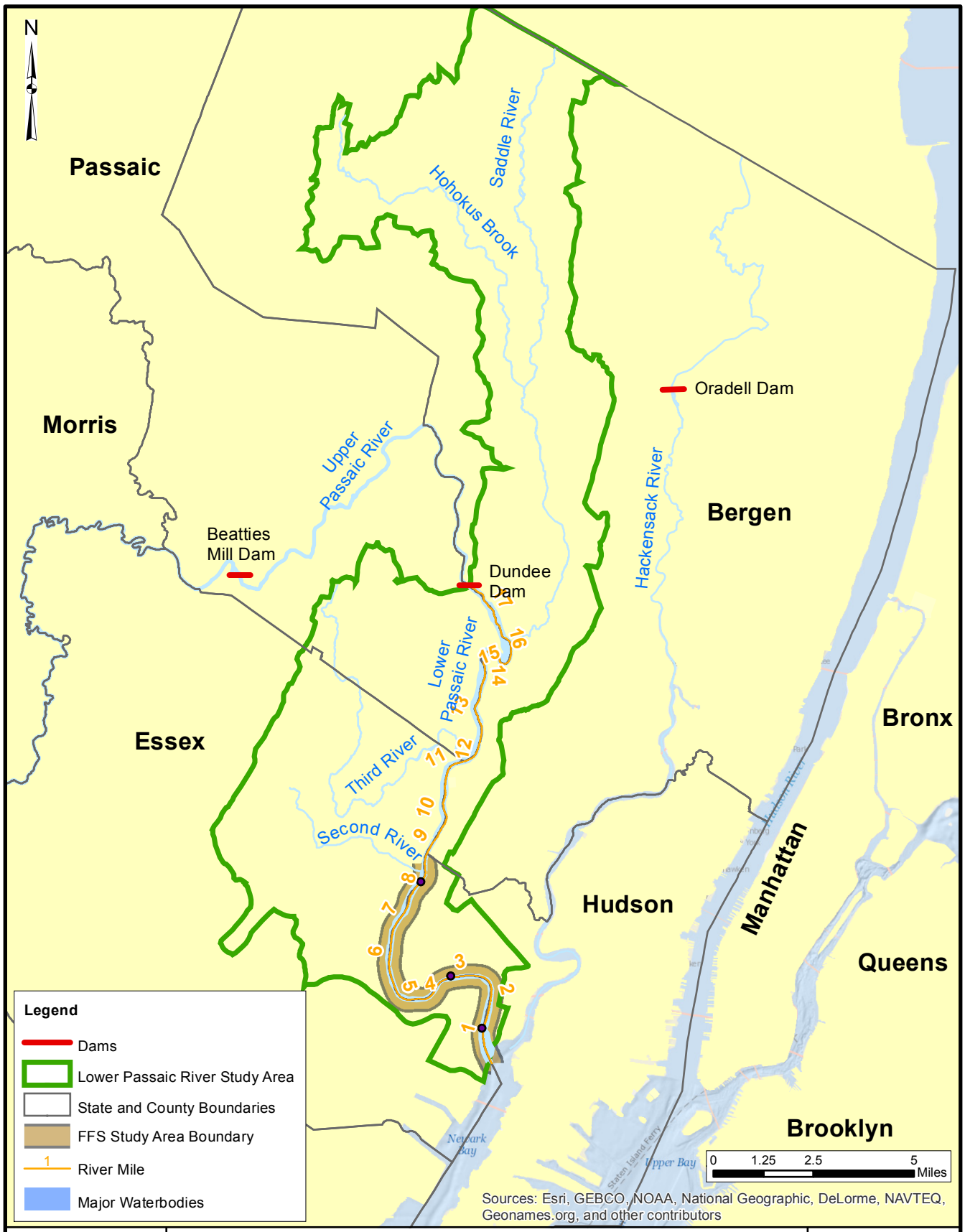
Table 3-1
Summary Statistics Used in Data Evaluation Report No. 4
(0-6 inch Surface Sediments)

Year and River Mile Interval			2008-2012 River Mile 0-2						2008-2012 River Mile 2-8						2008-2012 River Mile 8-12						2008-2012 River Mile 12-17.4					
Chemical Grou	Analyte	Unit	N	Minimum	Median	Maximum	Mean	Std Dev	N	Minimum	Median	Maximum	Mean	Std Dev	N	Minimum	Median	Maximum	Mean	Std Dev	N	Minimum	Median	Maximum	Mean	Std Dev
Metals	Cadmium	mg/kg	63	0.14	2.40	29.4	2.83	3.56	137	0.16	3.00	34.7	4.25	4.92	80	0.05	2.94	32.8	4.88	6.07	60	0.06	0.73	11.3	1.53	1.98
	Chromium	mg/kg	63	25.7	104	187	103	31.3	137	13.0	102	1,140	145	173	80	5.45	94.5	1,580	155	235	60	7.97	21.6	245	41.9	45.8
	Copper	mg/kg	63	21.8	132	249	134	40.5	137	17.9	154	930	182	132	80	5.67	146	778	173	144	60	7.72	43.8	382	69.2	68.2
	Lead	mg/kg	62	28.0	173	488	177	76.3	137	36.8	221	906	264	157	80	8.56	232	1,030	261	193	58	14.1	127	641	154	127
	Mercury	mg/kg	63	0.32	1.80	5.07	2.03	0.92	137	0.06	1.95	16.2	2.82	3.11	81	0.02	1.77	15.6	2.46	2.79	60	0.02	0.35	5.50	0.81	1.06
	Alumium	mg/kg	63	3,740	11,600	16,800	11,251	2,703	137	2,220	10,700	18,500	10,205	3,759	80	2,250	9,830	19,800	9,806	4,946	60	1,840	4,245	19,000	5,627	3,700
	Iron	mg/kg	63	6,920	26,500	41,400	25,727	6,116	137	7,360	25,000	47,500	24,489	7,329	80	6,540	22,800	39,100	21,644	8,066	60	6,190	12,150	53,100	15,038	7,994
Dioxin	2,3,7,8-TCDD	pg/g	56	0.09	208	2,370	304	359	137	0.77	280	34,100	1,609	4,569	80	4.92	294	23,200	1,357	3,581	60	0.05	3.30	585	77.4	146
	Total TCDD	pg/g	35	31.5	330	2,880	449	499	105	18.0	413	37,900	2,104	5,564	64	7.66	440	25,100	1,925	4,390	38	3.15	24.2	666	124	192
	2,3,7,8-TCDD to Total TCDD Ratio	Unitless	35	0.33	0.63	0.83	0.62	0.094	105	0.04	0.68	0.97	0.69	0.14	64	0.021	0.71	0.94	0.72	0.15	38	0.019	0.16	0.78	0.34	0.31
PCB	Total PCBs by Congeners	ug/kg	56	11.9	898	6,960	1,087	1,005	137	5.41	1,023	28,600	2,346	4,476	81	6.02	1,150	199,429	7,652	23,516	60	7.60	193	19,043	1,216	3,336
Pesticides	4,4'-DDE	ug/kg	56	0.00	24.0	110	30.7	23.8	137	0.00	34.0	771	70.7	117	80	1.00	32.5	615	75.9	126	60	0.00	5.50	150	15.6	25.4
	Total DDx	ug/kg	56	3.30	52.7	410	74.7	69.1	137	0.32	84.2	2,959	180	324	80	1.55	85.1	1,045	142	197	60	0.19	17.5	568	41.5	83.0
	Total Chlordane	ug/kg	56	0.05	27.5	230	37.5	38.1	137	0.31	40.0	254	43.7	31.0	80	0.43	46.6	154	50.4	36.1	60	0.38	25.0	330	32.7	44.4
	Dieldrin	ug/kg	56	0.02	3.10	25.0	4.72	4.74	137	0.01	3.97	152	7.44	17.3	80	0.11	4.74	85.4	6.89	10.4	60	0.02	2.62	43.0	4.07	5.95
PAH	High Molecular Weight PAHs	ug/kg	56	2,531	24,775	358,700	34,374	49,809	137	1,696	30,711	341,890	39,625	43,345	81	500	32,170	92,560	31,125	18,350	60	671	23,615	208,900	30,145	34,484
	Low Molecular Weight PAHs	ug/kg	56	405	3,648	102,305	6,798	14,602	137	306	4,620	749,070	14,788	66,668	81	83.5	4,548	26,838	5,241	4,068	60	78.8	4,135	63,100	7,133	11,419
	Total PAHs	ug/kg	56	2,936	27,295	358,700	37,501	50,341	137	2,002	32,307	480,800	45,402	56,182	81	500	35,100	97,680	35,139	20,777	60	750	28,093	240,800	36,647	42,812
TOC	Total Organic Carbon	%	63	0.38	4.00	18.9	4.87	3.45	137	0.28	5.02	24.2	5.34	3.20	81	0.32	4.30	17.8	4.42	2.99	60	0.19	2.23	18.4	3.28	3.20

Notes:
1) MPI 2008, CPG 2008, CPG 2009, CPG 2010 and CPG 2012 datasets are used in the summary statistics.
2) Total PCB is calculated by summing detected congeners; non-detected congeners are equal to zero.
3) Total DDx is calculated by summing detected 4,4'-DDE, 4,4'-DDD and 4,4'-DDT.
4) Total Chlordane is calculated by summing detected alpha-chlordane and gamma-chlordane.
5) High Molecular Weight PAHs is calculated by summing detected Benzo(a)anthracene, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(g,h,i)perylene, Benzo(k)fluoranthene, Chrysene, Dibenzo(a,h)anthracene, Fluoranthene, Indeno(1,2,3-cd)pyrene and Pyrene.
6) Low Molecular Weight PAHs is calculated by summing detected Acenaphthene, Acenaphthylene, Anthracene, Fluorene, Naphthalene, Phenanthrene and 2-Methylnaphthalene.

R2-0027081

FIGURES



FFS Study Area Location Map

Lower Eight Miles of the Lower Passaic River

Figure 1-1

2014

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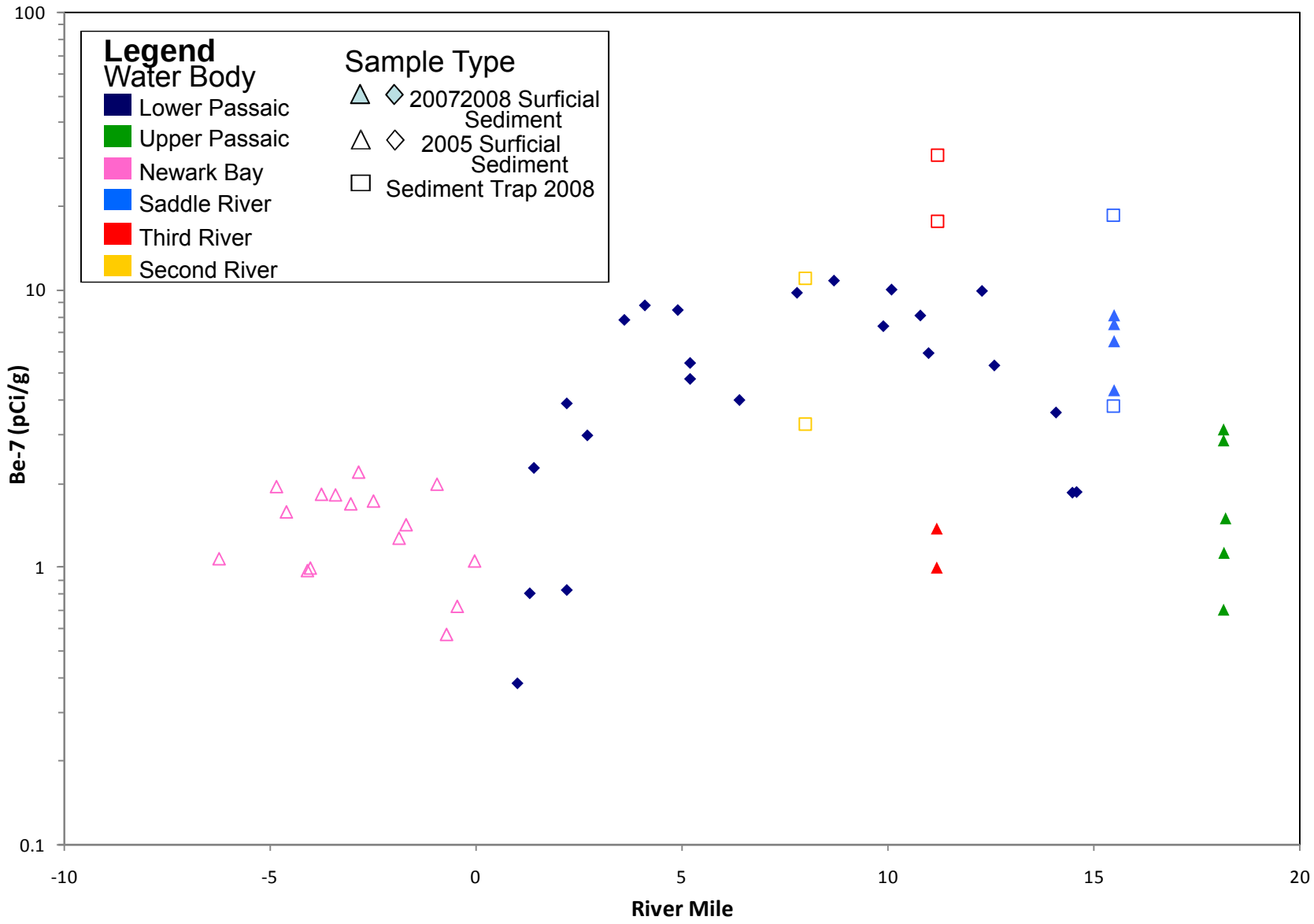
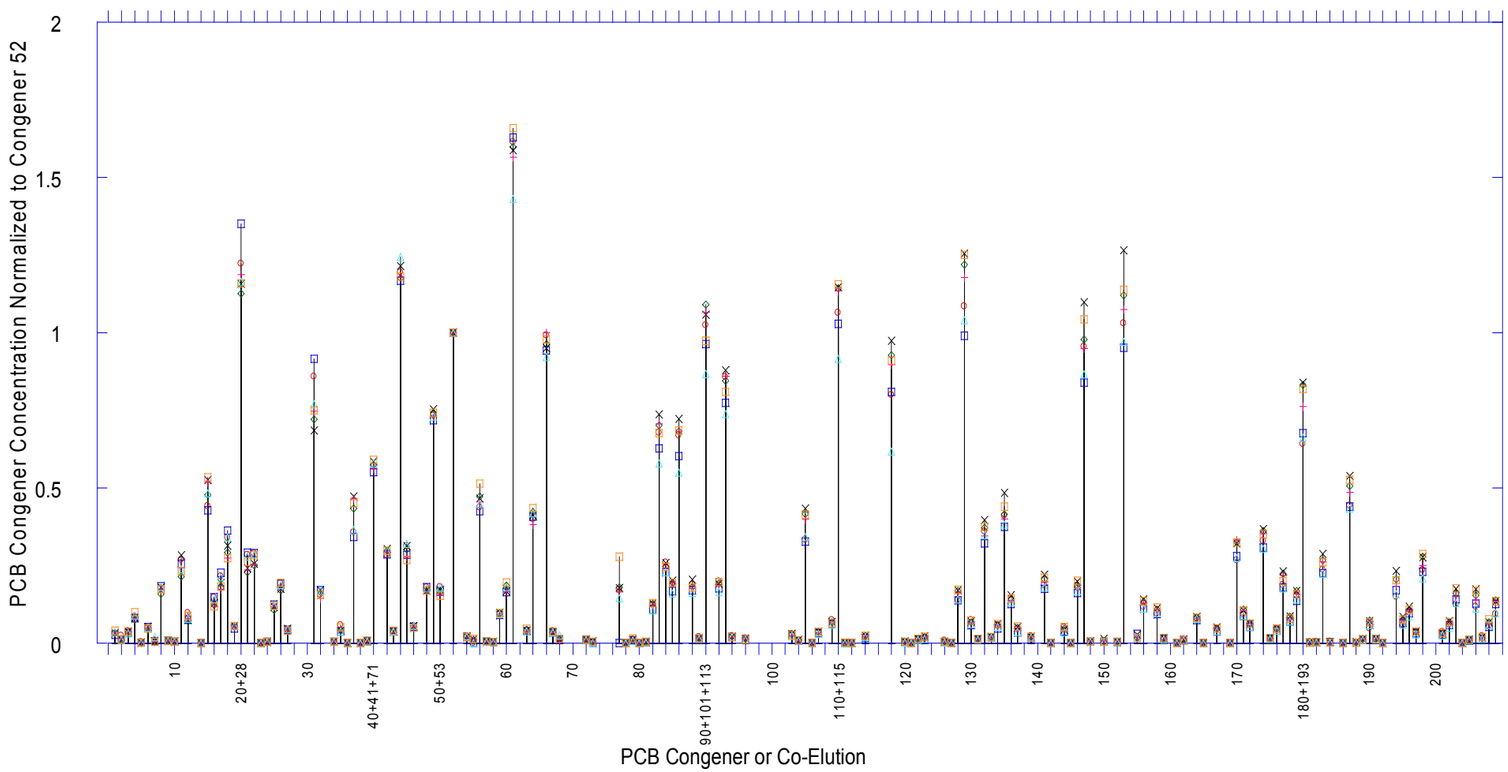
R2-0027083



	Beryllium-7 Activity vs. River Mile *Lower Eight Miles of the Lower Passaic River*	Figure 1.2-1 2014

R2-0027084



Legend

- Dec5 Downriver
- Dec6 Downriver
- Dec6 Upriver
- Dec7 Upriver
- Dec8 Upriver
- Dec10 Downriver
- Dec12 Downriver

Notes

Upriver and downriver refer to the flow direction as it changes with the tide.

"Dec5 Downriver" represents the average PCB congener concentration from morning and afternoon samples collected on December 5, 2005.

"Dec6 Downriver" represents the average PCB congener concentration from morning and afternoon samples collected on December 6, 2005.

"Dec6 Upriver" represents the average PCB congener concentration from morning and afternoon samples collected on December 6, 2005.

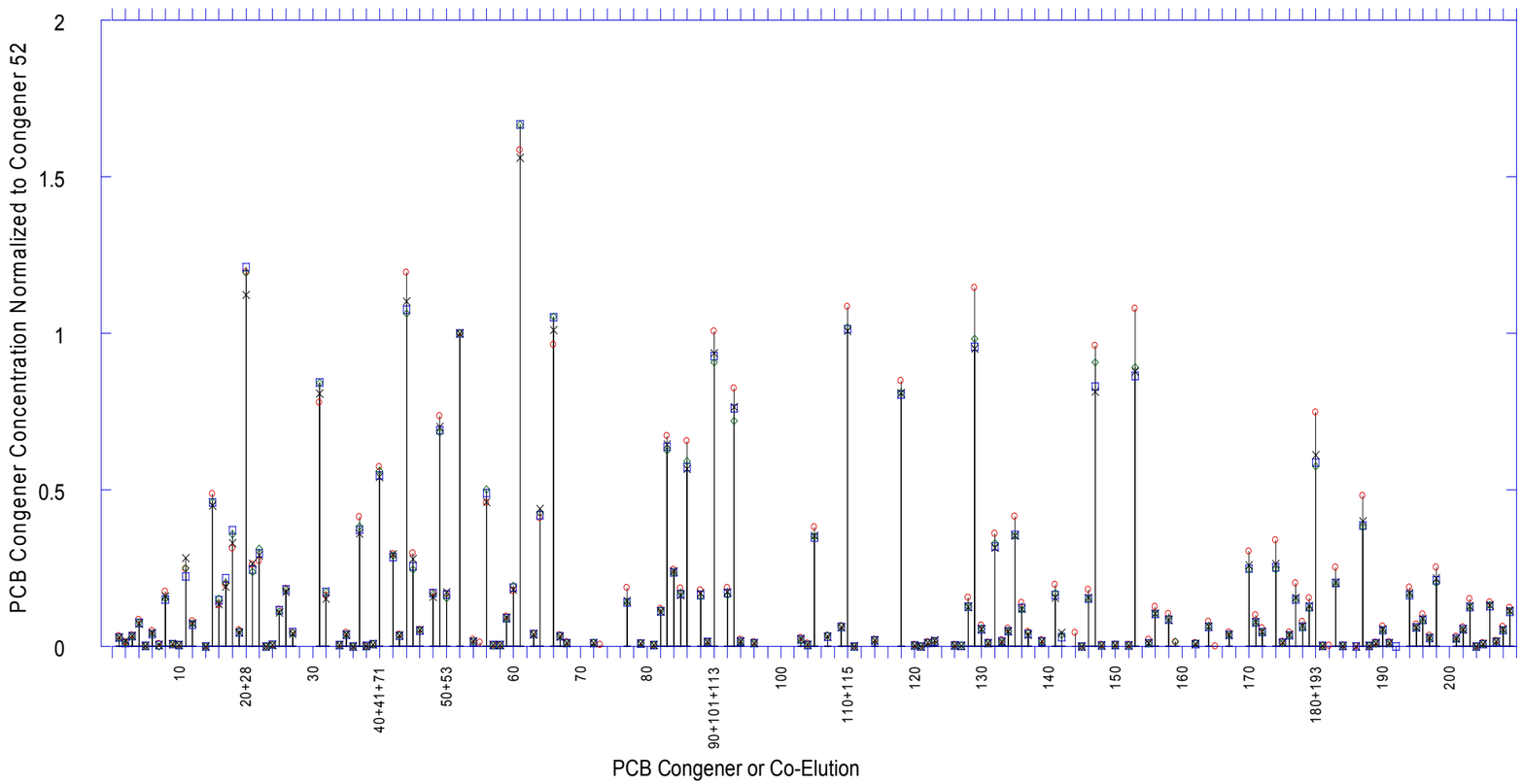
"Dec10 Downriver" represents the average PCB congener concentration from morning and afternoon samples collected on December 10, 2005.

PCB Congener Concentration Normalized to Congener 52 Pattern on Suspended Solids: USGS TOPS

Lower Eight Miles of the Lower Passaic River

Figure 1.2-2

2014



Legend

- Average USGS TOPS
- Field-Filtered TOPS
- Laboratory-Filtered TOPS
- Infiltrex

Notes

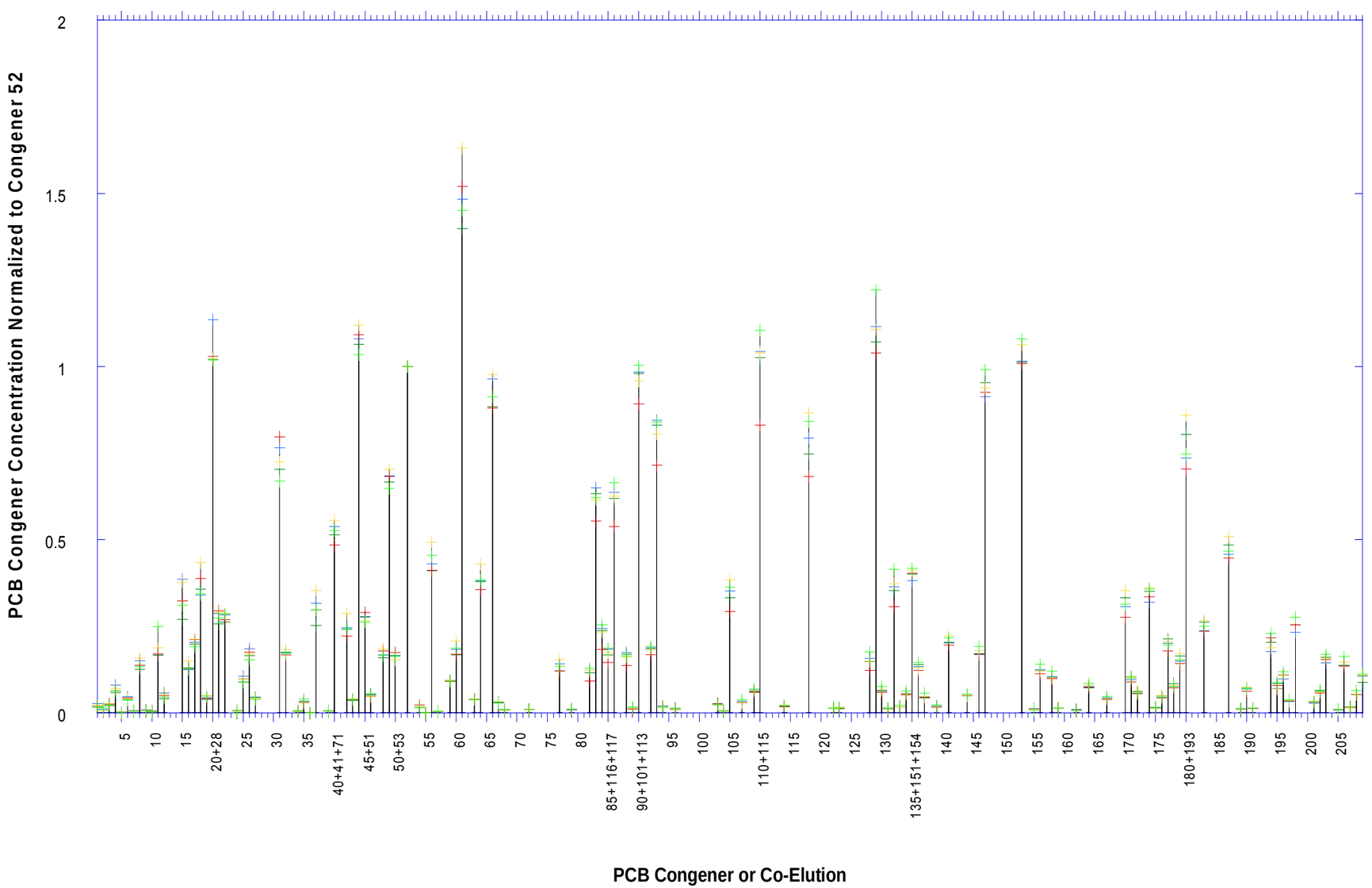
"Average USGS TOPS" represents the average PCB congener concentration from samples collected on December 5, 2005 through December 12, 2005.

PCB Congener Concentration Normalized to Congener 52 Pattern on Suspended Solids: USGS TOPS, Field-Filtered TOPS, Laboratory-Filtered TOPS, and Infiltrex

Lower Eight Miles of the Lower Passaic River

Figure 1.2-3

2014



Legend

- RM1.4
- RM2.2
- RM7.8
- RM11
- RM12.6

Notes

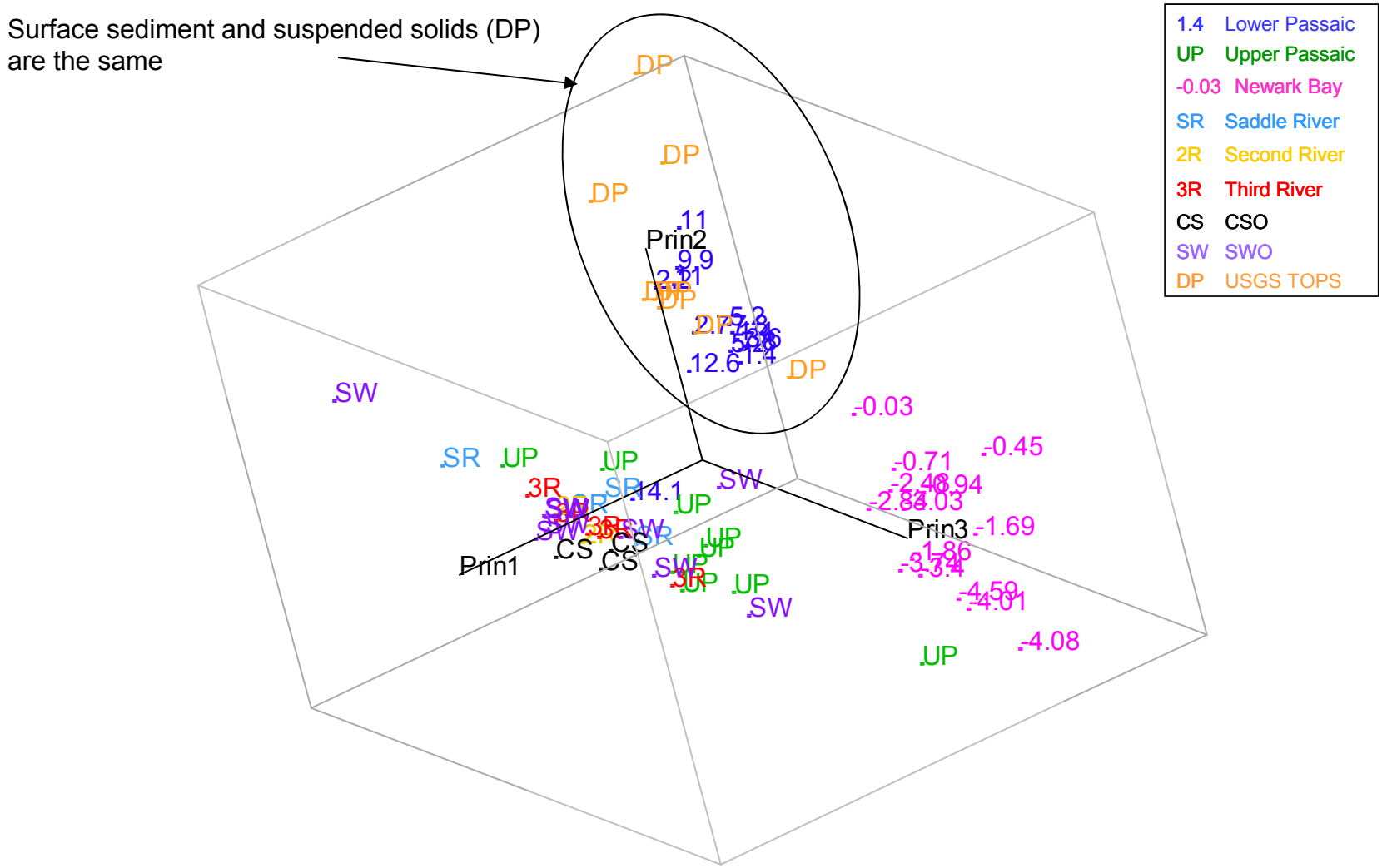
Normalized PCB congener concentration <0.01 are not plotted.

PCB Congener Concentration Normalized to Congener 52 for the Lower Passaic River High Resolution Cores Surface Sediments

Lower Eight Miles of the Lower Passaic River

Figure 1.2-4

2014



Surface Sediment and Suspended Solids
Principal Components

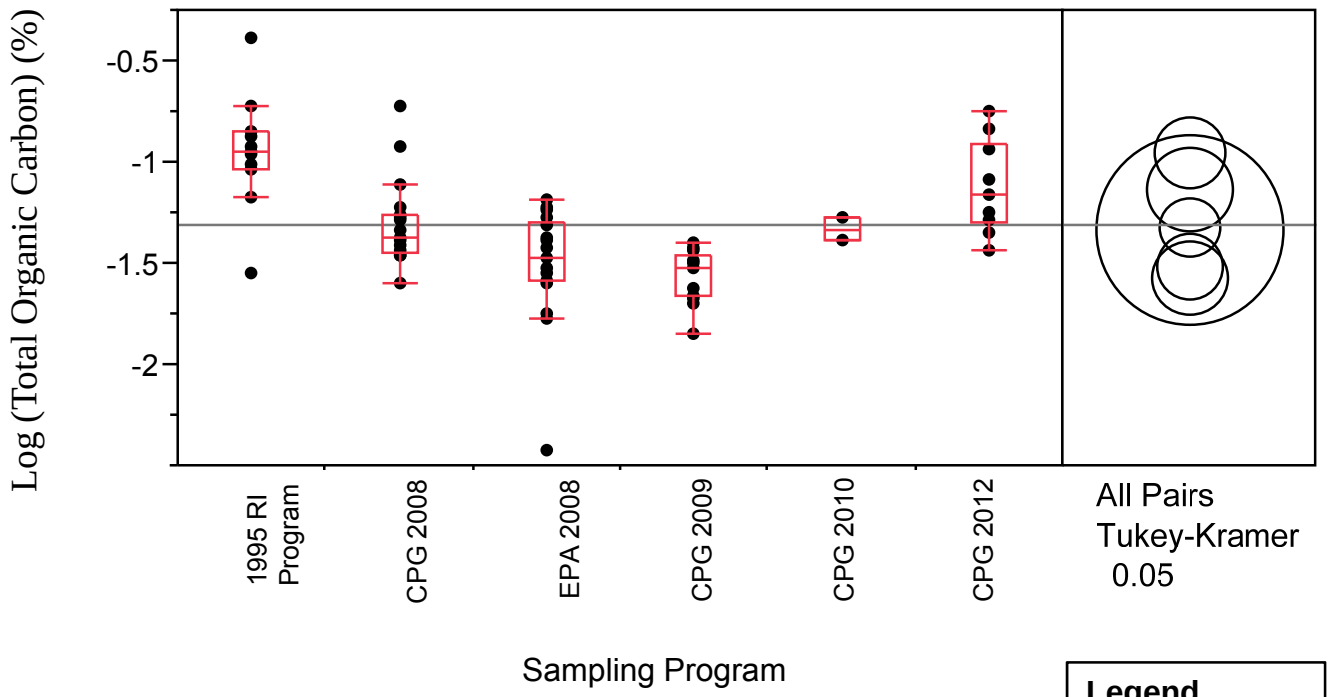
Lower Eight Miles of the Lower Passaic River

Figure 1.2-5

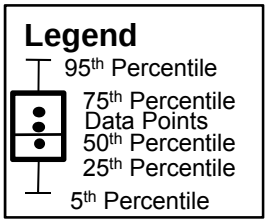
2014

R2-0027088

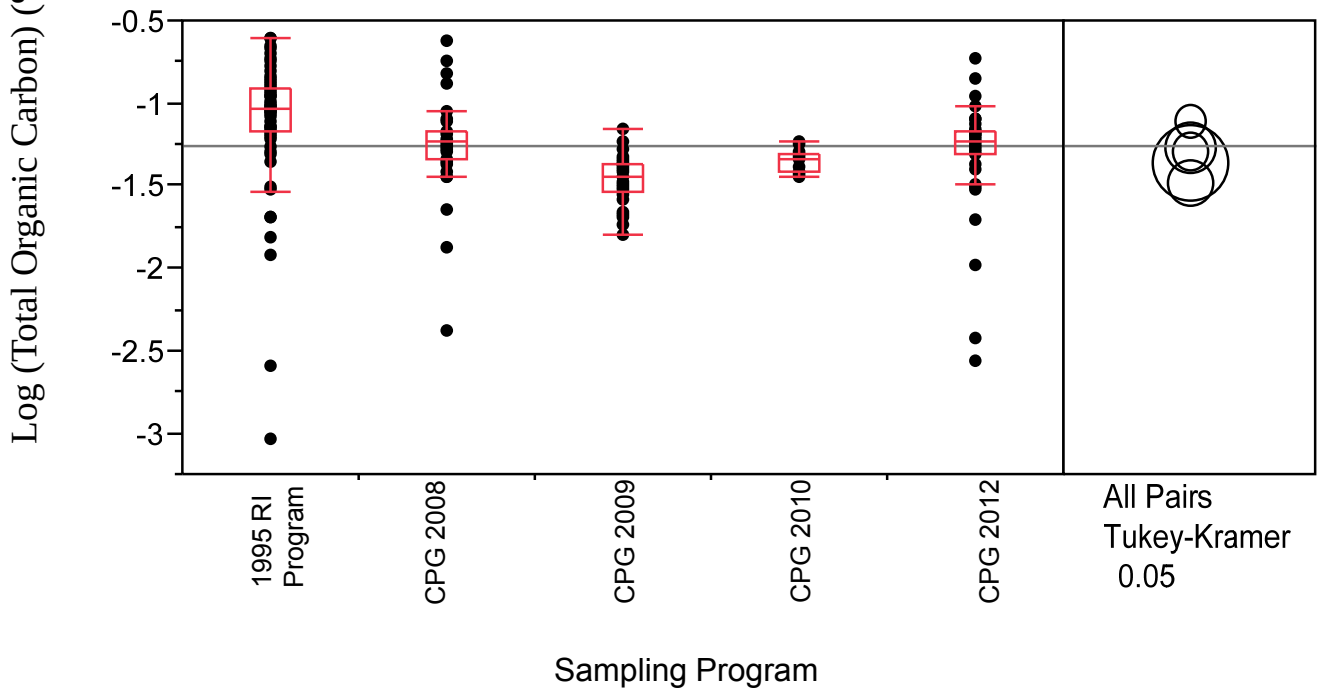
RM0 to RM2



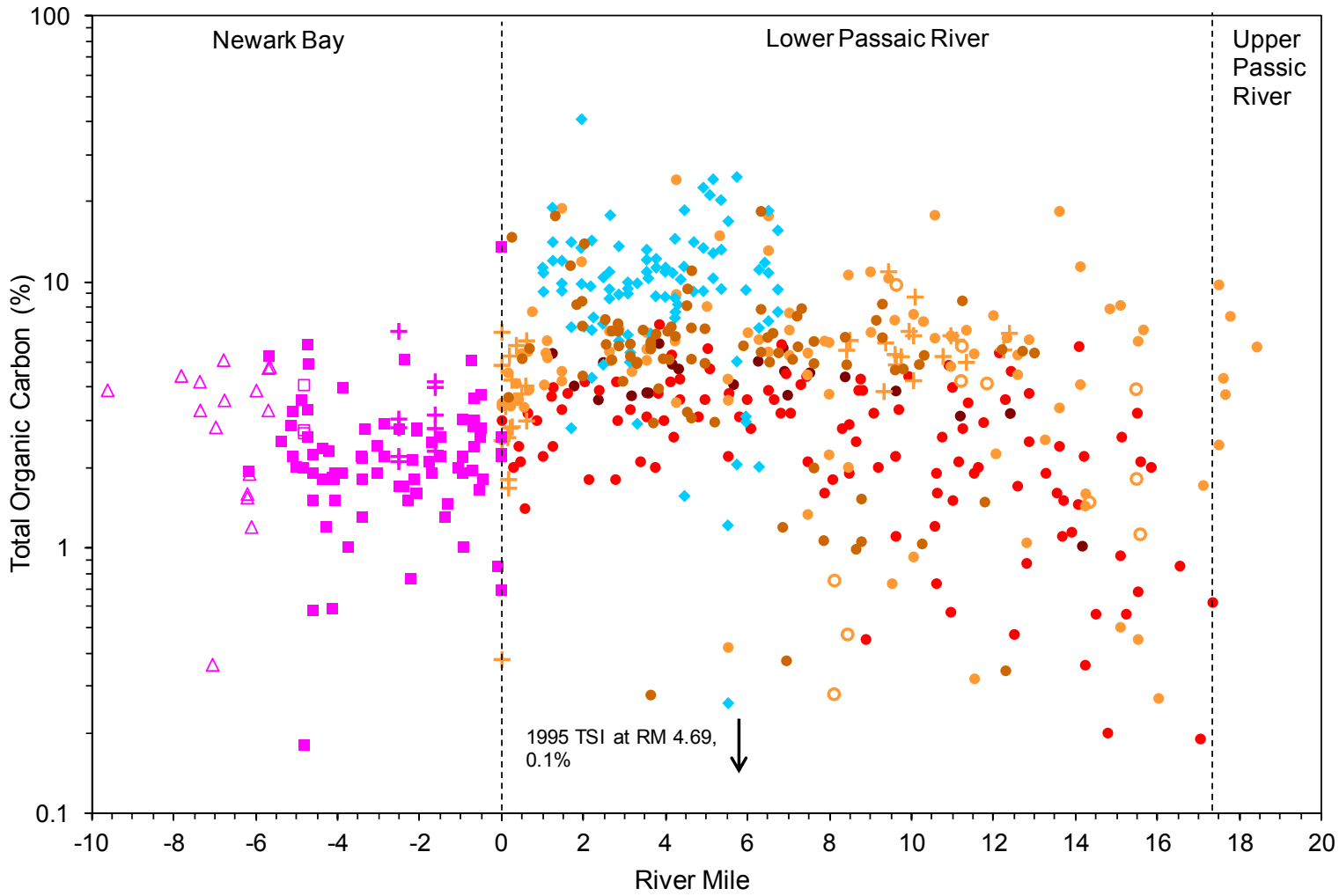
Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.



RM2 to RM8



	Total Organic Carbon (0-6 inch) by Sampling Program at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 1.3-1** 2014



Legend

- 2012 CPG
- 2010 CPG
- 2009 CPG
- 2008 CPG
- 2008 CPG Tributary Below HoT
- 2008 EPA
- 2005&2007 Newark Bay
- 2005&2007 Shooters Island & Arthur Kill
- 2005&2007 Kill Van Kull
- 2005&2007 Port Elizabeth & Newark
- 1995 TSI

Total Organic Carbon (0-6 inches) *vs.* River Mile

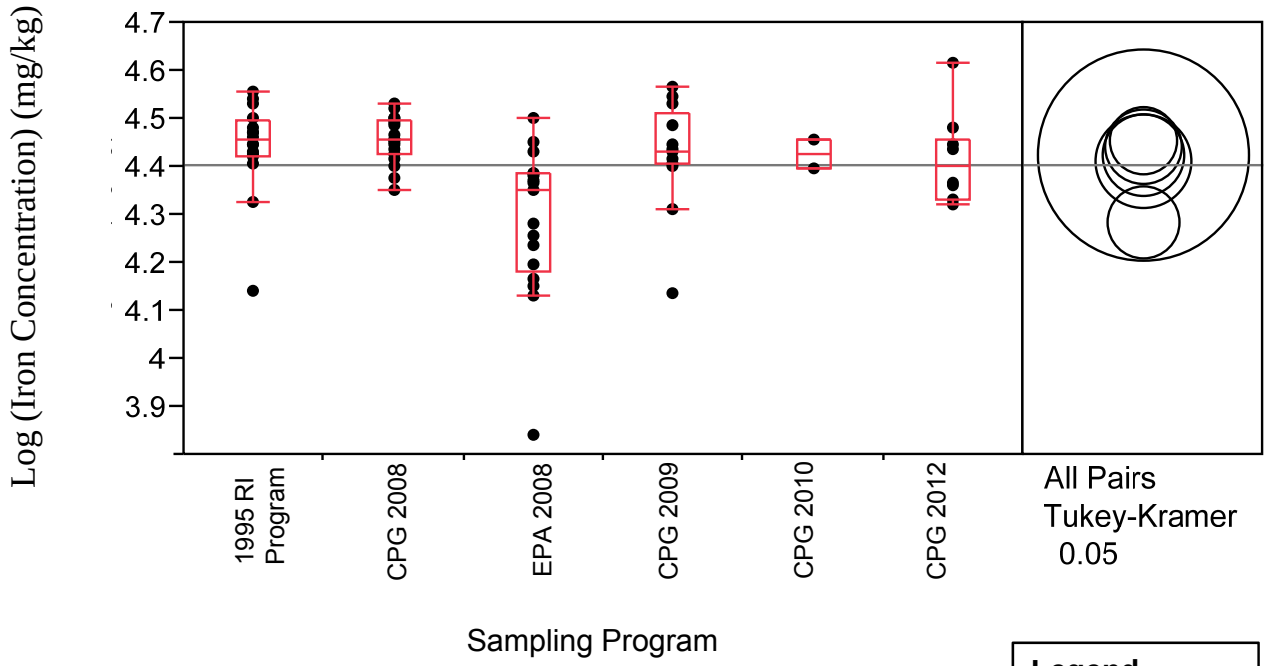
Lower Eight Miles of the Lower Passaic River

Figure 1.3-2

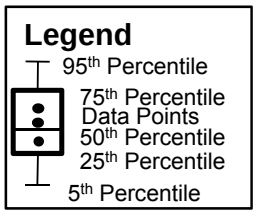
2014

R2-0027090

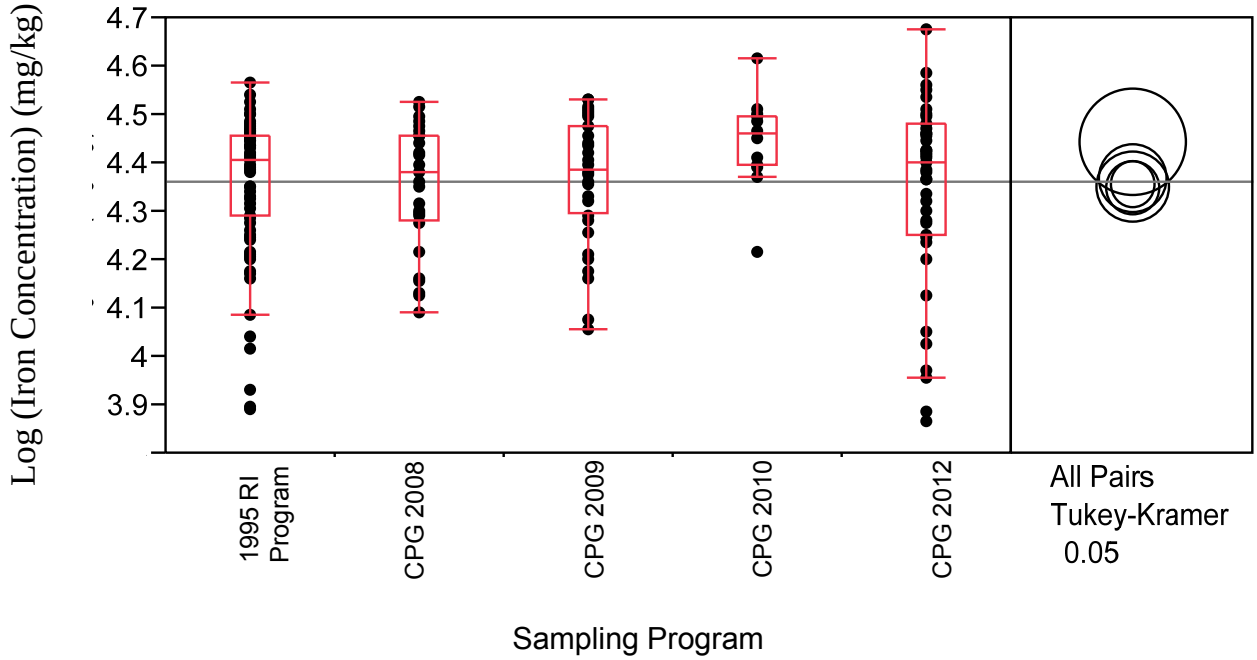
RM0 to RM2



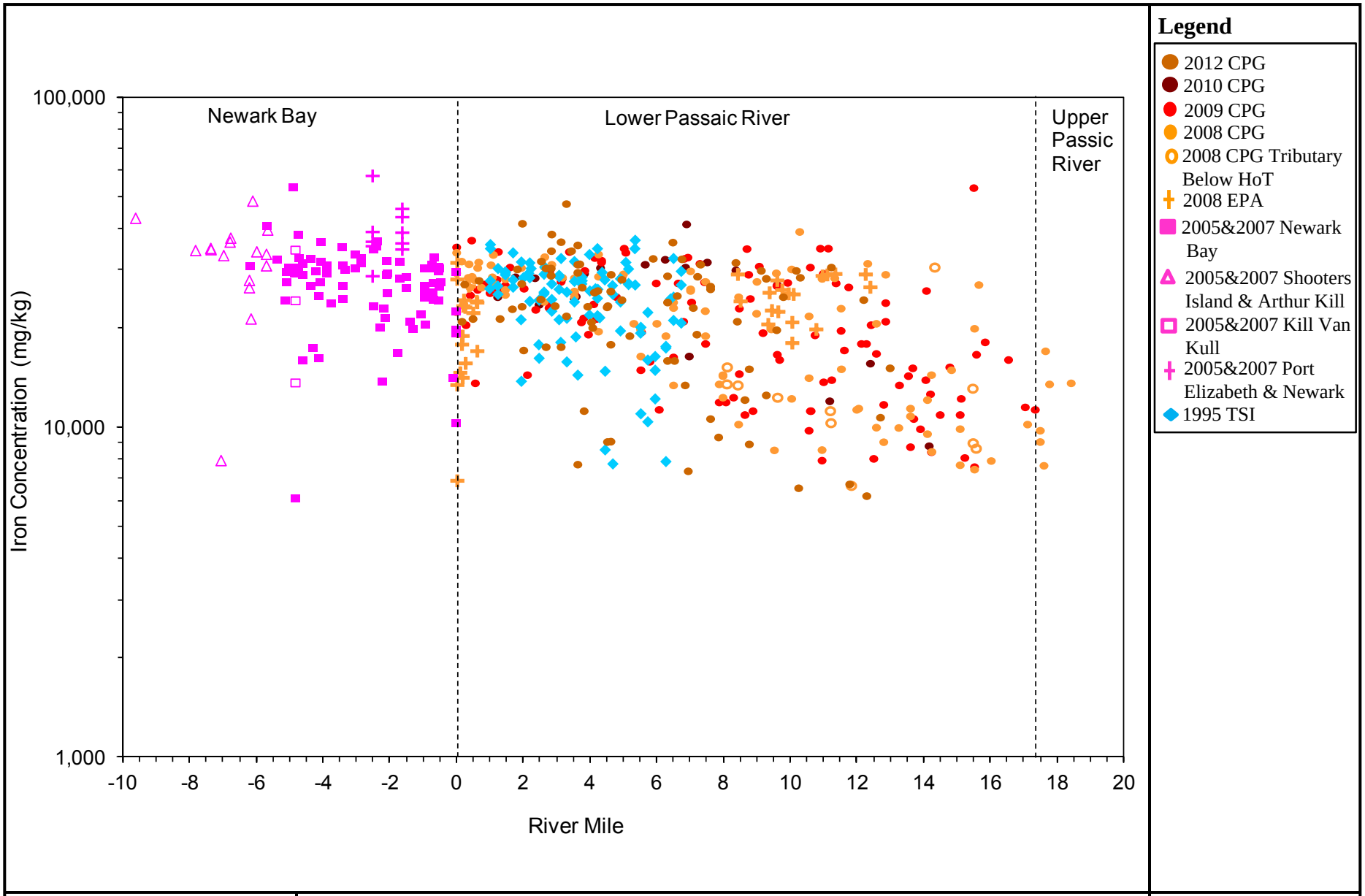
Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.



RM2 to RM8



	Iron Concentration by Sampling Program at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 1.3-3** 2014



Iron Concentration (0-6 inches) *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 1.3-4

2014

R2-0027092

Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\2,3,7,8-TCDD_Surficial_Sed_1991_2000_Samples.mxd

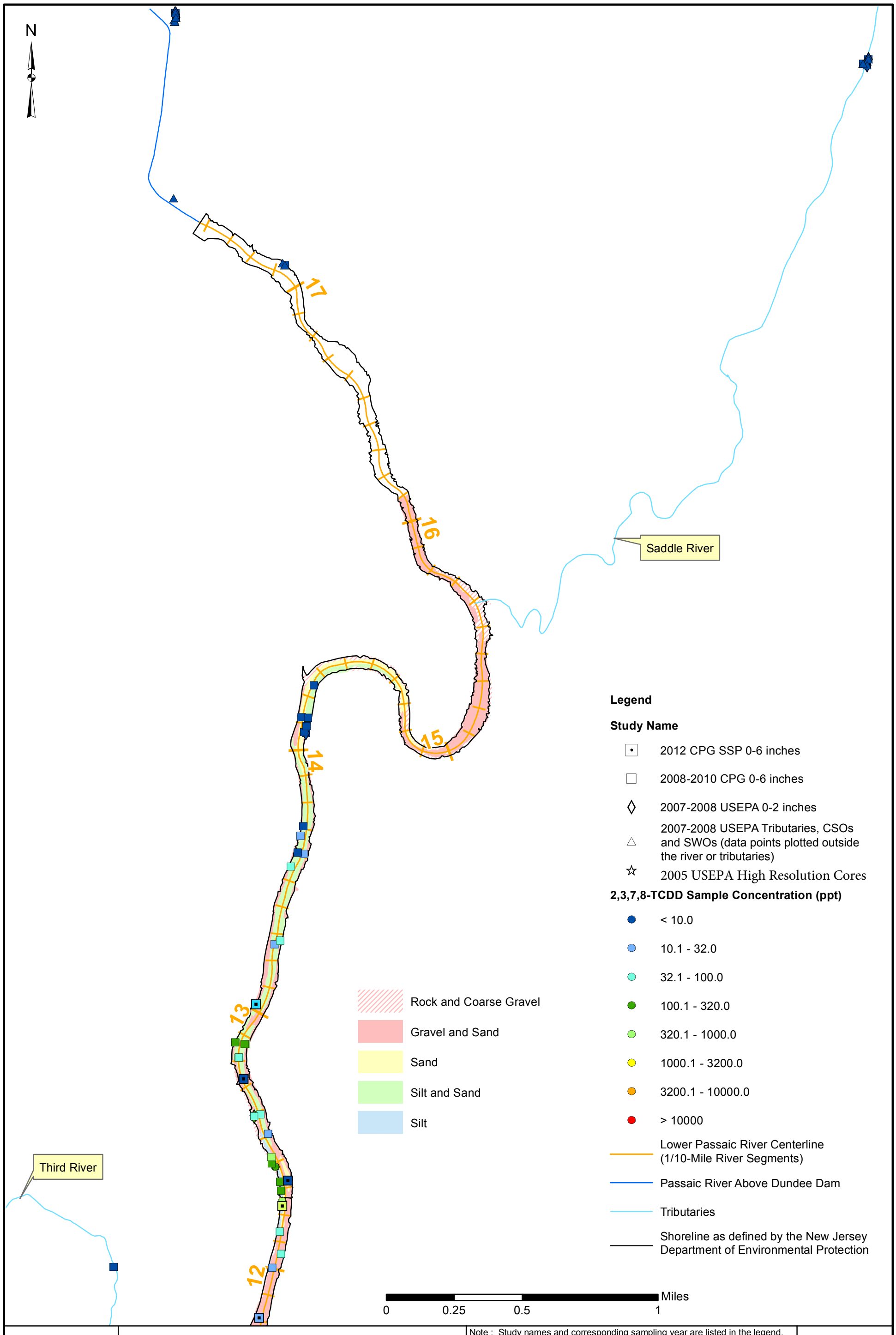
2,3,7,8-TCDD Surface Sediment Samples from 1991 to 2000

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 2.1-1

2014



2,3,7,8-TCDD Surface Sediment Samples from 2005 to 2012

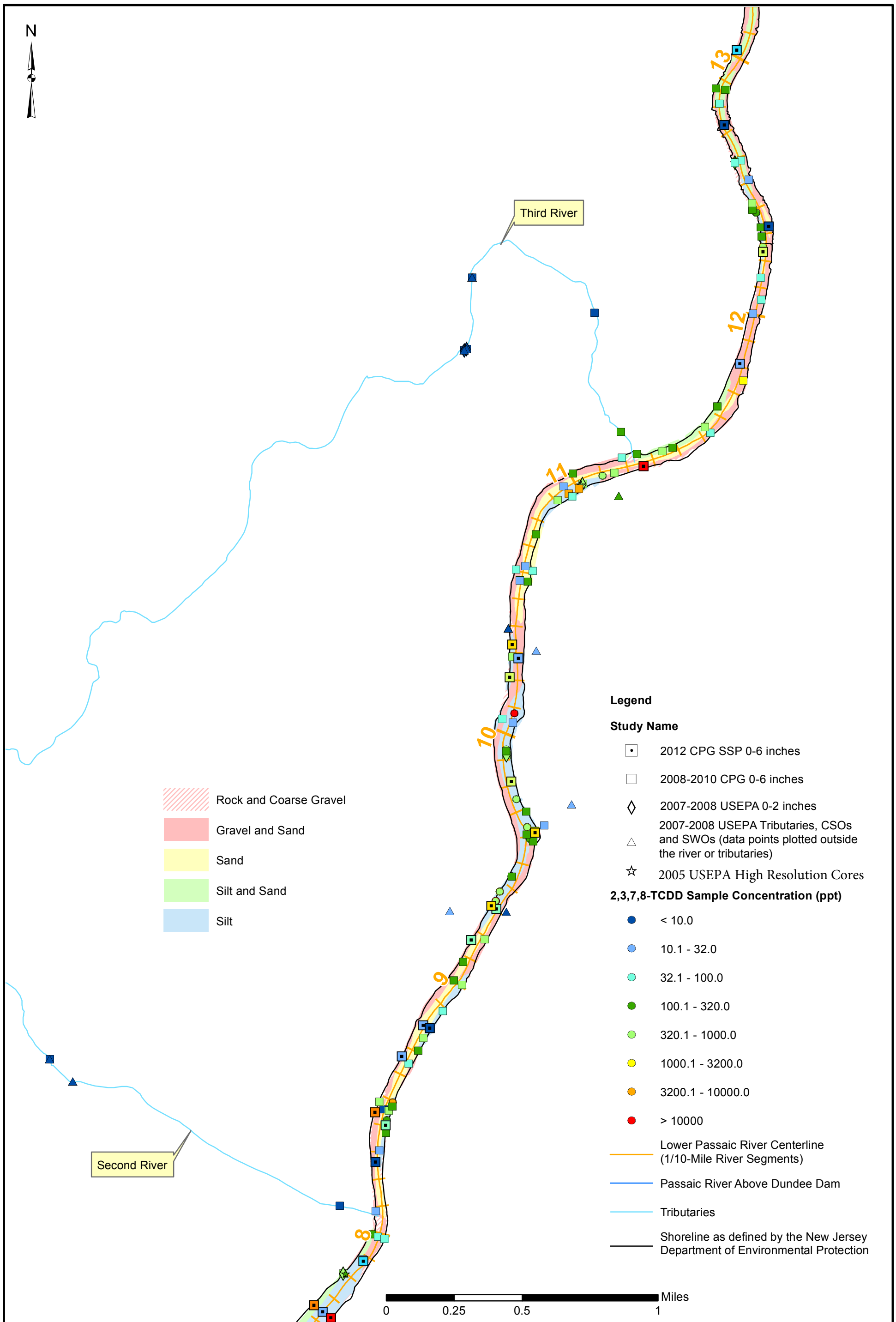
Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 2.1-2a

2014

Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\2,3,7,8-TCDD_Surficial_Sed_05_12_Samples.mxd



2,3,7,8-TCDD Surface Sediment Samples from 2005 to 2012

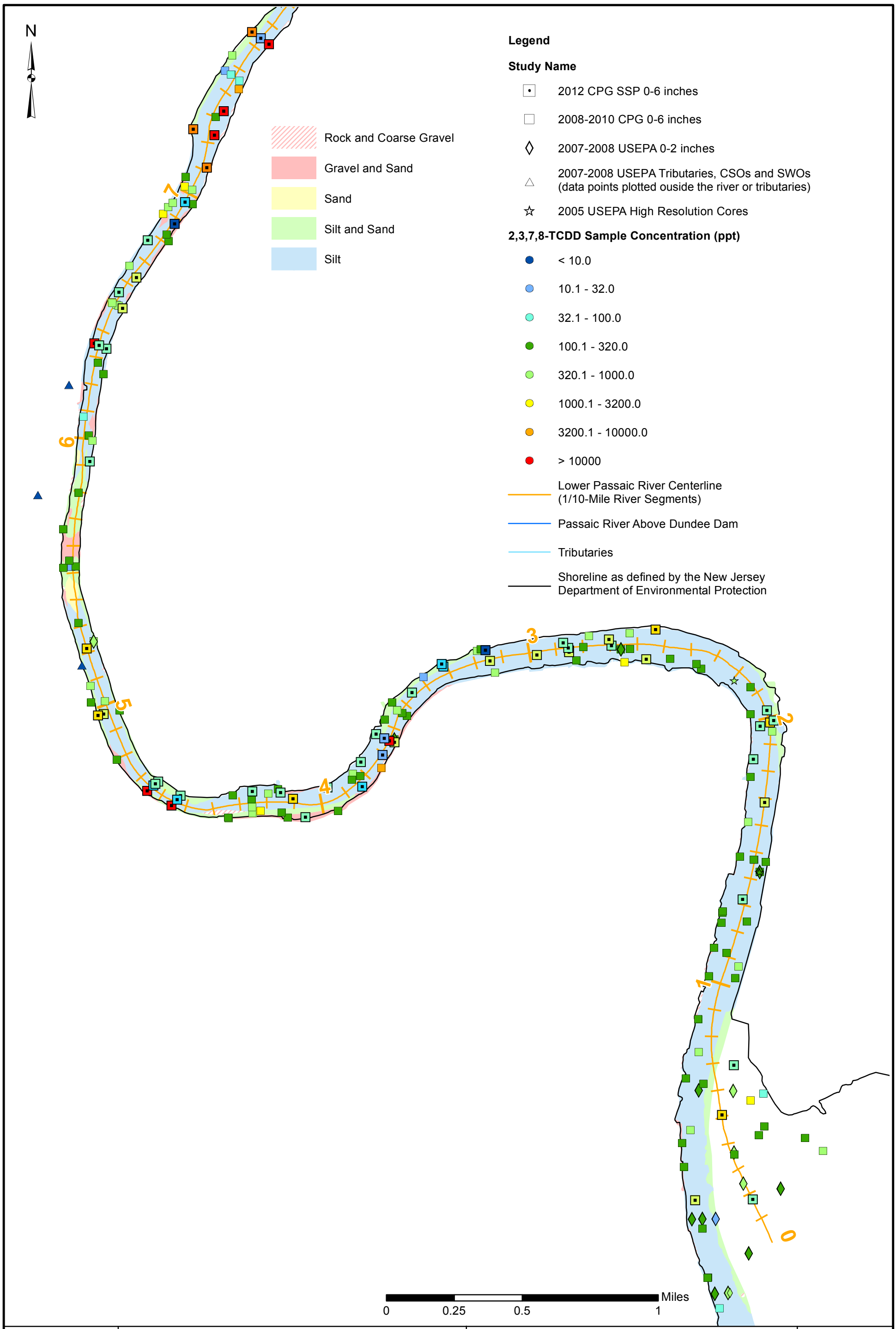
Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 2.1-2b

2014

Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\2,3,7,8-TCDD_Surficial_Sed_05_12_Samples.mxd



2,3,7,8-TCDD Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

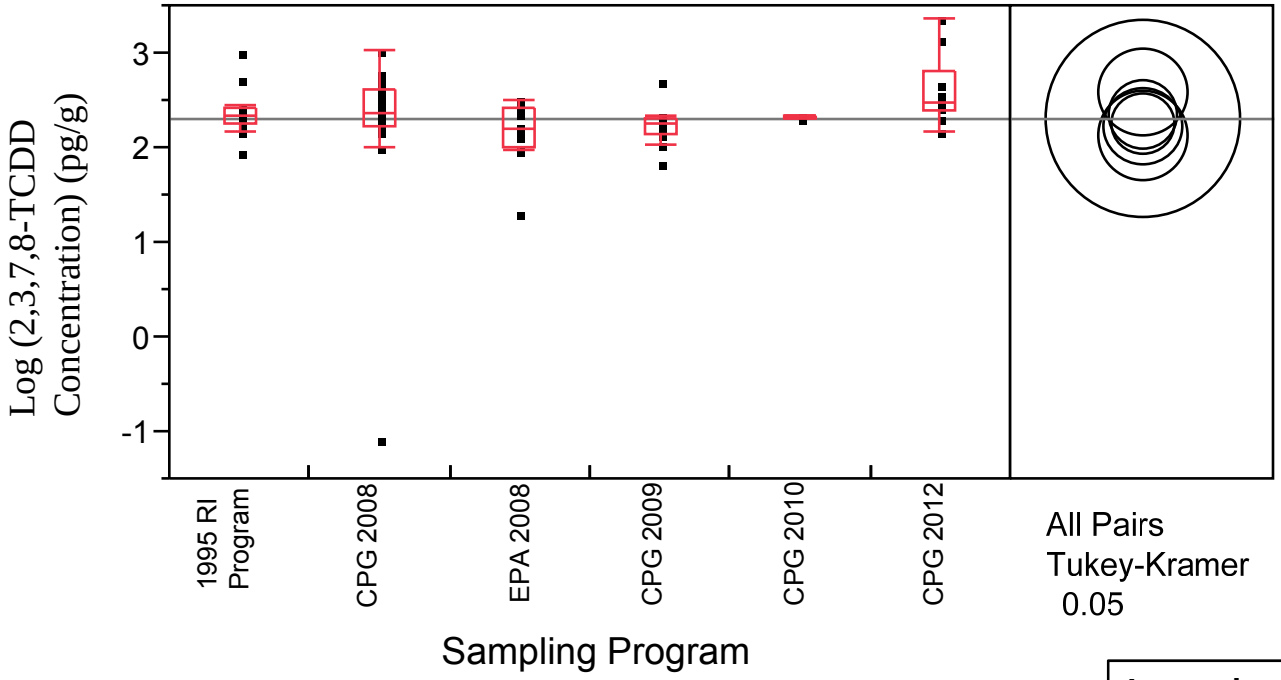
Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 2.1-2c

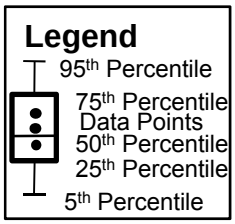
2014

Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\2,3,7,8-TCDD_Surficial_Sed_05_12_Samples.mxd

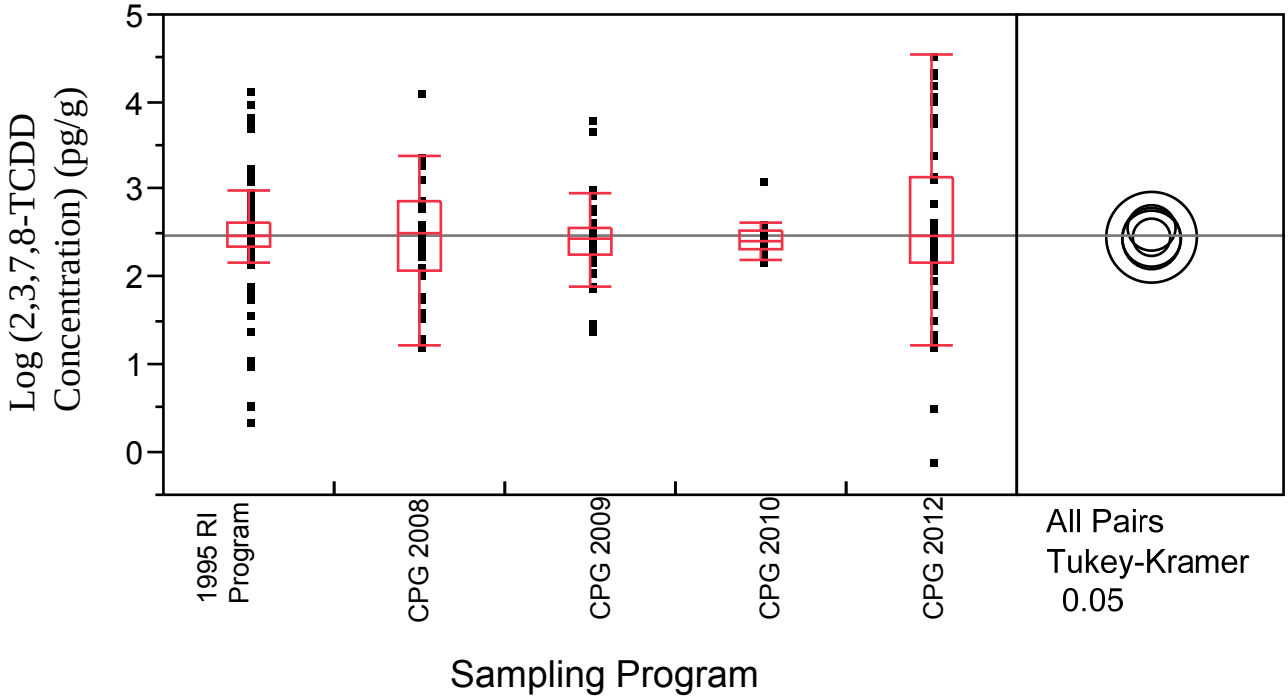
RM0 to RM2



Notes: 1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) 2008 CPG data was corrected by applying a factor of 1.89 (CSC and Interface, Inc., 2010)

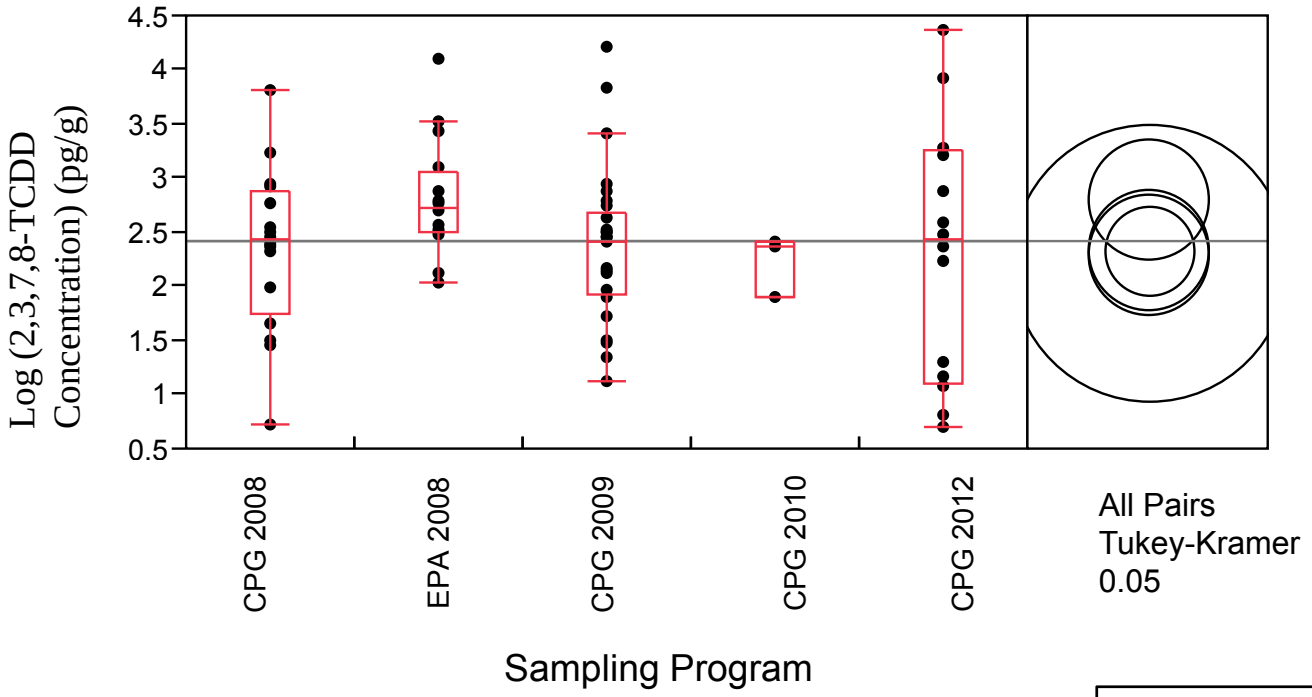


RM2 to RM8

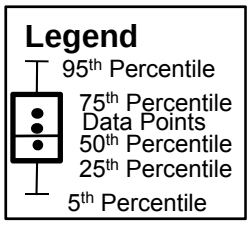


	2,3,7,8-TCDD (0-6 inch) by Sampling Program at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 2.2-1a** 2014

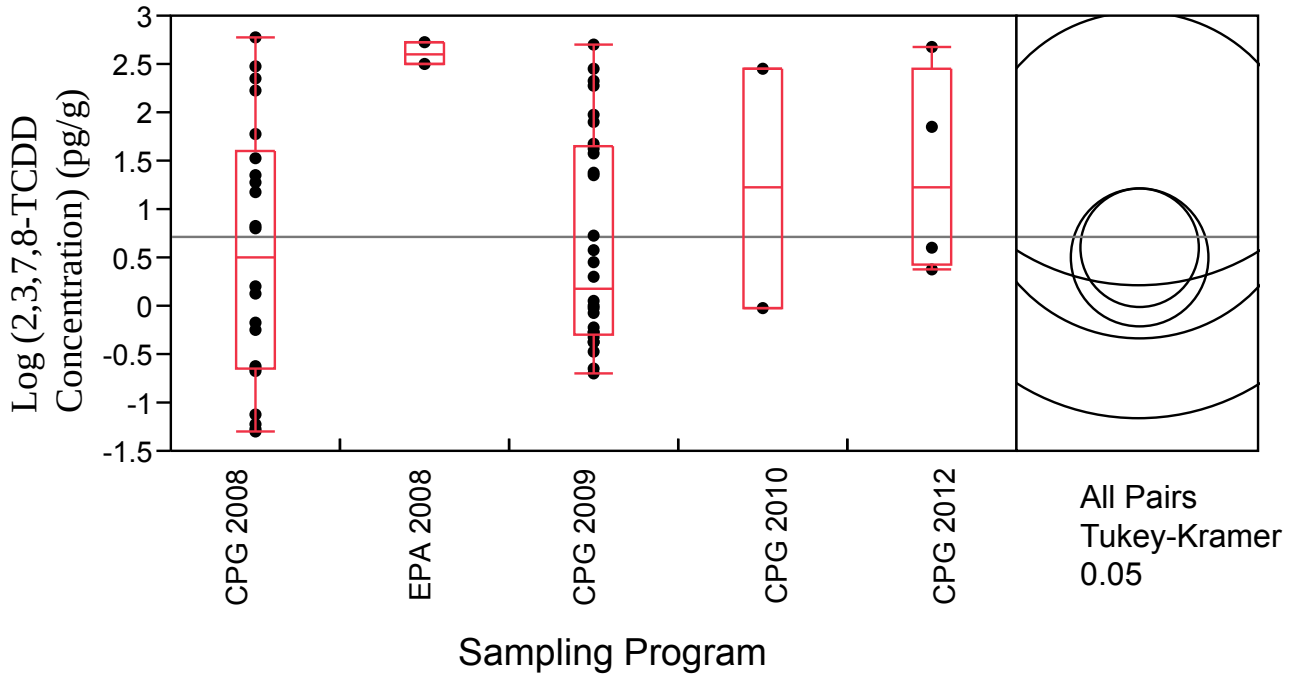
RM8 to RM12



Notes: 1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) 2008 CPG data was corrected by applying a factor of 1.89 (CSC and Interface, Inc., 2010)

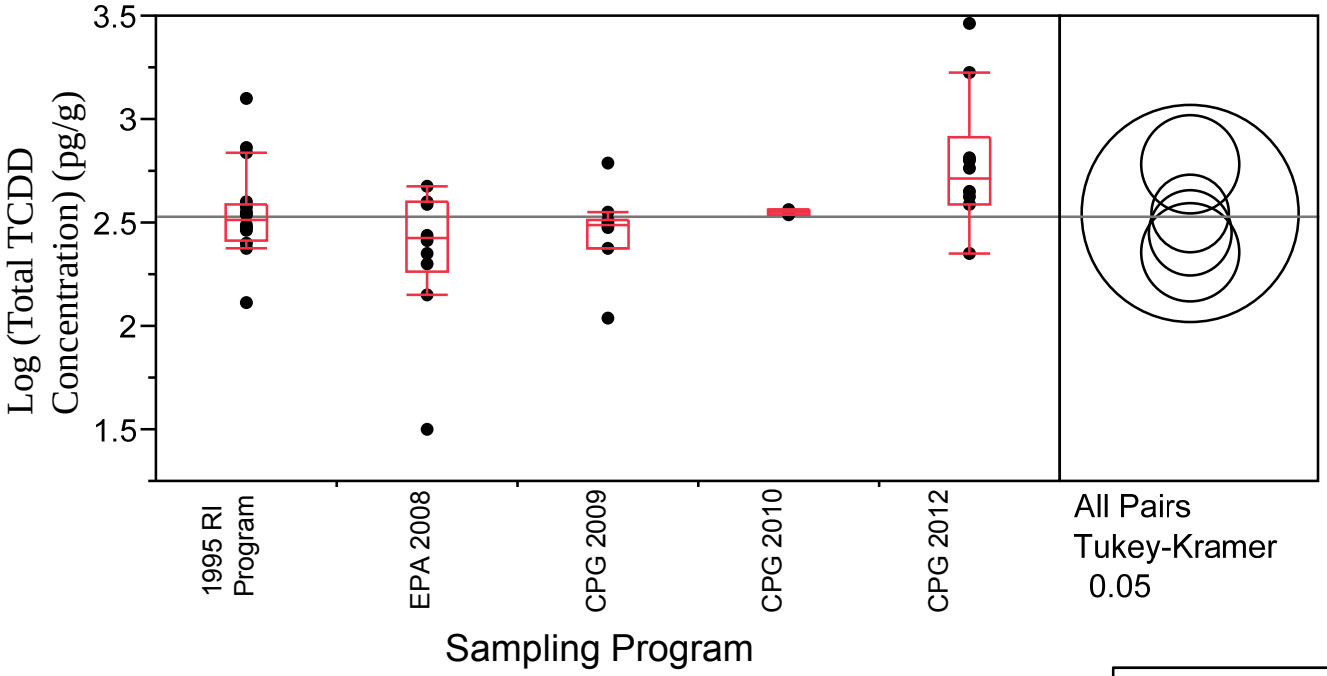


RM12 to RM17.4

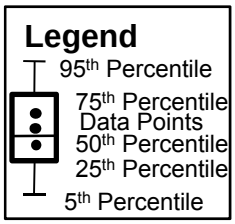


	2,3,7,8-TCDD (0-6 inch) by Sampling Program at RM8 to RM12 and RM12 to RM17.4 *Lower Eight Miles of the Lower Passaic River*	**Figure 2.2-1b** 2014

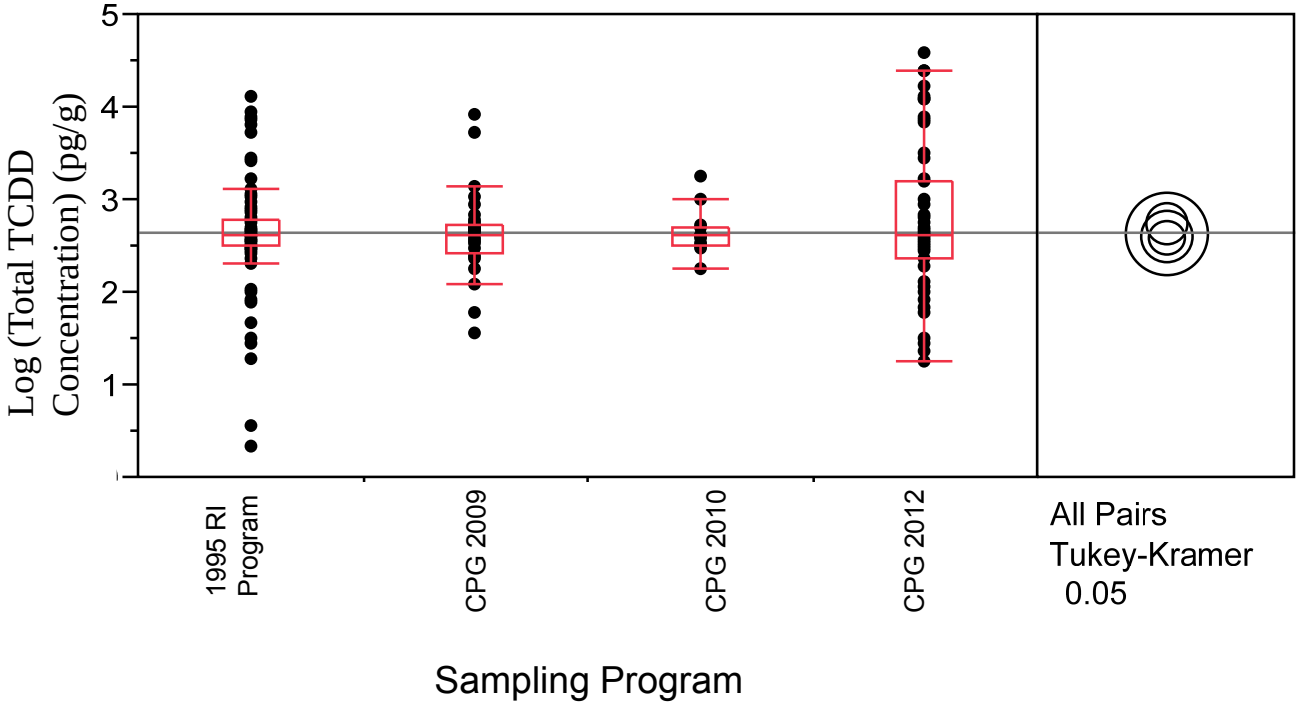
RM0 to RM2



Notes: 1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Note: the 2008 CPG Total TCDD data were not plotted because a correction factor was not developed to address the low bias in the results.

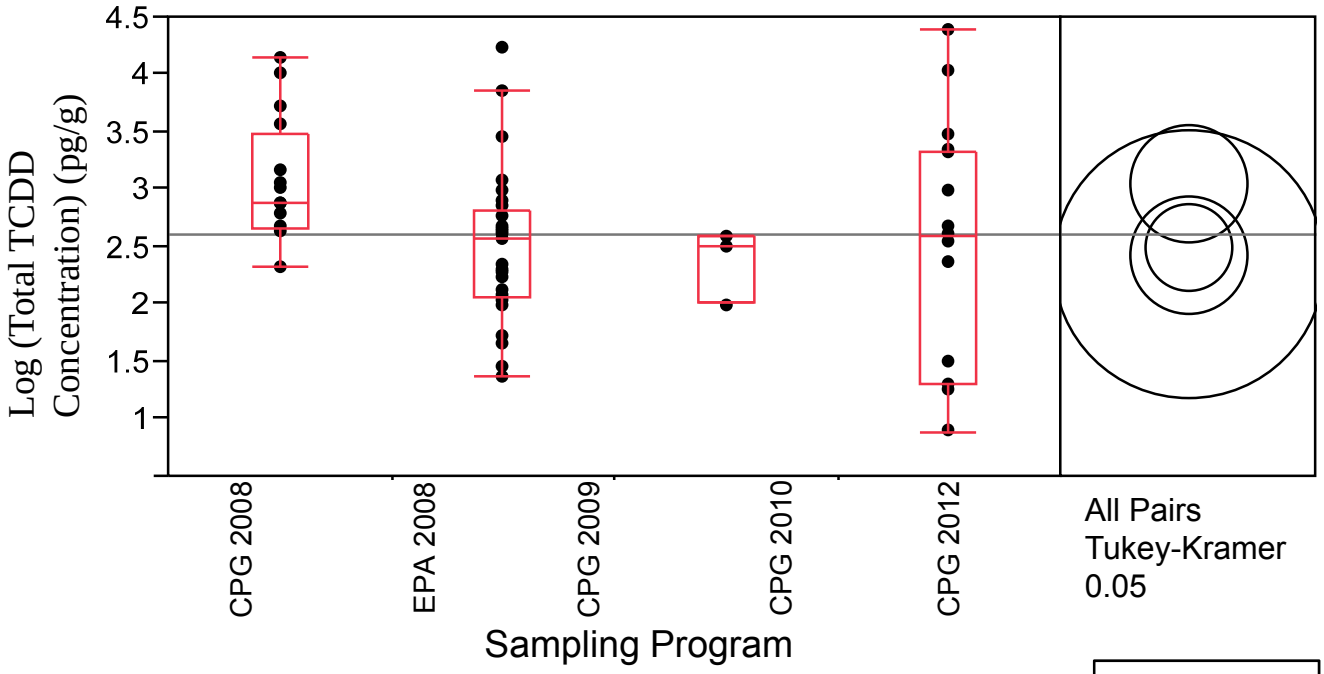


RM2 to RM8

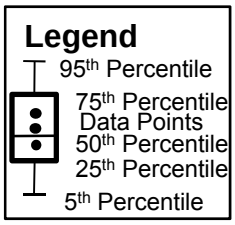


	Total TCDD (0-6 inch) by Sampling Program at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 2.2-2a** 2014

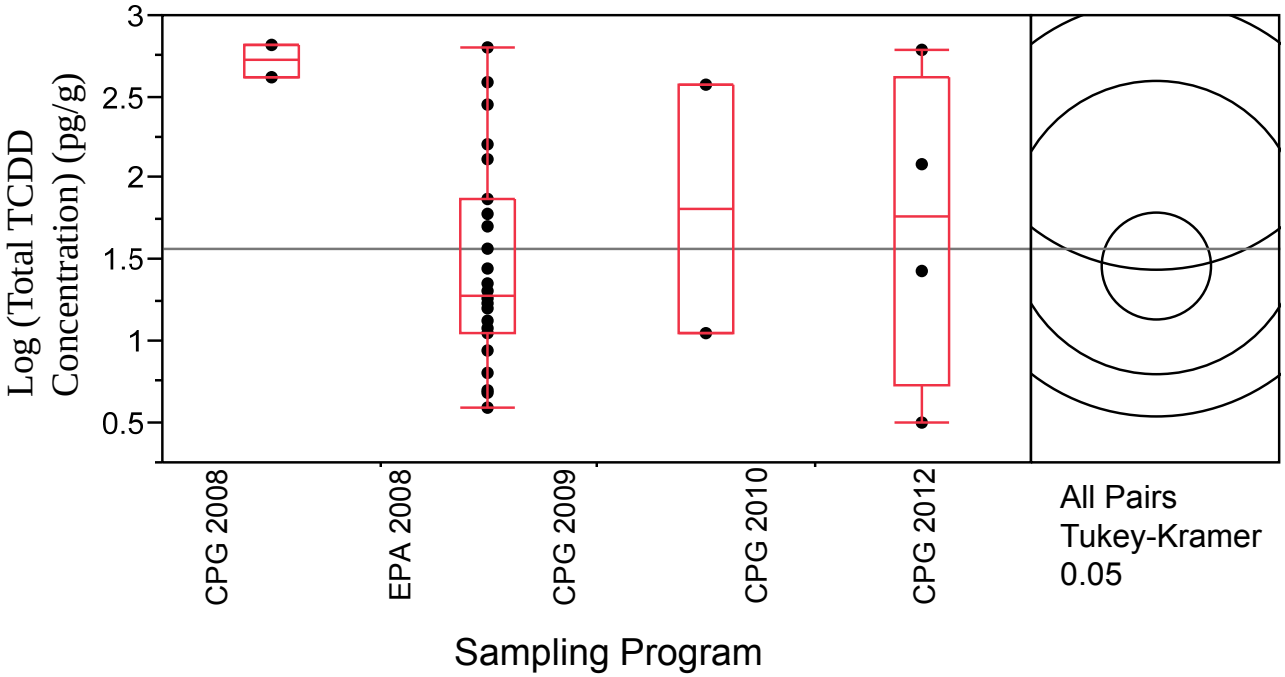
RM8 to RM12



Notes: 1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Note: the 2008 CPG Total TCDD data were not plotted because a correction factor was not developed to address the low bias in the results.

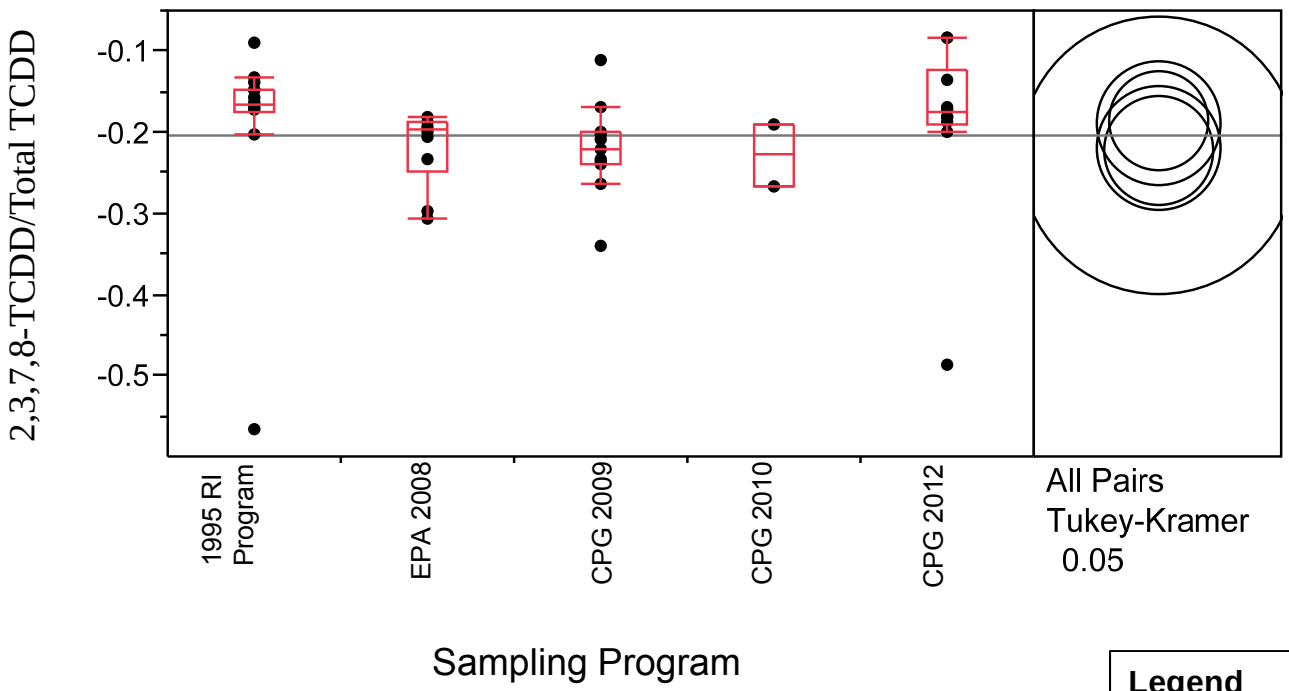


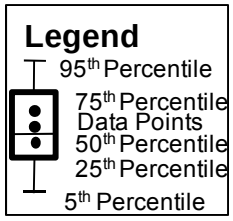
RM12 to RM17.4



	Total TCDD (0-6 inch) by Sampling Program at RM8 to RM12 and RM12 to RM17.4 *Lower Eight Miles of the Lower Passaic River*	**Figure 2.2-2b** 2014

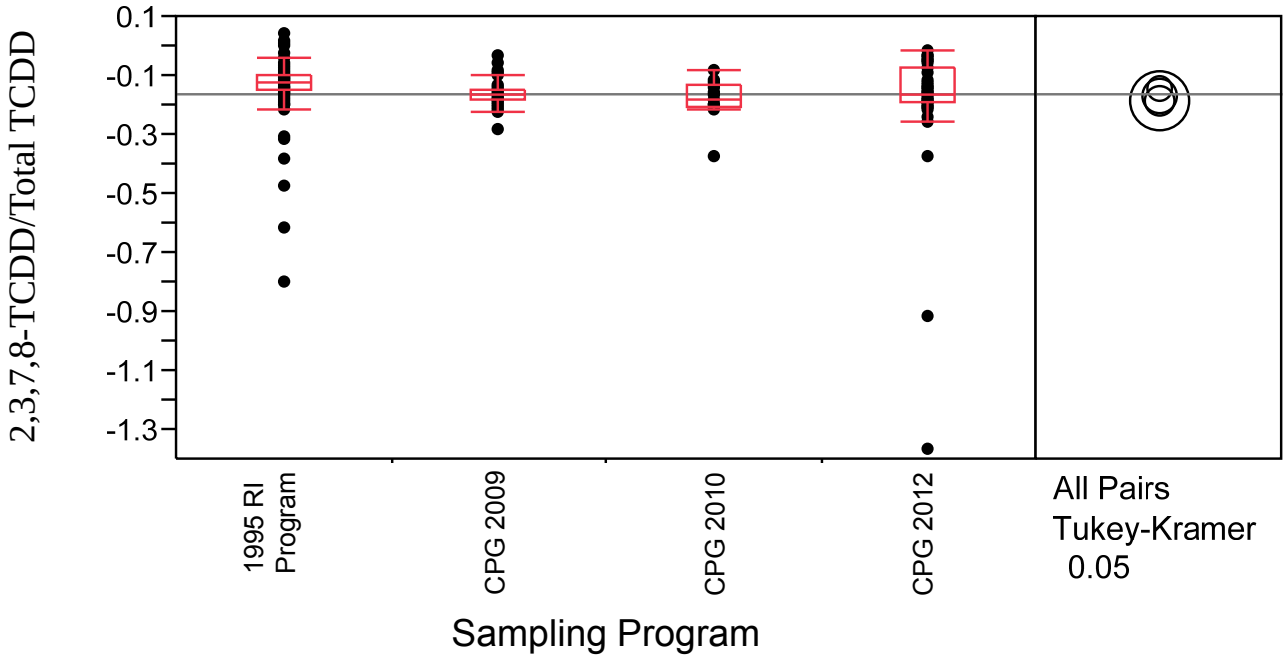
RM0 to RM2





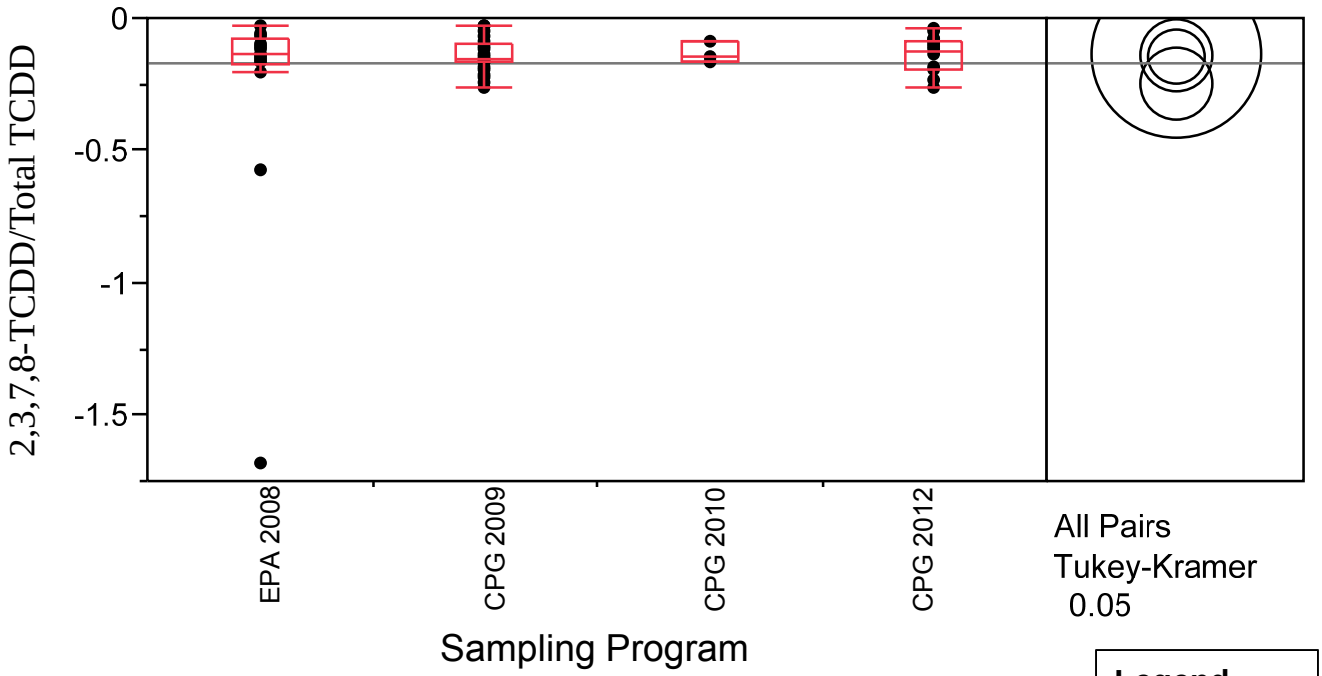
Notes: 1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Note: the ratios for the 2008 CPG data were not plotted due to analytical issues with the 2008 Total TCDD data that resulted in low bias, non-representative results.

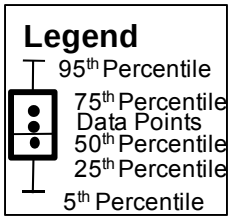
RM2 to RM8



	2,3,7,8-TCDD to Total TCDD Ratio (0-6 inch) by Sampling at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 2.2-3a** 2014

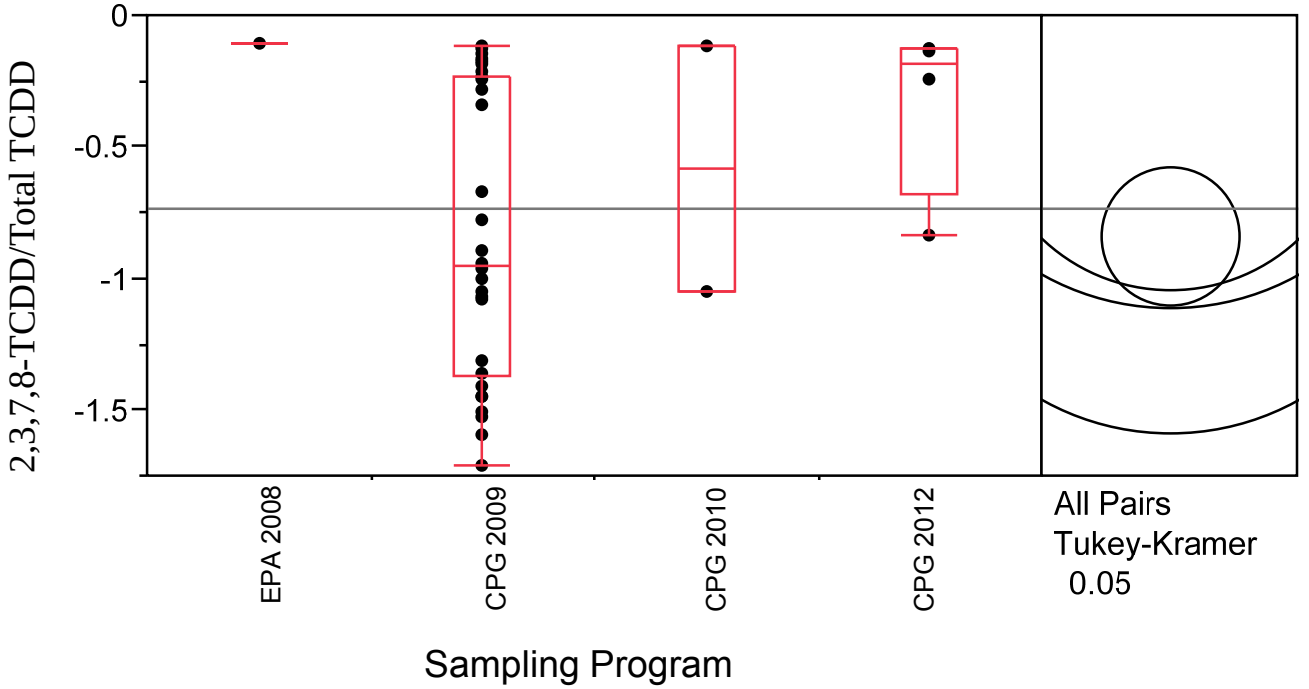
RM8 to RM12



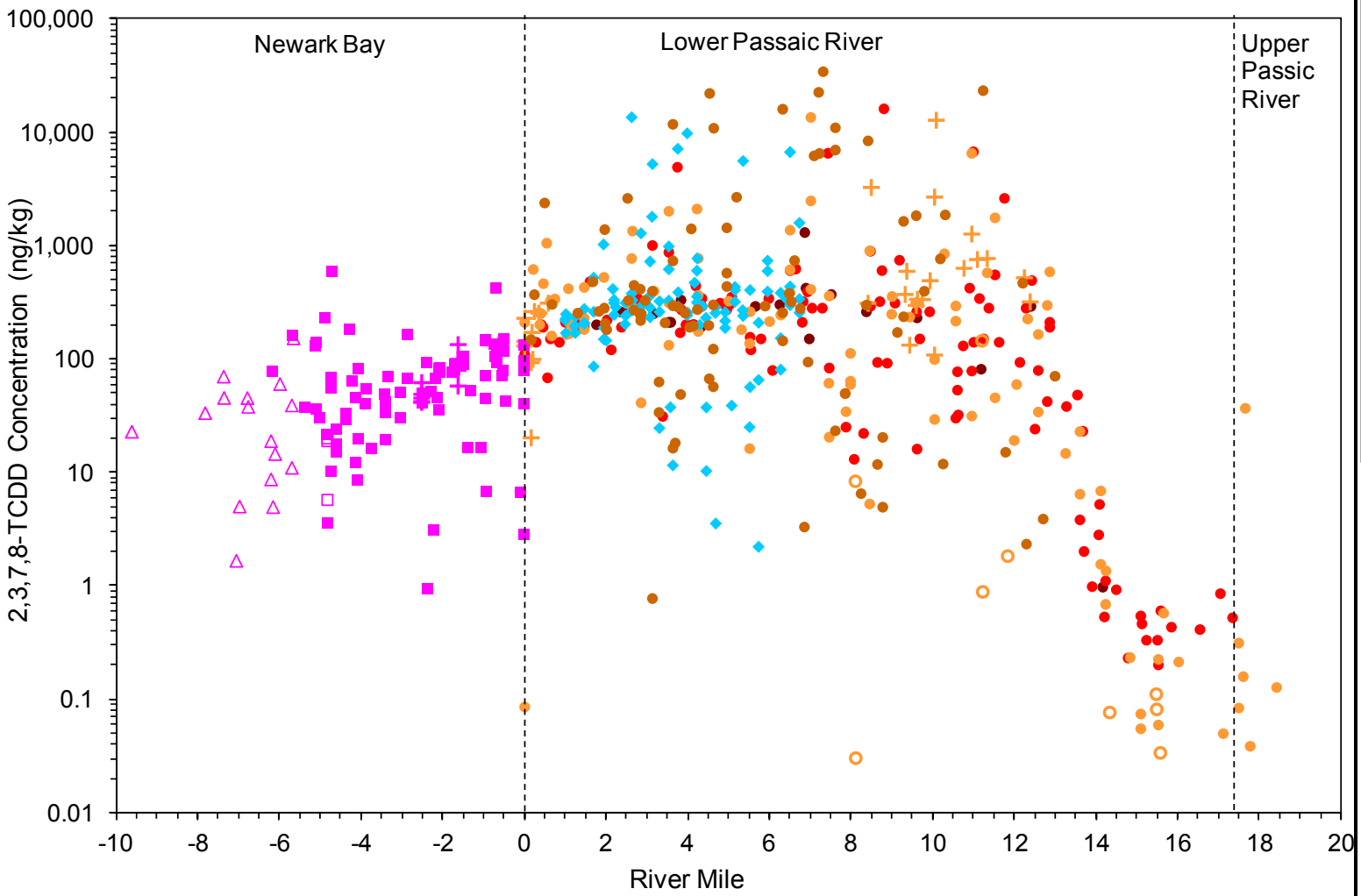


Notes: 1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Note: the ratios for the 2008 CPG data were not plotted due to analytical issues with the 2008 Total TCDD data that resulted in low bias, non-representative results.

RM12 to RM17.4



	2,3,7,8-TCDD to Total TCDD Ratio (0-6 inch) by Sampling Program at RM8 to RM12 and RM12 to RM17.4 *Lower Eight Miles of the Lower Passaic River*	**Figure 2.2-3b** 2014



Legend

- 2012 CPG
- 2010 CPG
- 2009 CPG
- 2008 CPG
- 2008 CPG Tributary Below HoT
- 2008 EPA
- 2005&2007 Newark Bay
- 2005&2007 Shooters Island & Arthur Kill
- 2005&2007 Kill Van Kull
- 2005&2007 Port Elizabeth & Newark
- 1995 TSI

Note:: 2,3,7,8-TCDD Concentrations generated during the 2008 CPG coring program were biased low and have been corrected by applying a factor of 1.89. The factor was provided by CSC and Interface, Inc. 2010.

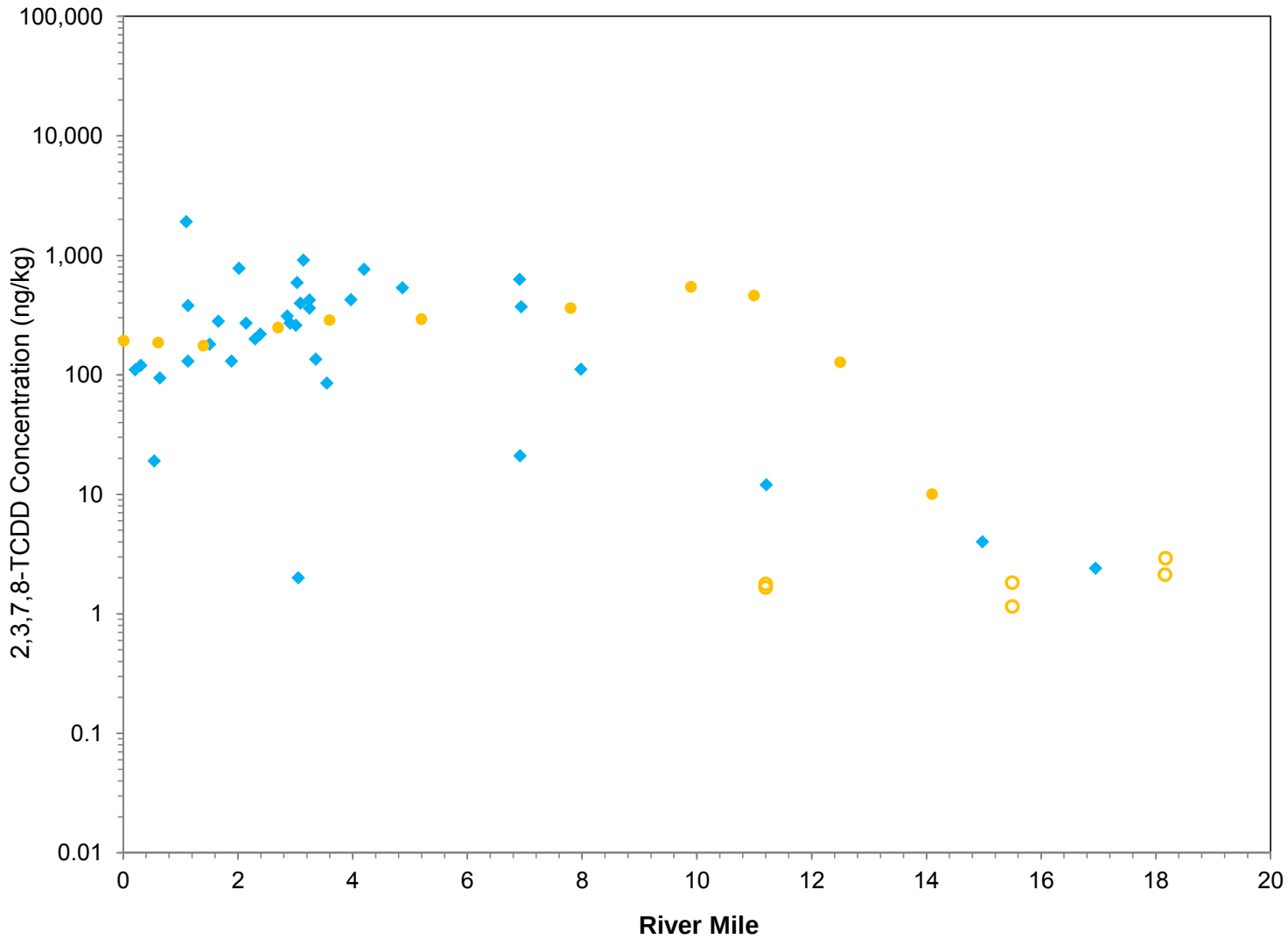
2,3,7,8-TCDD Concentration (0-6 inches) *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2.3-1

2014

R2-0027103



Legend

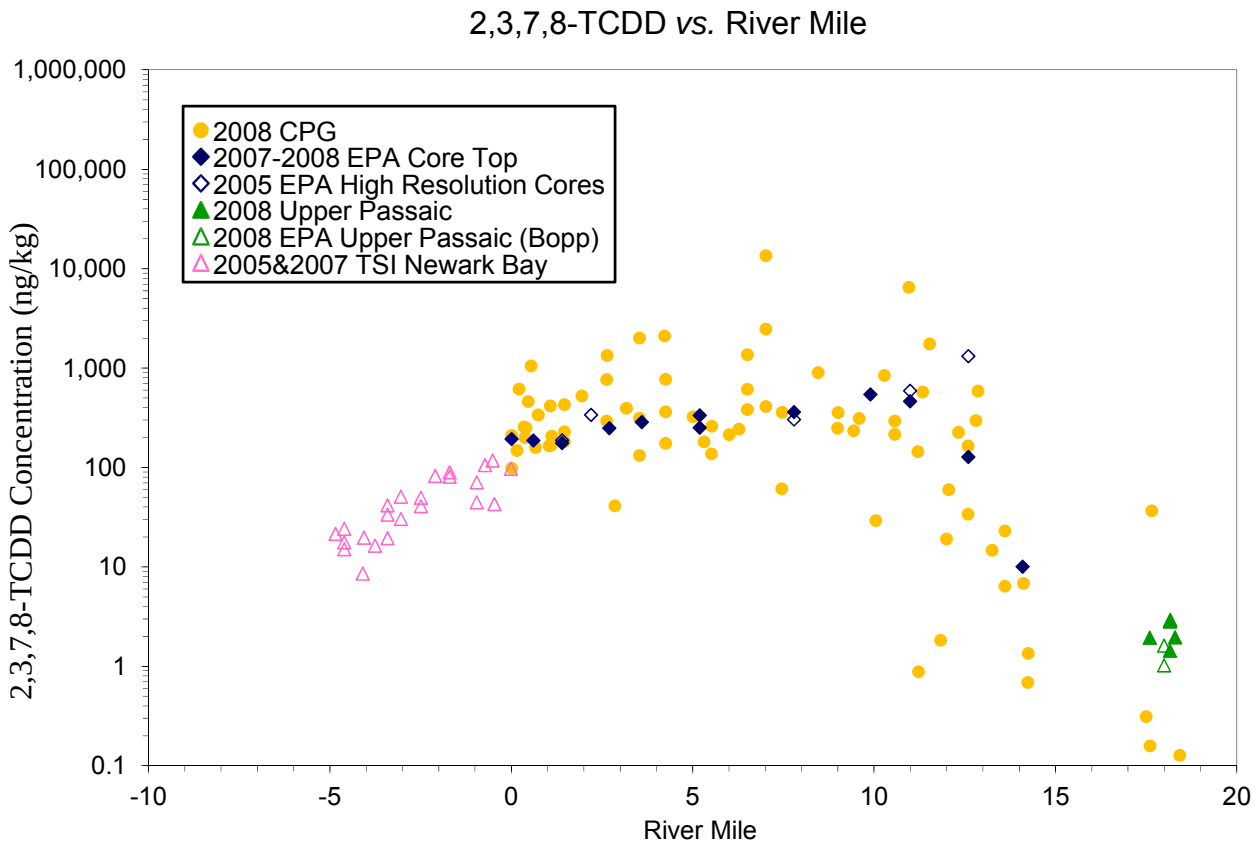
- 1991-1993
- 2007-2008 EPA
- 2007-2008 EPA Tributary Above HoT

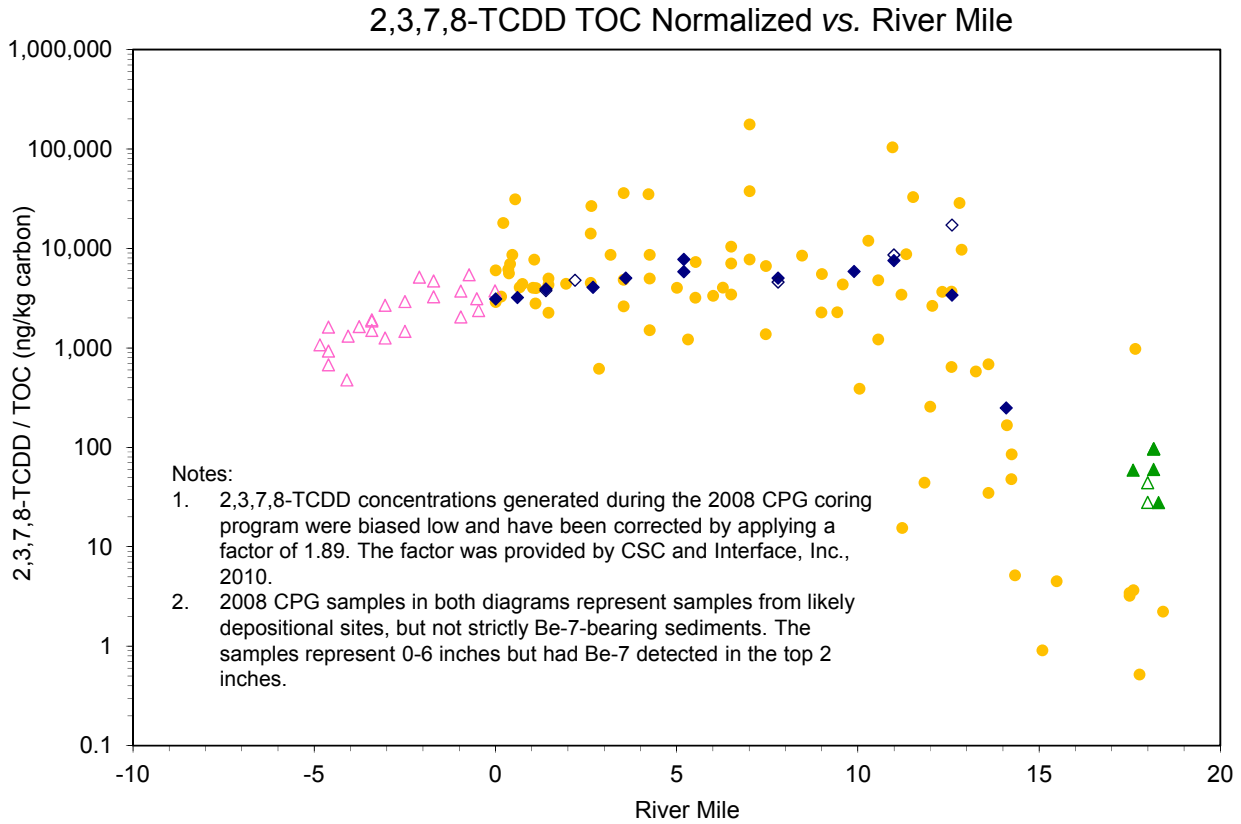
2,3,7,8-TCDD Concentration (0 - ≤2 inches) *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

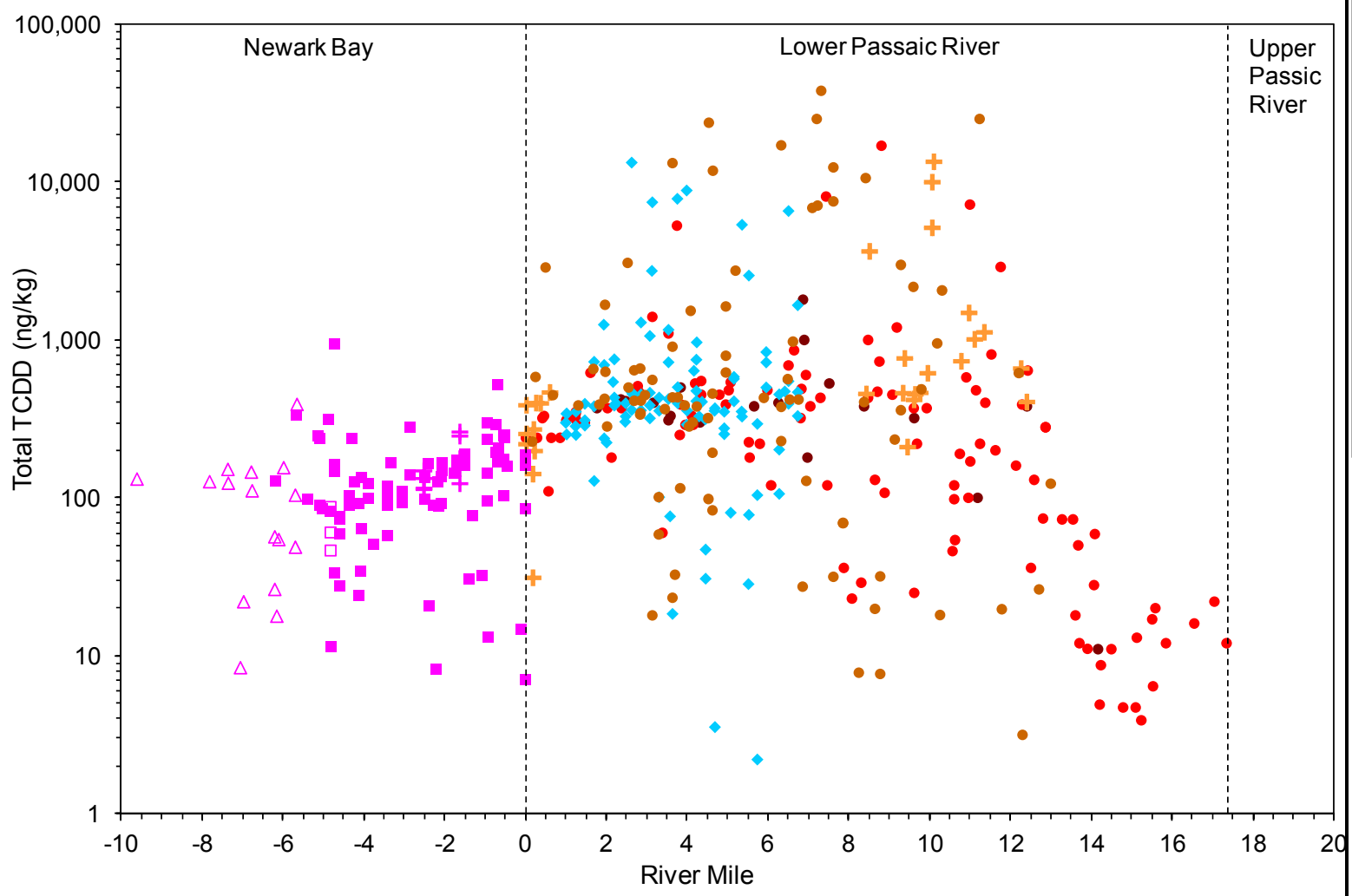
Figure 2.3-2

2014





	2,3,7,8-TCDD in Recently-Deposited Sediments in the Lower Passaic River, Newark Bay and the Upper Passaic River *Lower Eight Miles of the Lower Passaic River*	**Figure 2.3-3** 2014



Legend

- 2012 CPG
- 2010 CPG
- 2009 CPG
- 2008 CPG
- 2008 CPG Tributary Below HoT
- 2008 EPA
- 2005&2007 Newark Bay
- 2005&2007 Shooters Island & Arthur Kill
- 2005&2007 Kill Van Kull
- 2005&2007 Port Elizabeth & Newark
- 1995 TSI

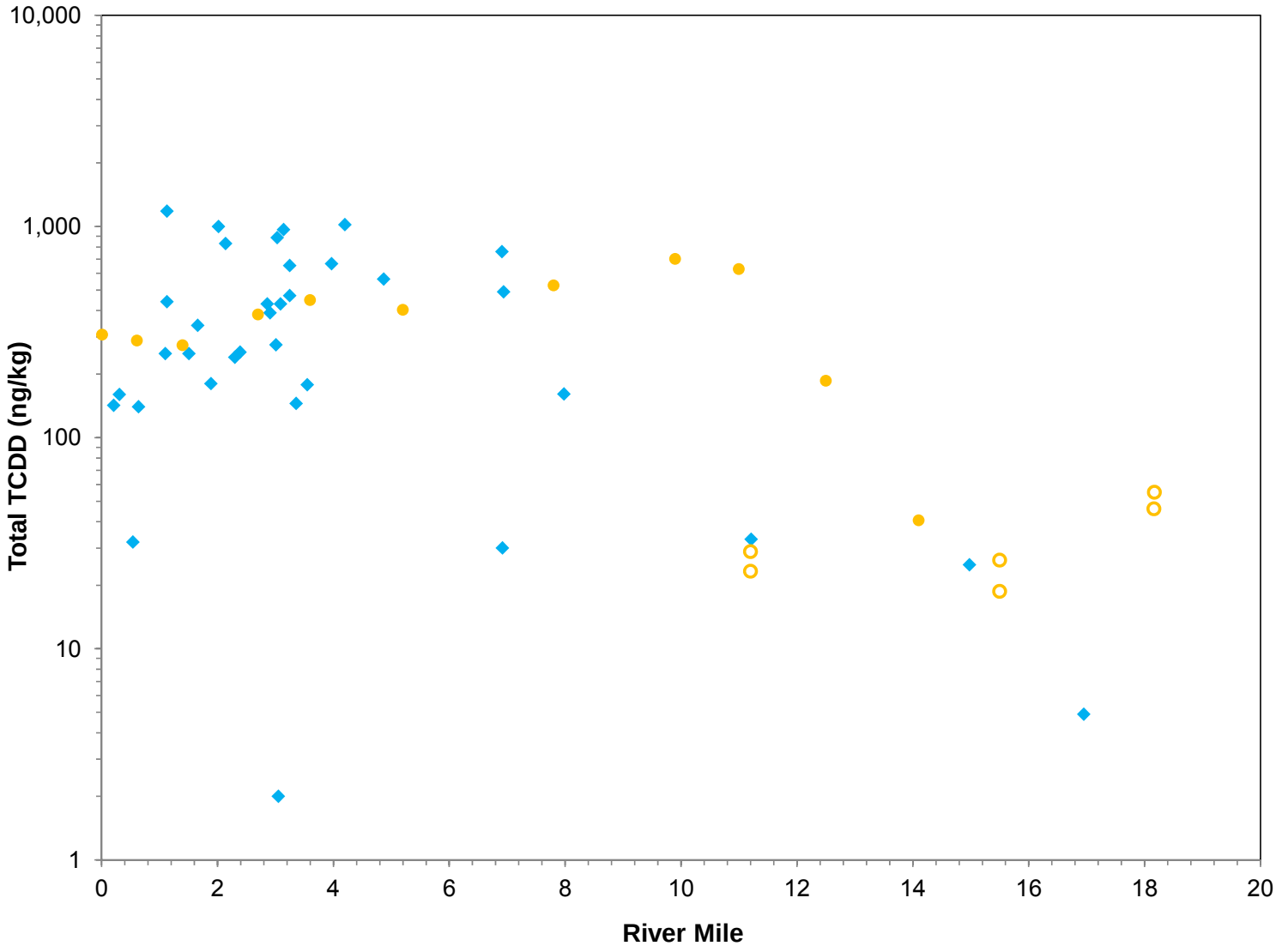
Note: the 2008 CPG Total TCDD data were not presented on this diagram due to analytical issues with the 2008 data that resulted in low bias, non-representative results.

Total TCDD Concentration (0-6 inches) *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2.3-4

2014



Legend

- 1991-1993
- 2007-2008 EPA
- 2007-2008 EPA Tributary Above HoT

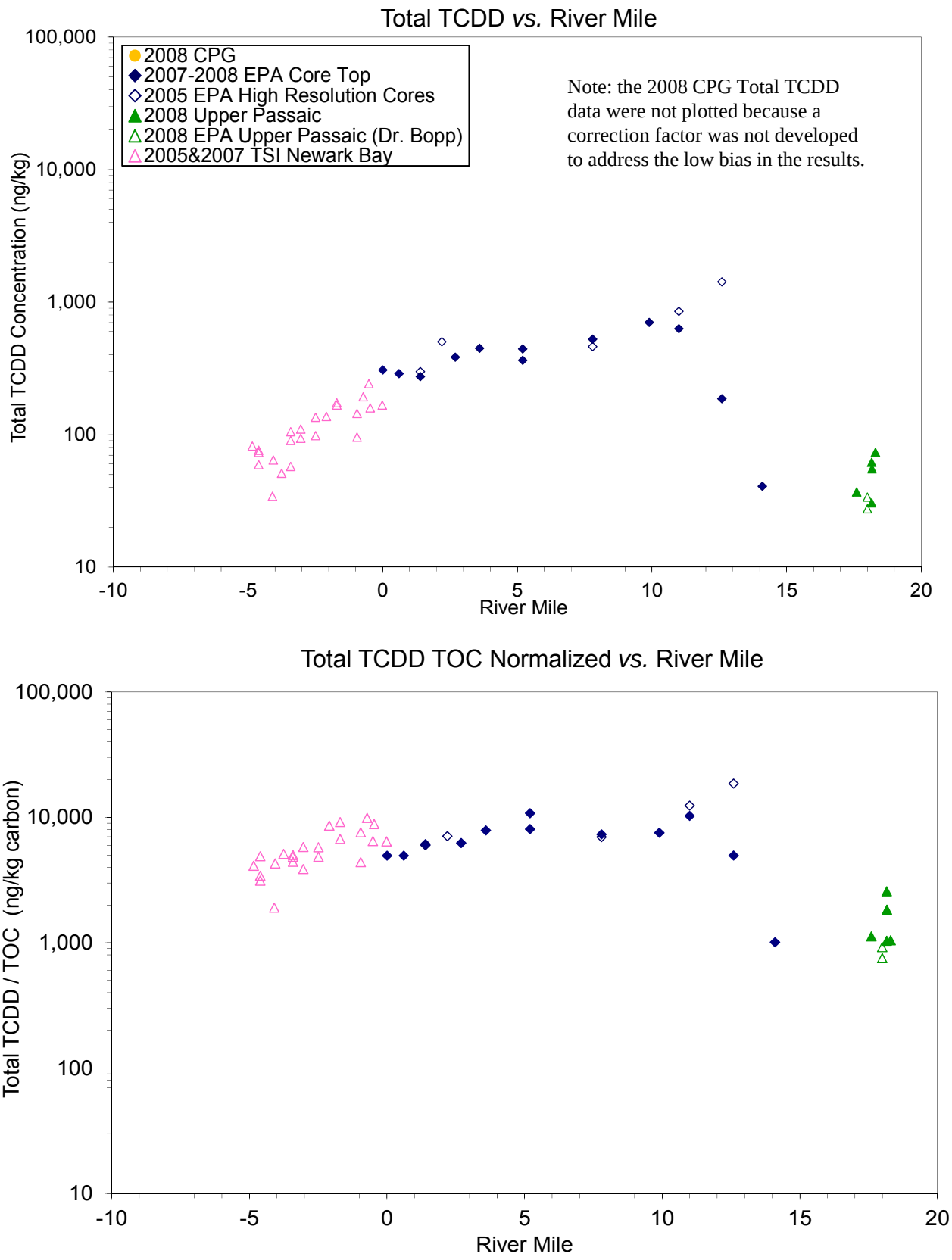
Total TCDD Concentration (0 - ≤2 inches) *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

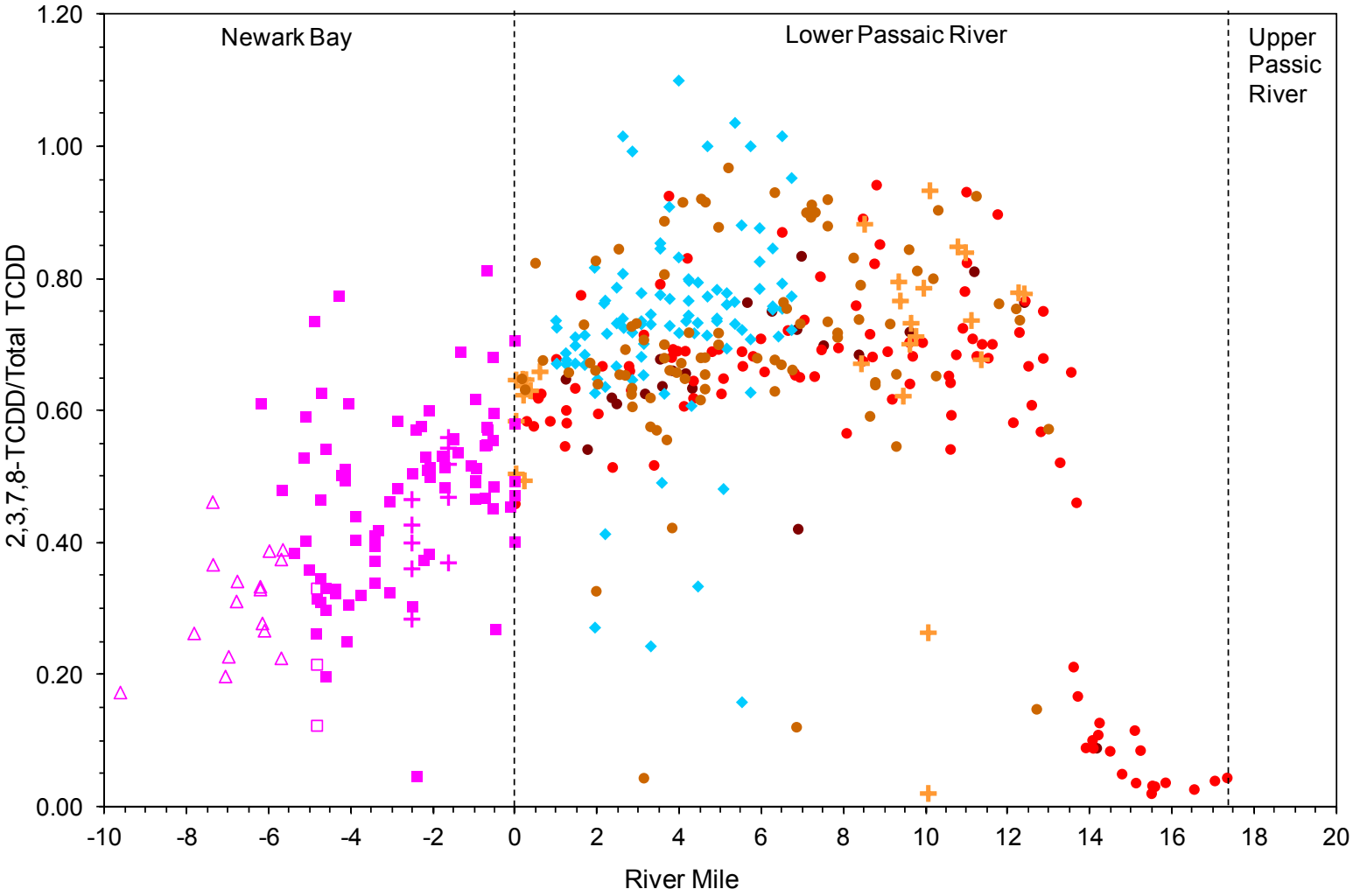
Figure 2.3-5

2014

R2-0027107



	Total TCDD in Recently-Deposited Sediments in the Lower Passaic River, Newark Bay and the Upper Passaic River *Lower Eight Miles of the Lower Passaic River*	**Figure 2.3-6** 2014



Legend

- 2012 CPG
- 2010 CPG
- 2009 CPG
- 2008 CPG
- 2008 CPG Tributary Below HoT
- 2008 EPA
- 2005&2007 Newark Bay
- 2005&2007 Shooters Island & Arthur Kill
- 2005&2007 Kill Van Kull
- 2005&2007 Port Elizabeth & Newark
- 1995 TSI

Note: the ratios for the 2008 CPG data were not plotted due to analytical issues with the 2008 Total TCDD data that resulted in low bias, non-representative results.

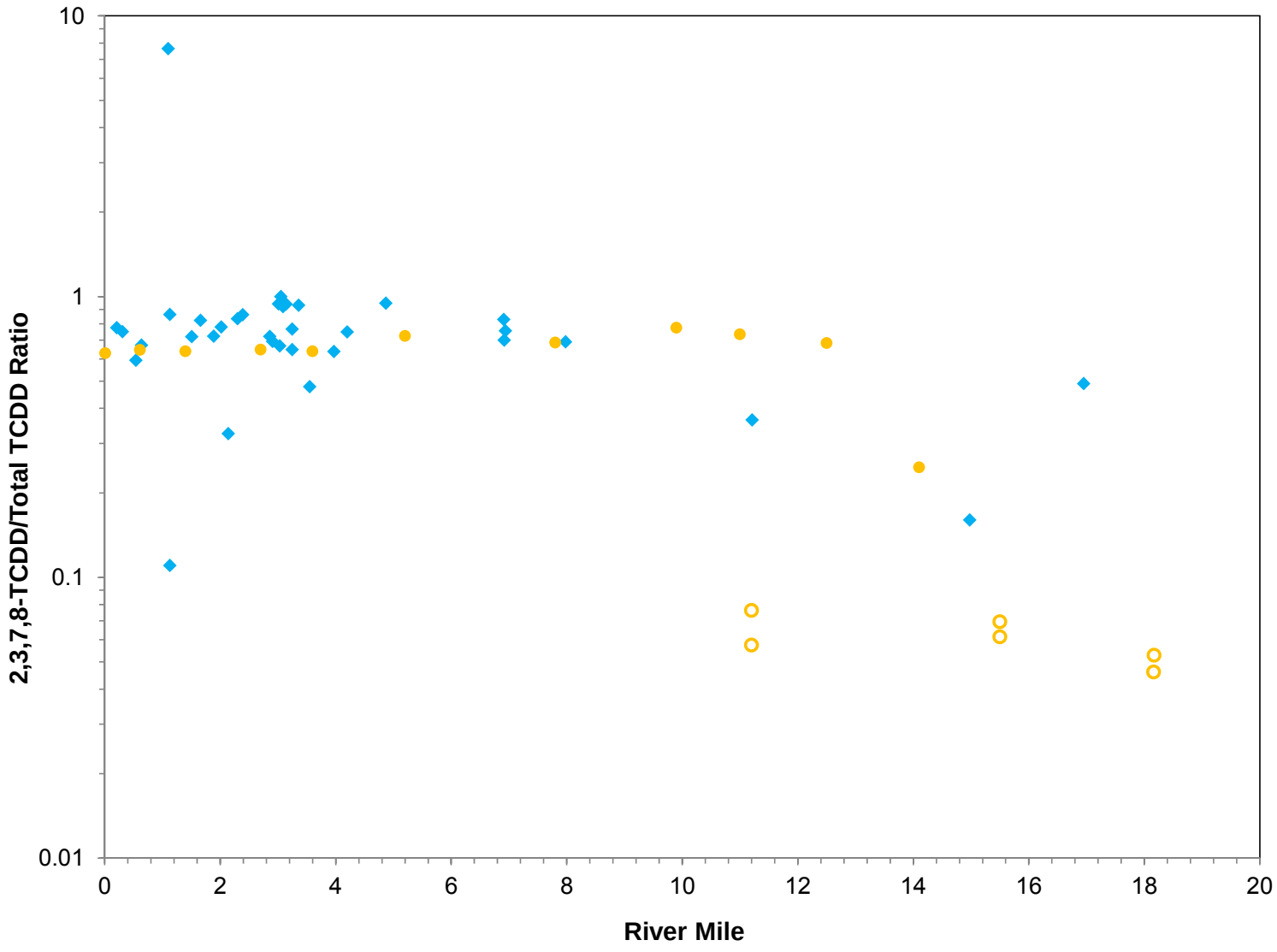
2,3,7,8-TCDD to Total TCDD Ratio (0-6 inches) *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2.3-7

2014

R2-0027109



Legend

- 1991-1993
- 2007-2008 EPA
- 2007-2008 EPA Tributary Above HoT

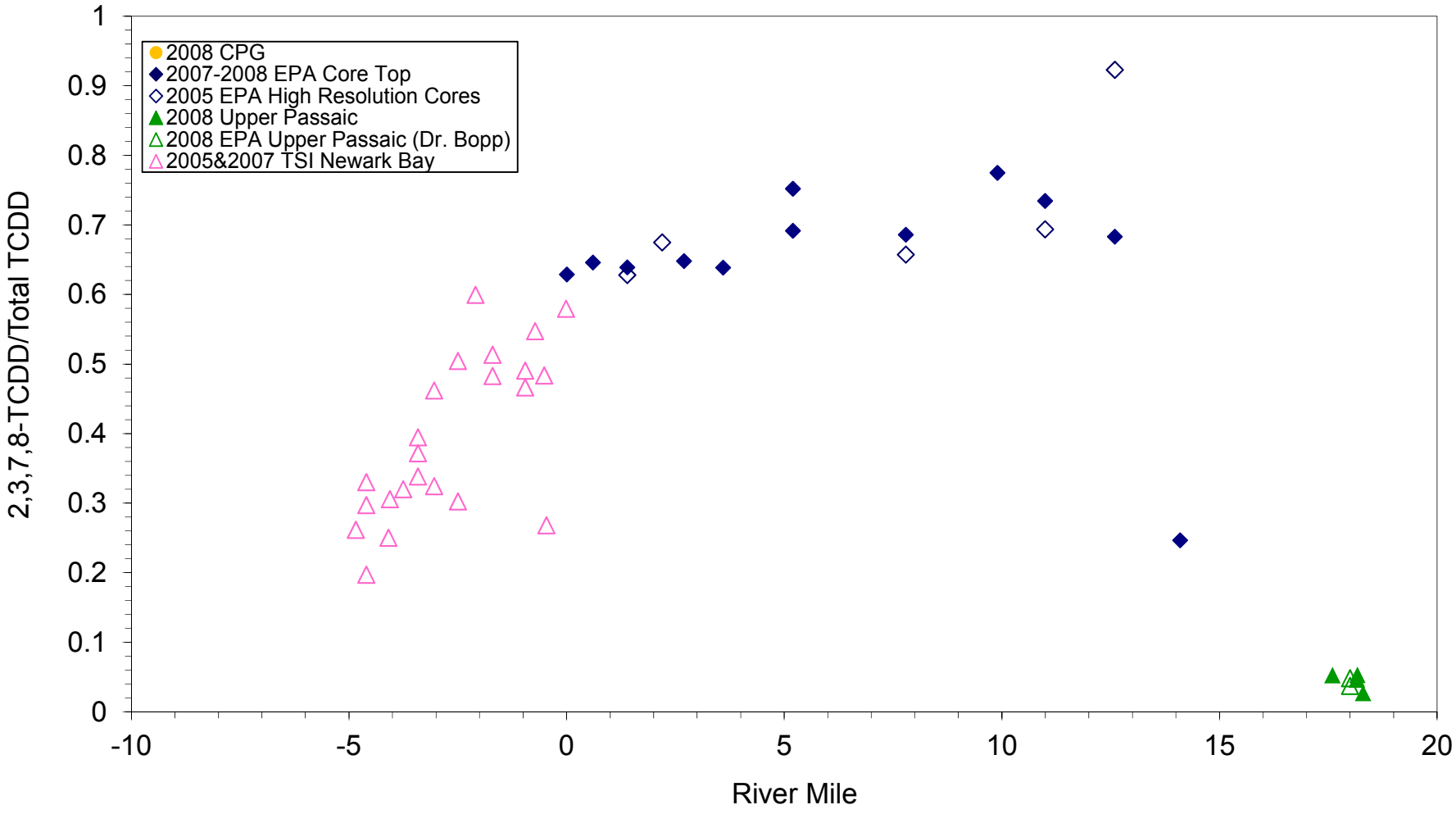
2,3,7,8-TCDD to Total TCDD Ratio (0 - ≤2 inches) *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2.3-8

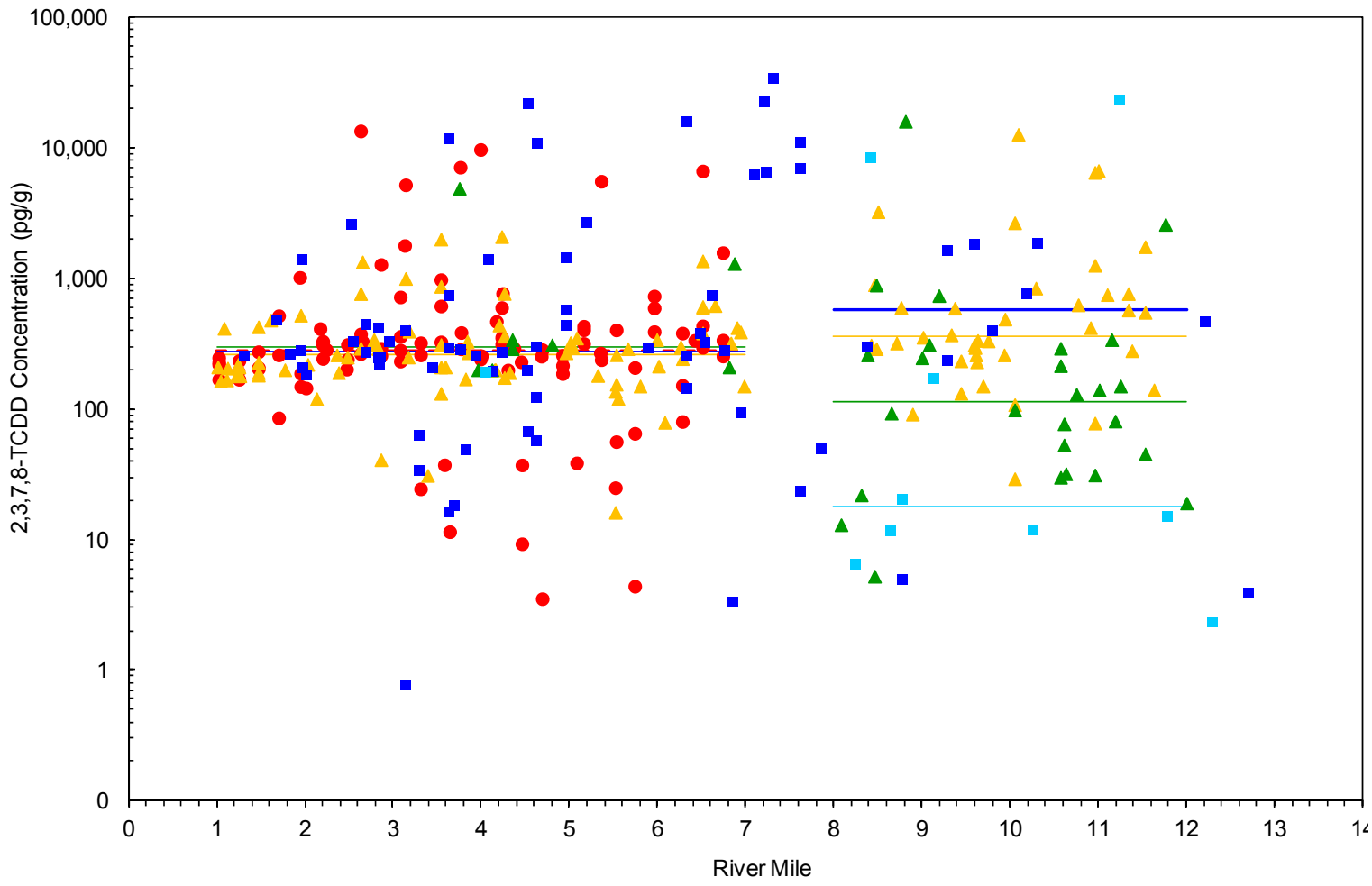
2014

R2-0027110



Note: the ratios for the 2008 CPG data were not plotted due to analytical issues with the 2008 Total TCDD data that resulted in low bias, non-representative results.

	2,3,7,8-TCDD to Total TCDD Ratio in Recently-Deposited Sediments in the Lower Passaic River, Newark Bay and the Upper Passaic River *Lower Eight Miles of the Lower Passaic River*	**Figure 2.3-9** 2014



Legend

- 2012 Fine-Grained
- 2012 Fine-Grained Median
- 2012 Coarse-Grained
- 2012 Coarse-Grained Median
- 2008-2010 Fine-Grained
- 2008-2010 Fine-Grained Median
- 2008-2010 Coarse-Grained
- 2008-2010 Coarse-Grained Median
- 1995
- 1995 Median

Comparison of 2,3,7,8-TCDD Surface Concentration (0-6 inches)
RM1 to RM7 *vs.* RM8 to RM12

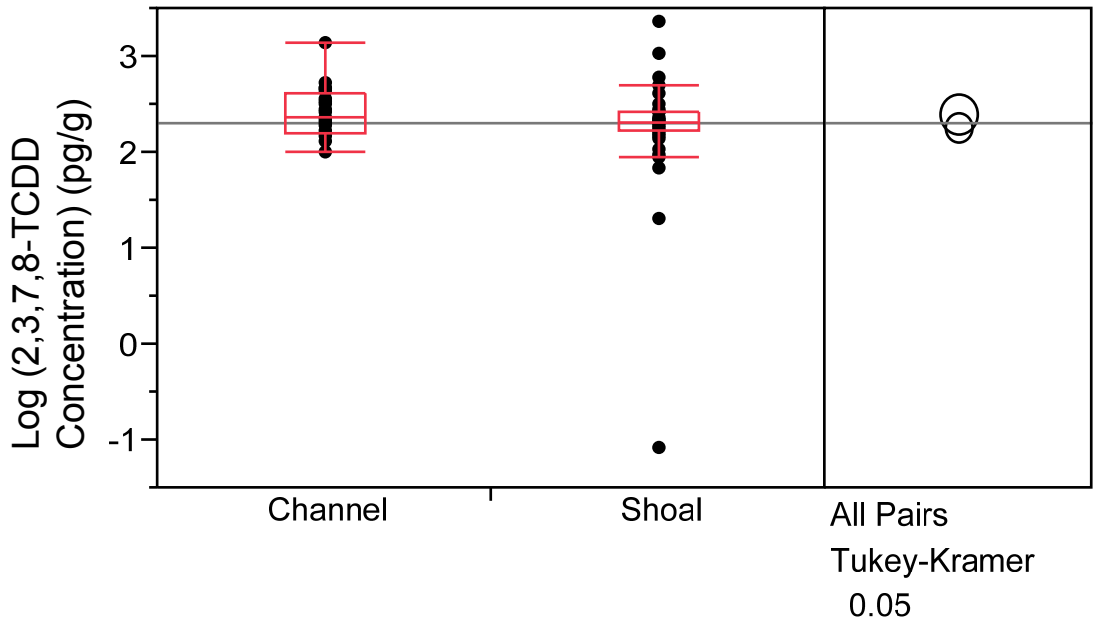
Lower Eight Miles of the Lower Passaic River

Figure 2.4-1

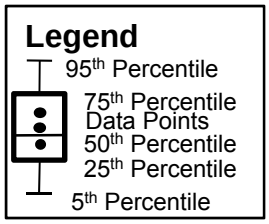
2014

R2-0027112

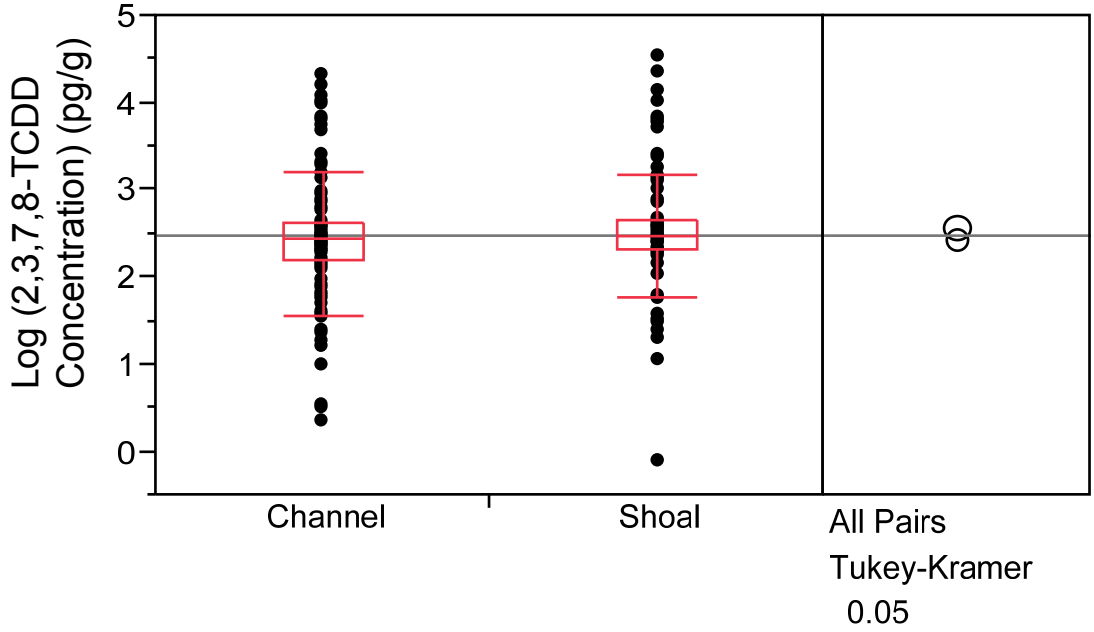
RM0 to RM2



Notes:
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 1995, 2008 EPA, 2008 CPG, 2009 CPG and 2010 and 2012 CPG.
3) 2008 CPG data was corrected by applying a factor of 1.89 (CSC, 2010)

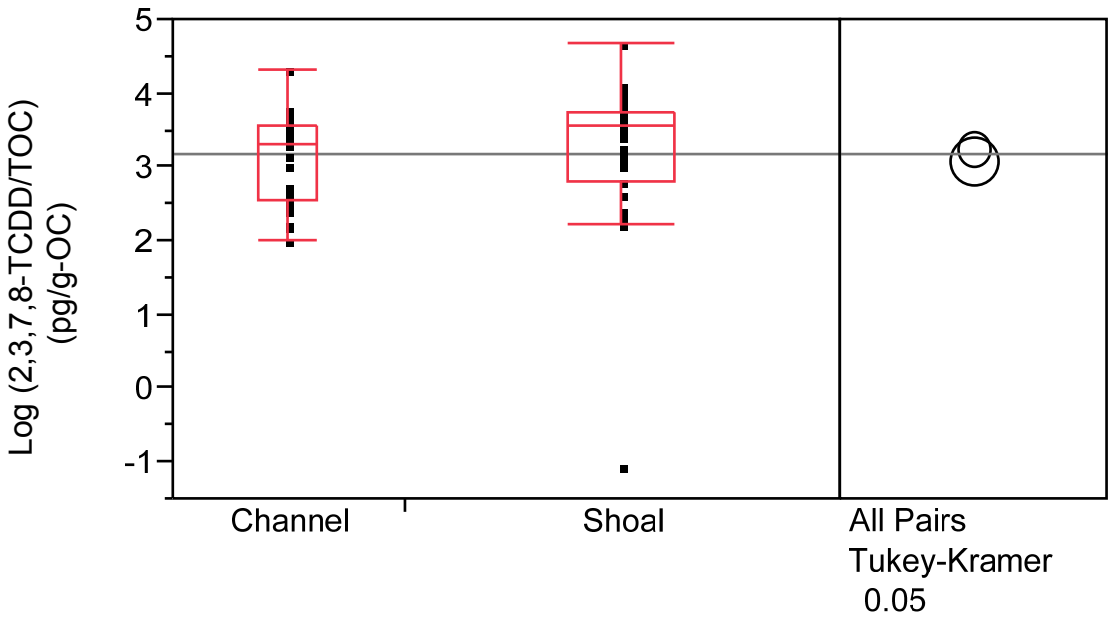


RM2 to RM8

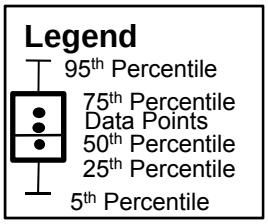


	2,3,7,8-TCDD (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 2.4-2a** 2014

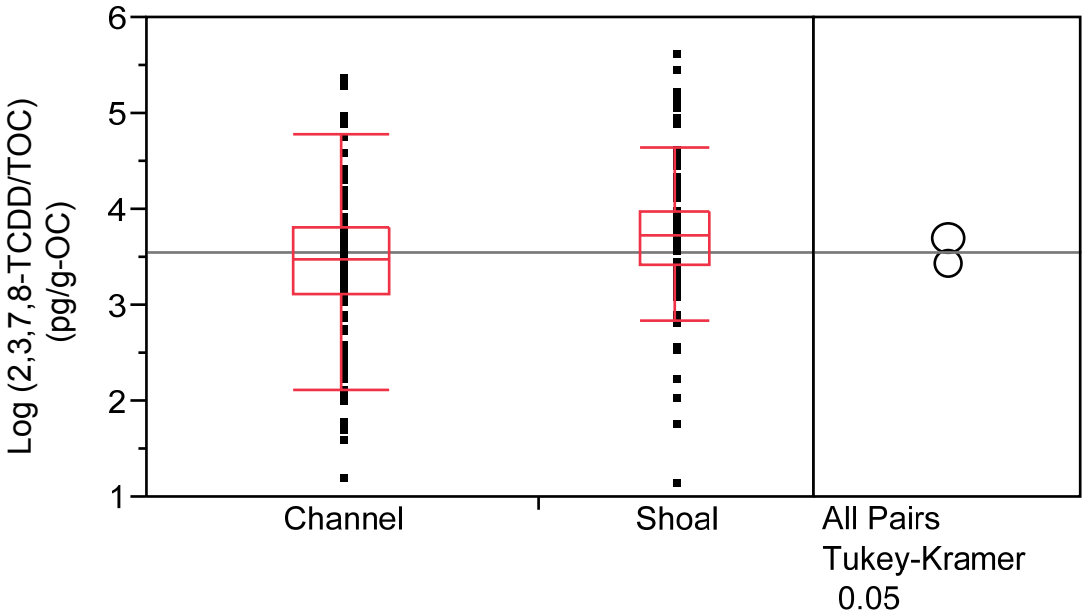
RM0 to RM2



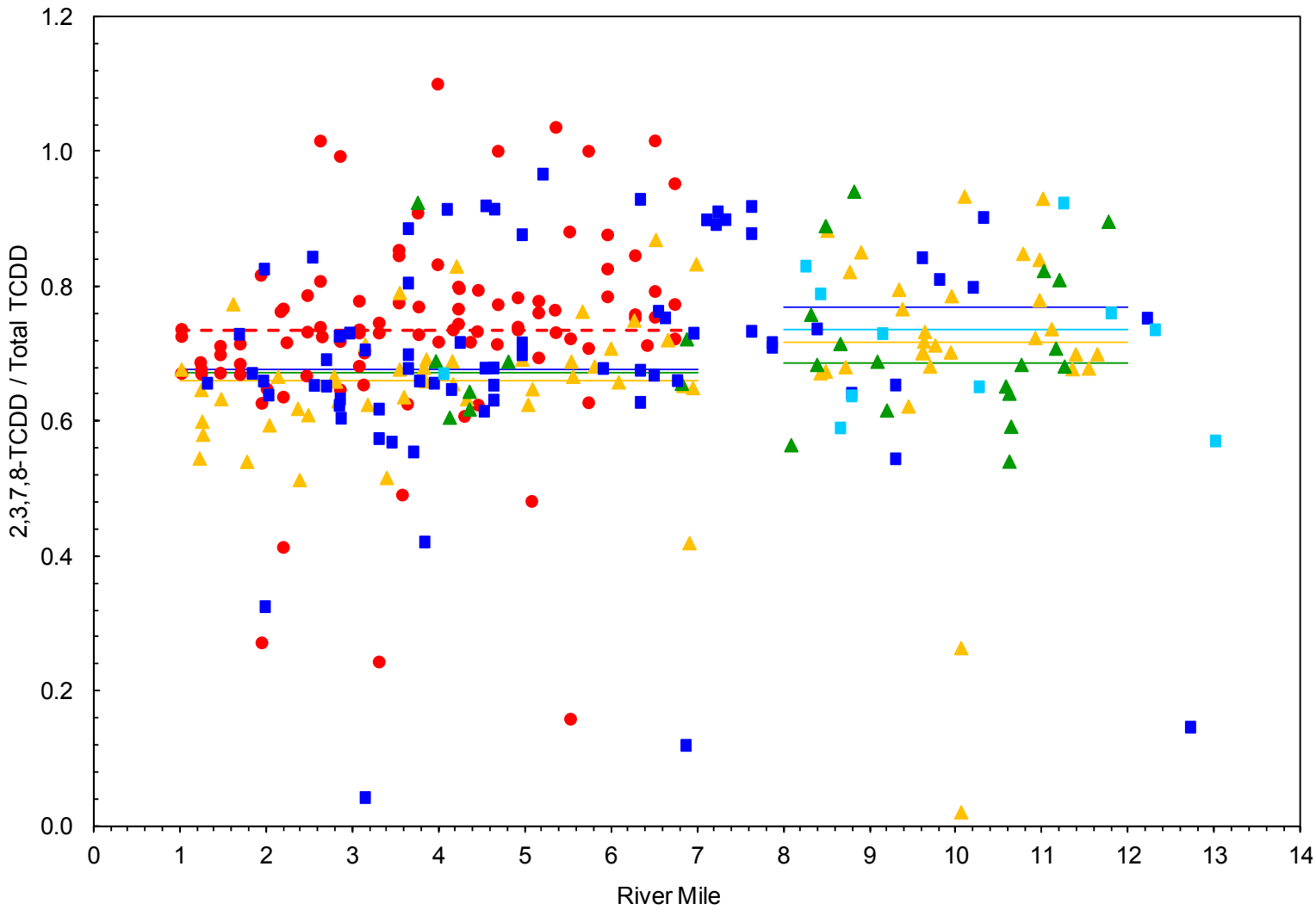
Notes:
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 1995, 2008 EPA, 2008 CPG, 2009 CPG and 2010 and 2012 CPG.
3) 2008 CPG data was corrected by applying a factor of 1.89 (CSC, 2010)



RM2 to RM8



	TOC Normalized 2,3,7,8-TCDD (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 2.4-2b** 2014



Note: the ratios for the 2008 CPG data were not plotted due to analytical issues with the 2008 Total TCDD data that resulted in low bias, non-representative results.

Legend

- 2012 Fine-Grained
- 2012 Fine-Grained Median
- 2012 Coarse-Grained
- 2012 Coarse-Grained Median
- 2008-2010 Fine-Grained
- 2008-2010 Fine-Grained Median
- 2008-2010 Coarse-Grained
- 2008-2010 Coarse-Grained Median
- 1995
- 1995 Median

Comparison of 2,3,7,8-TCDD to Total TCDD Ratio (0-6 inches)
RM1 to RM7 *vs.* RM8 to RM12

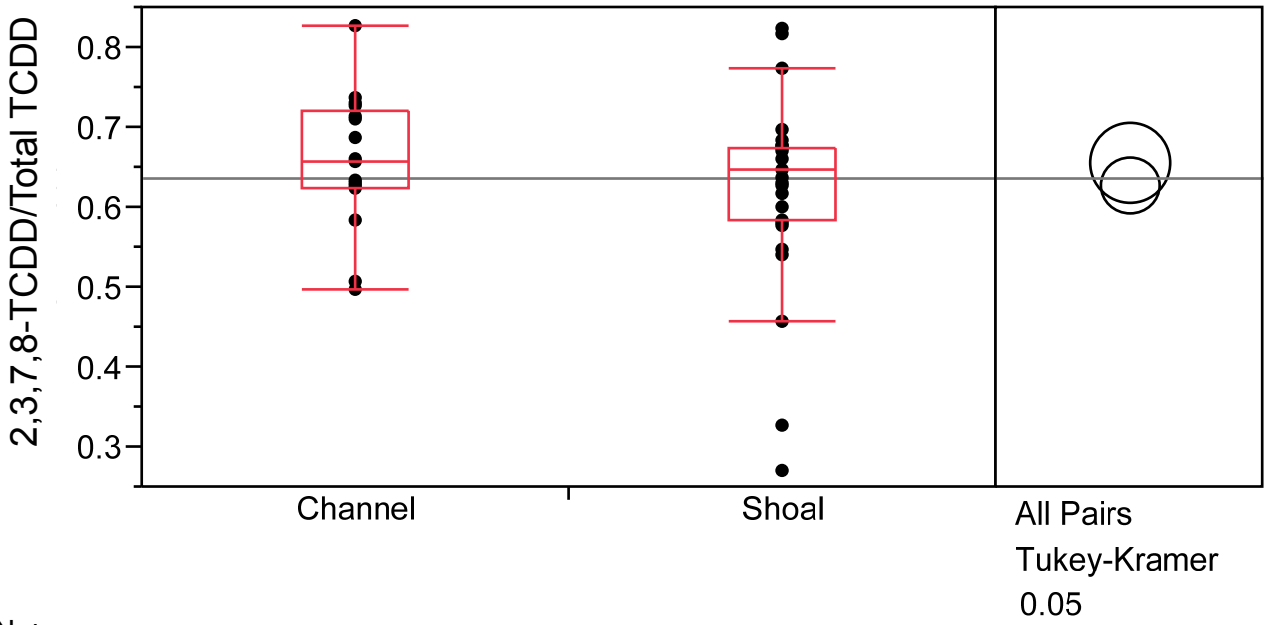
Lower Eight Miles of the Lower Passaic River

Figure 2.4-3

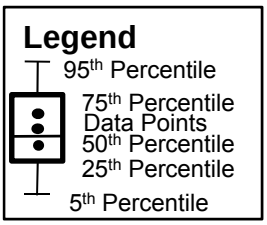
2014

R2-0027115

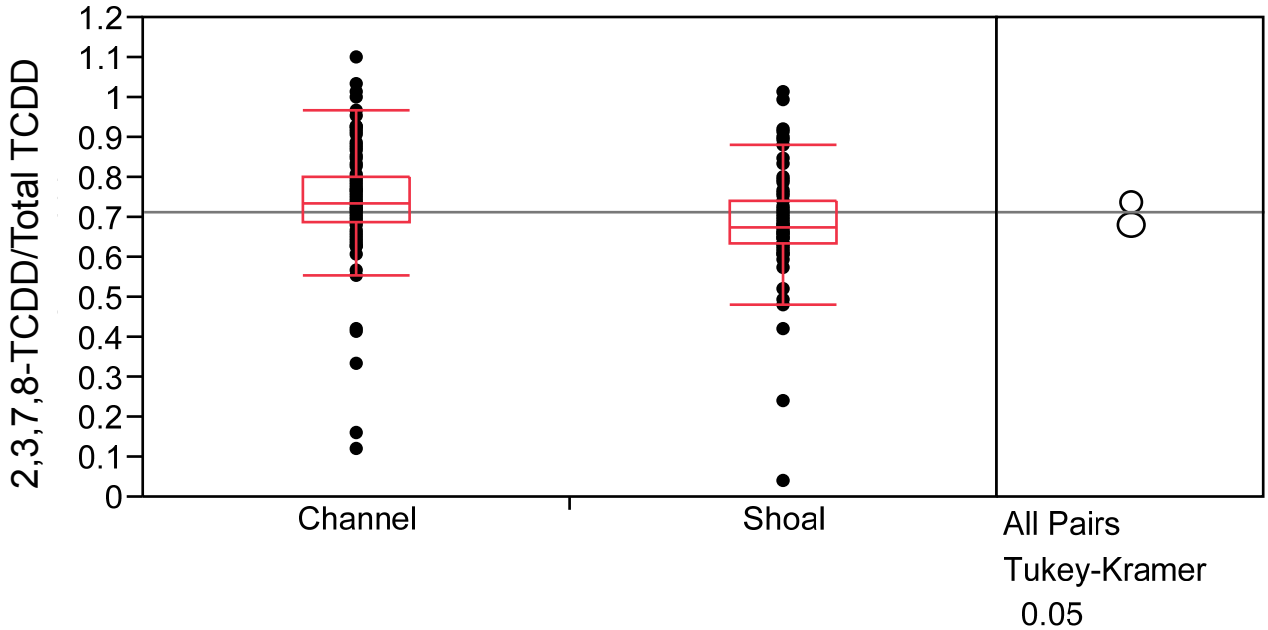
RM 0-2



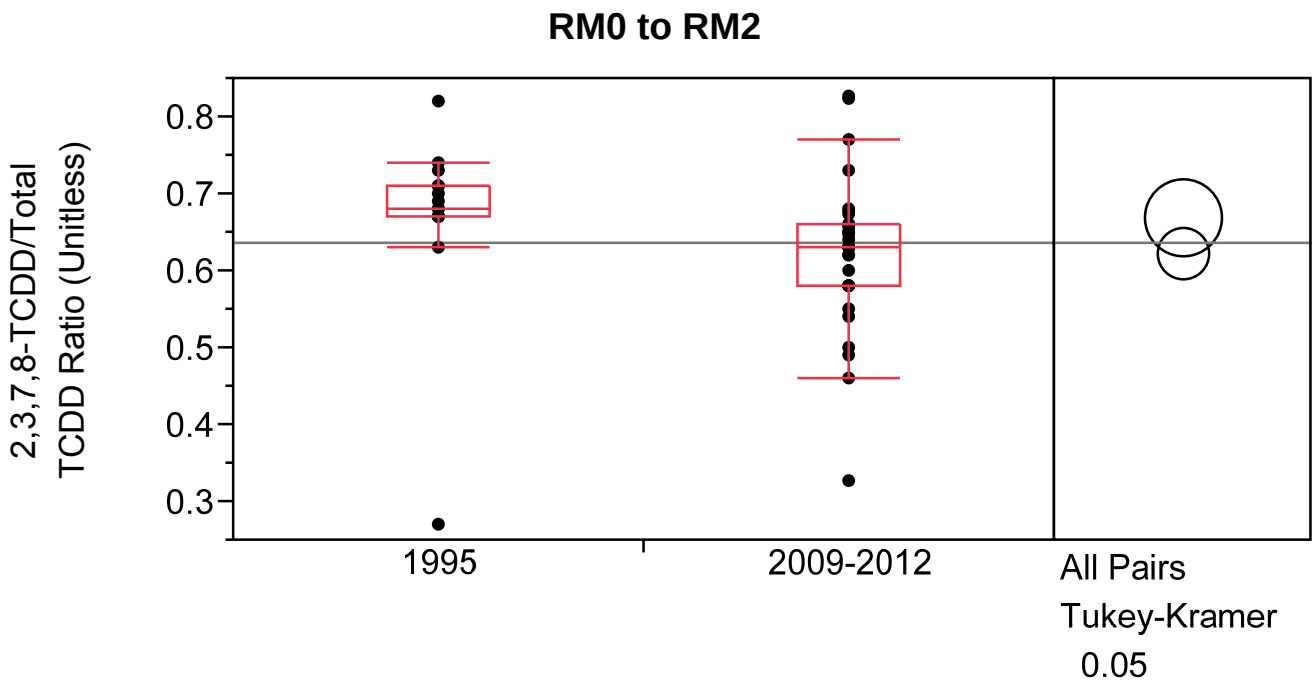
Notes:
1) Horizontal line represents the mean concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 1995, 2008 EPA, 2009 CPG, 2010 CPG and 2012 CPG.
3) The ratios for the 2008 CPG data were not included because a correction factor was not developed to address the low bias in the results.



RM 2-8



	2,3,7,8-TCDD to Total TCDD Ratio (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 2.4-4** 2014



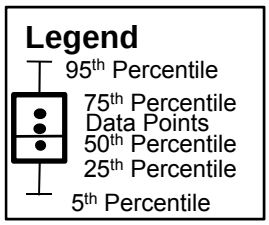
Notes:

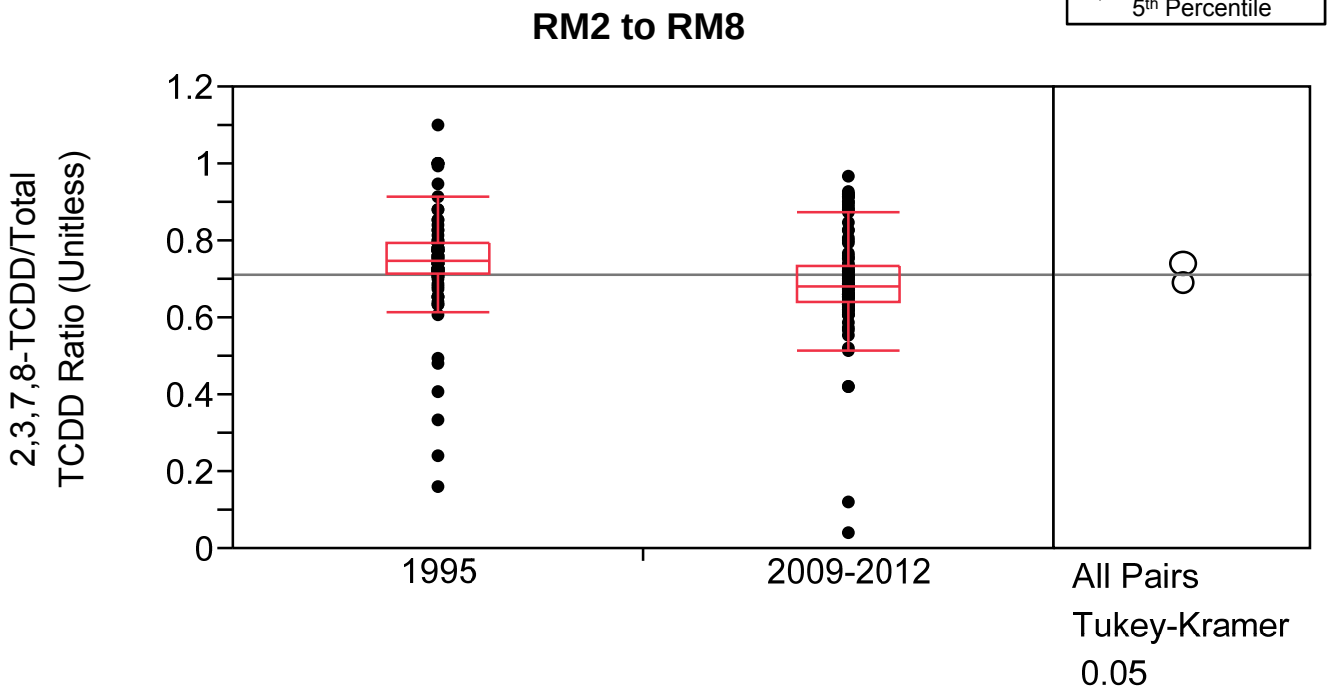
1) Horizontal line represents the mean concentration across all data points, equivalent to the untransformed median concentration.

See text for explanation of Tukey-Kramer circles.

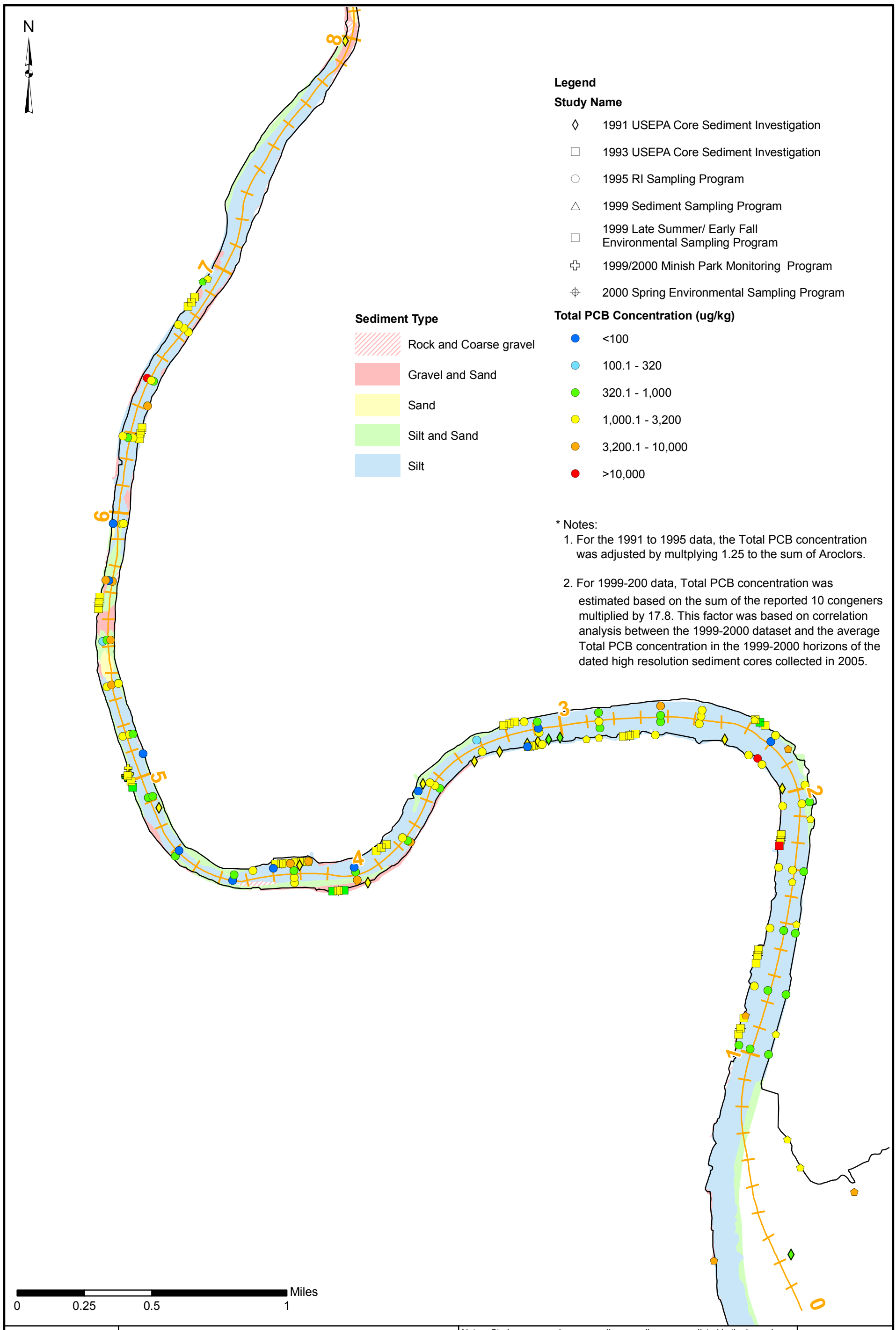
2) Data included 1995, 2008 EPA, 2009 CPG, 2010 CPG and 2012 CPG.

3) The ratios for the 2008 CPG data were not included because a correction factor was not developed to address the low bias in the results.





	2,3,7,8-TCDD to Total TCDD Ratio (0-6 inch) by Study Period: 1995 *vs.* 2009-2012 *Lower Eight Miles of the Lower Passaic River*	**Figure 2.4-5** 2014



Total PCB in Surface Sediment Samples from 1991 to 2000

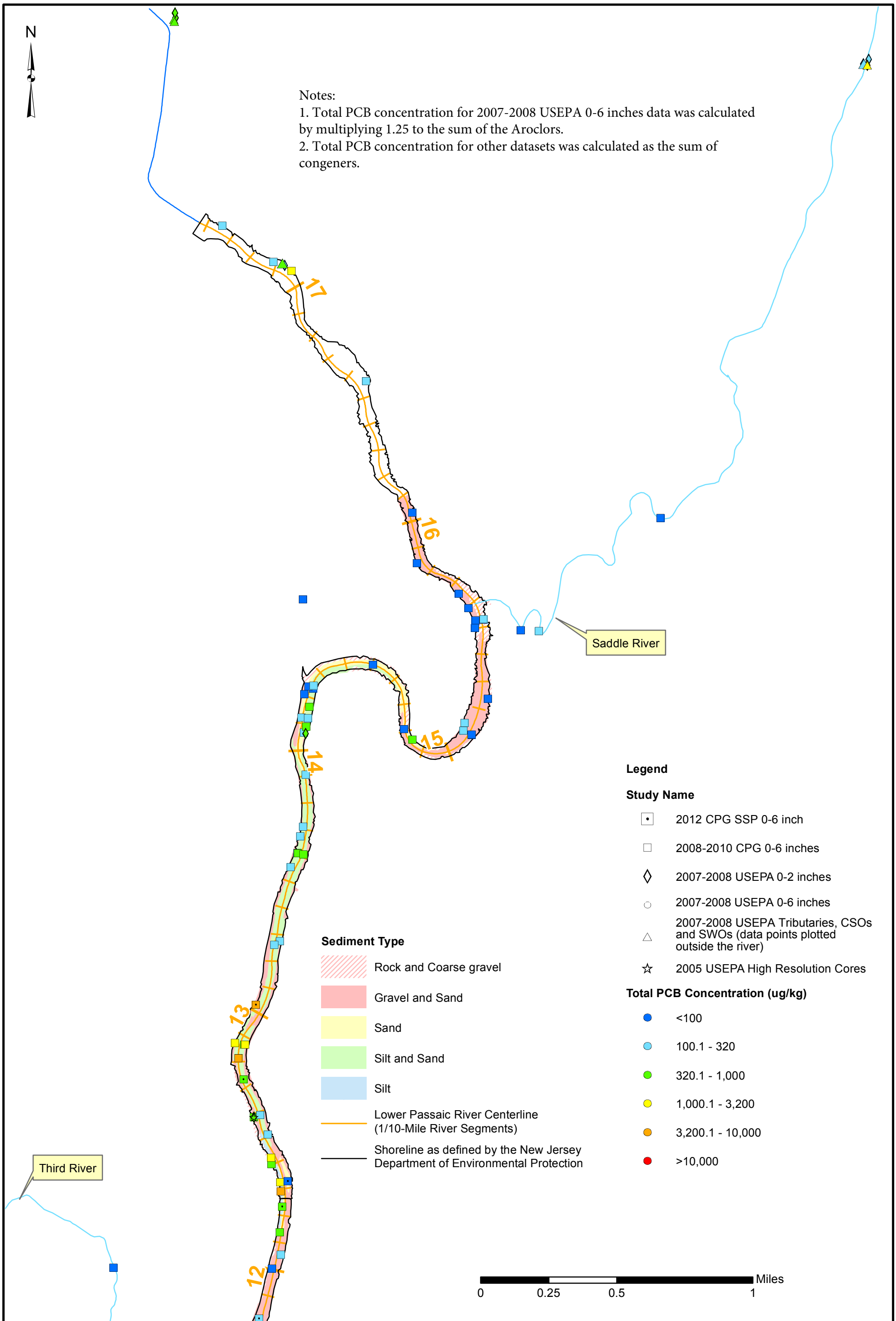
Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.1-1

2014

Path: S:\Projects\passaic\MapDocuments\4553001-CERCLA\2012_Update\TotalPCB_Surficial_Sed_1991_2000



Total PCB Surface Sediment Samples from 2005 to 2012

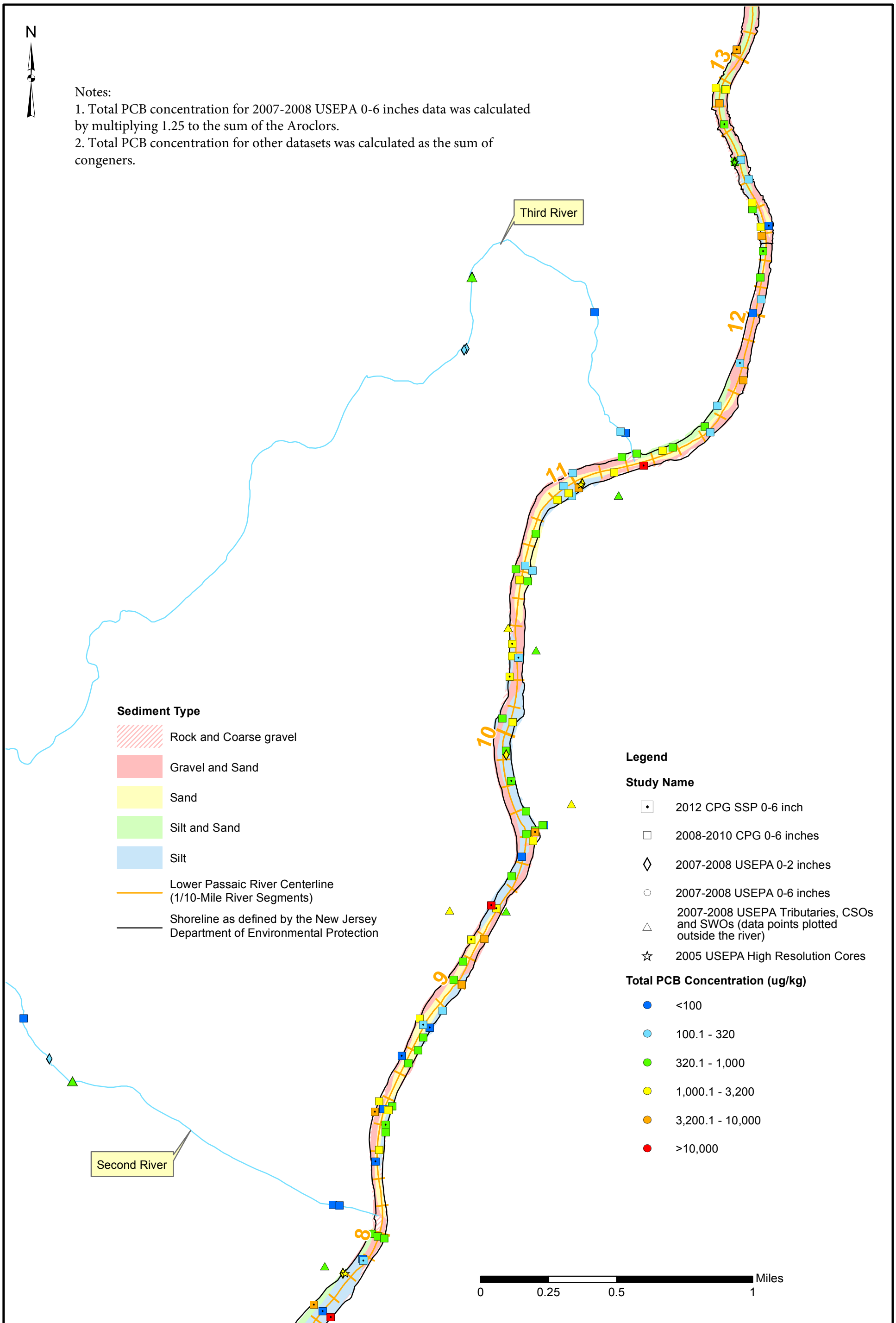
Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.1-2a

2014

Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\TotalPCB_Surficial_Sed_2005_2012.mxd



Total PCB Surface Sediment Samples from 2005 to 2012

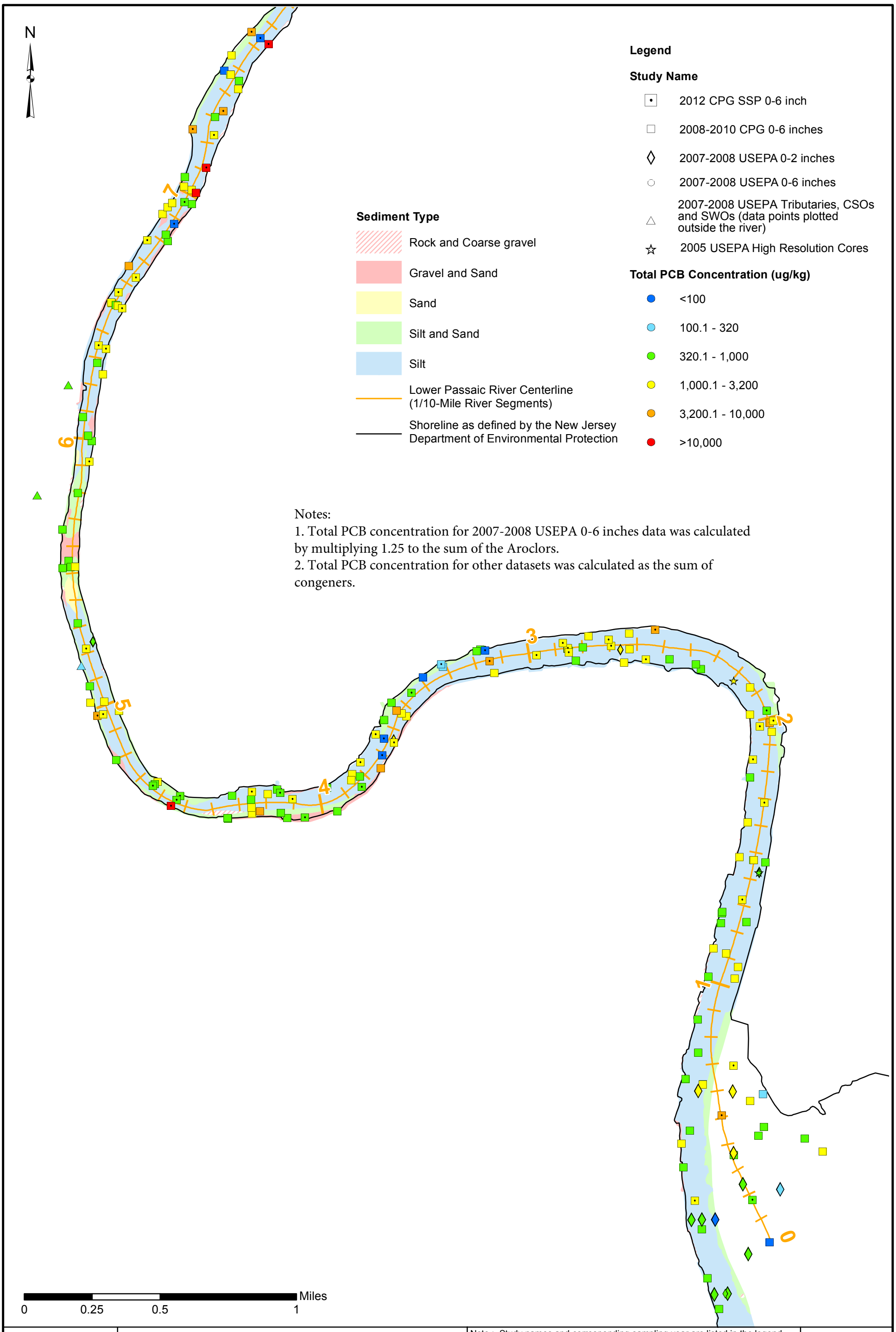
Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.1-2b

2014

Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\TotalPCB_Surficial_Sed_2005_2012.mxd



Total PCB Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

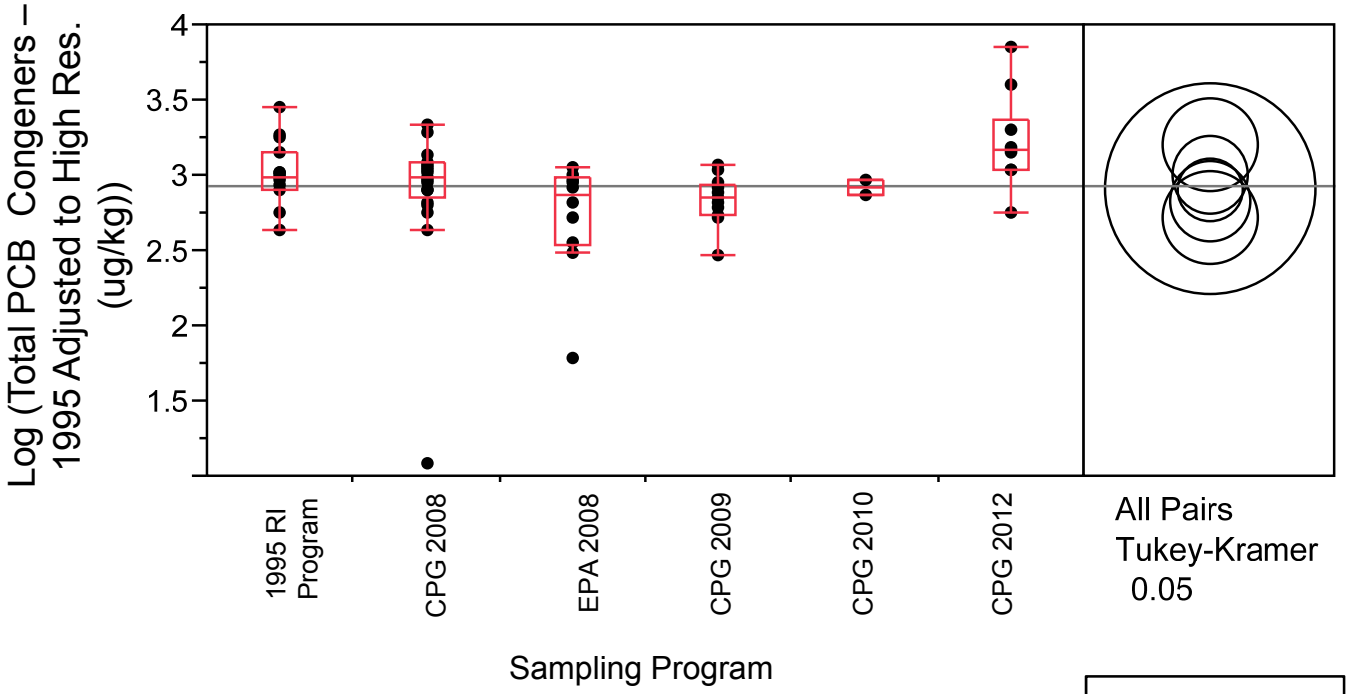
Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.1-2c

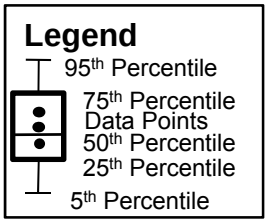
2014

Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\TotalPCB_Surficial_Sed_2005_2012.mxd

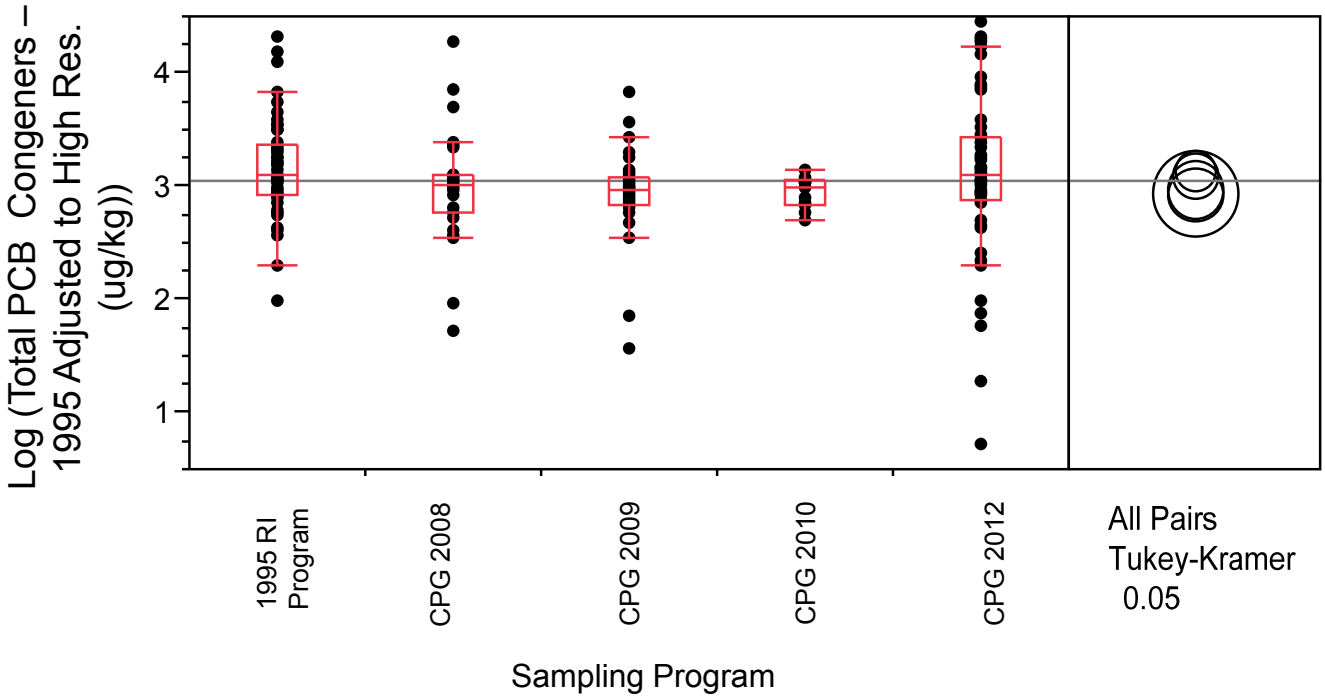
RM0 to RM2



Note: Horizontal line represents the mean concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.

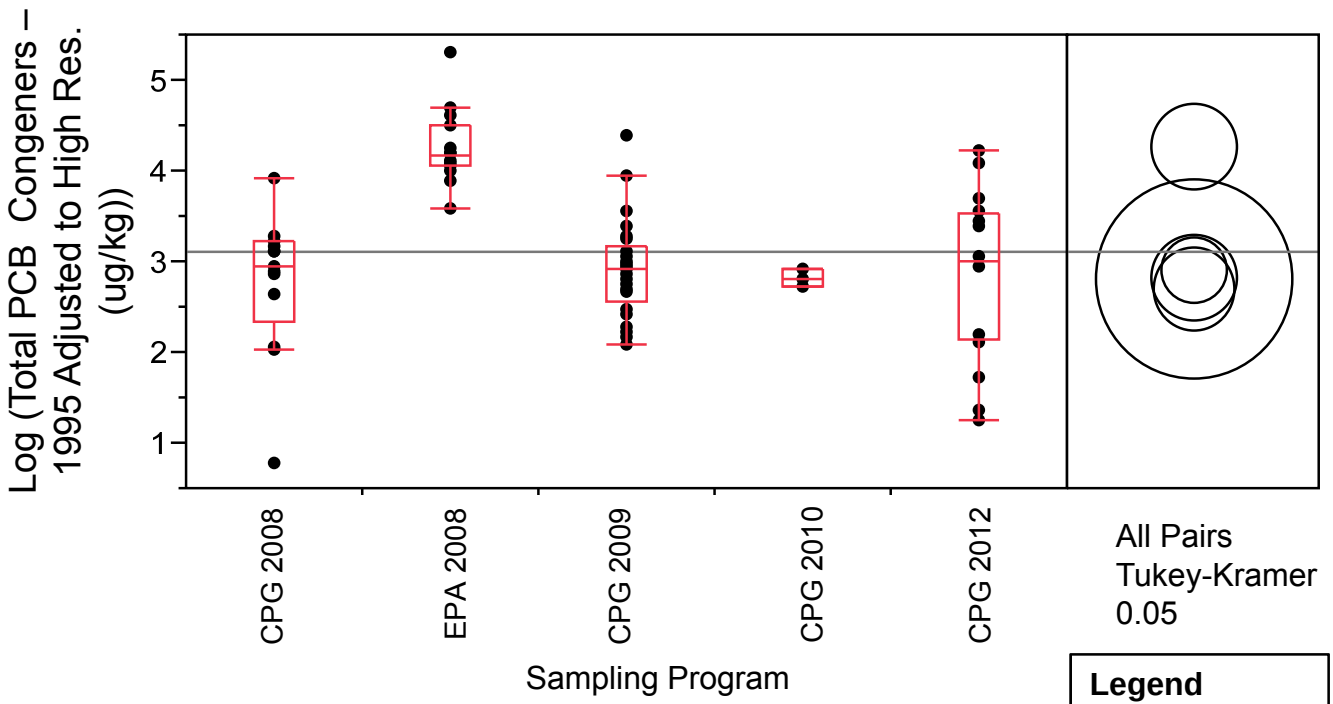


RM2 to RM8

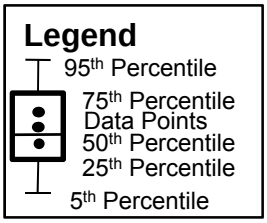


	Total PCBs (0-6 inch) by Sampling Program at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.1-3a** 2014

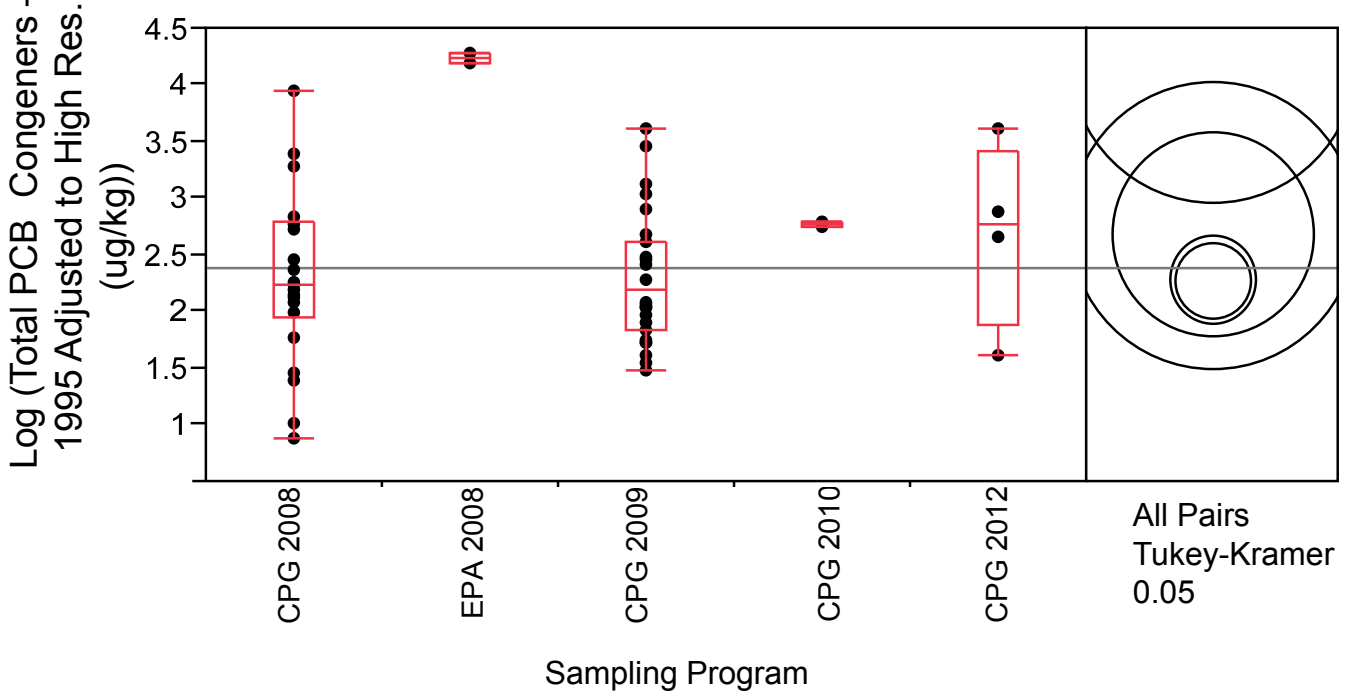
RM8 to RM12



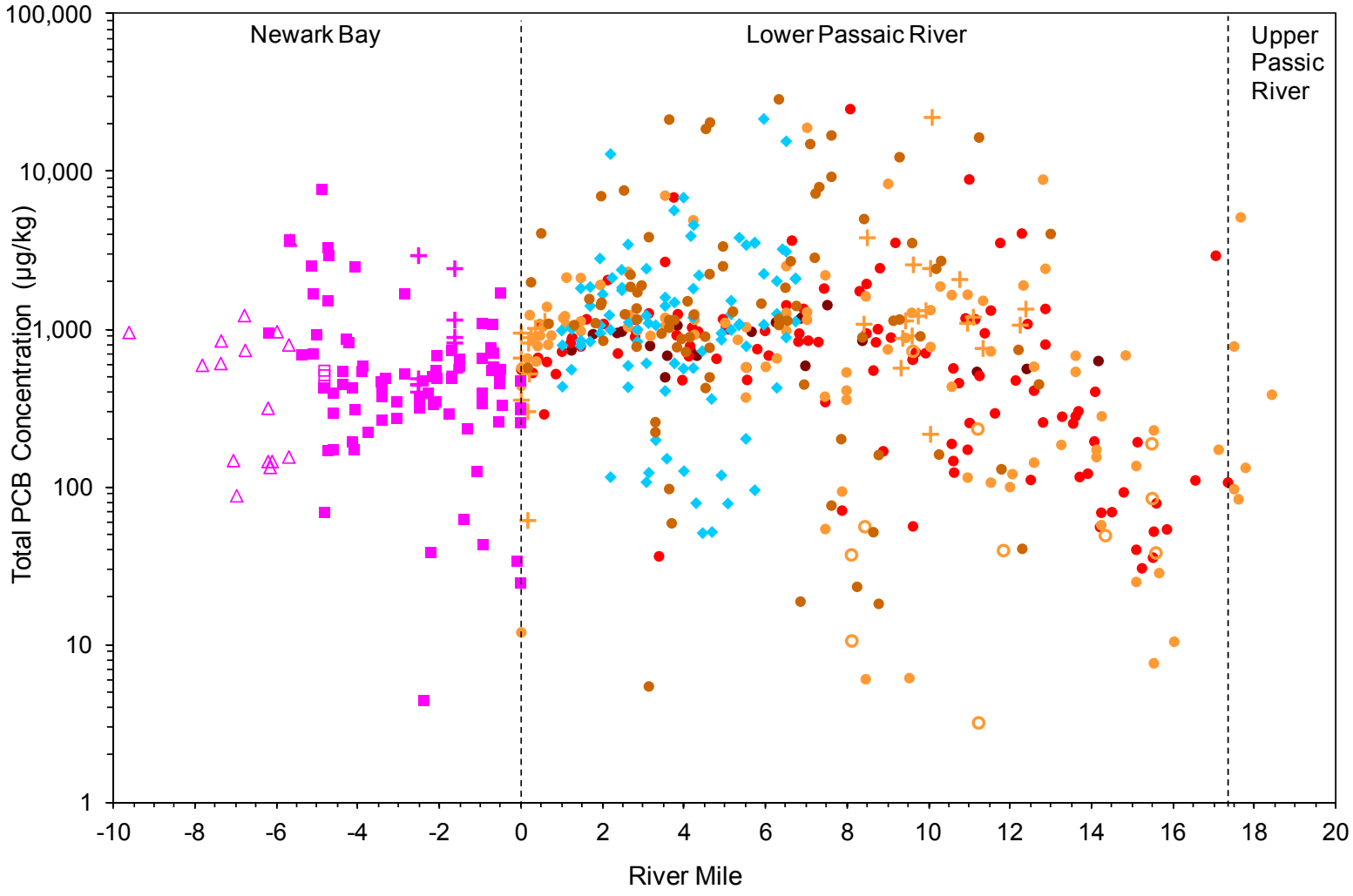
Note: Horizontal line represents the mean concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.



RM12 to RM17.4



	Total PCBs (0-6 inch) by Sampling Program at RM8 to RM12 and RM12 to RM17.4 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.1-3b** 2014



Legend

- 2012 CPG
- 2010 CPG
- 2009 CPG
- 2008 CPG
- 2008 CPG Tributary Below HoT
- 2008 EPA
- 2005&2007 Newark Bay
- 2005&2007 Shooters Island & Arthur Kill
- 2005&2007 Kill Van Kull
- 2005&2007 Port Elizabeth & Newark
- 1995 TSI

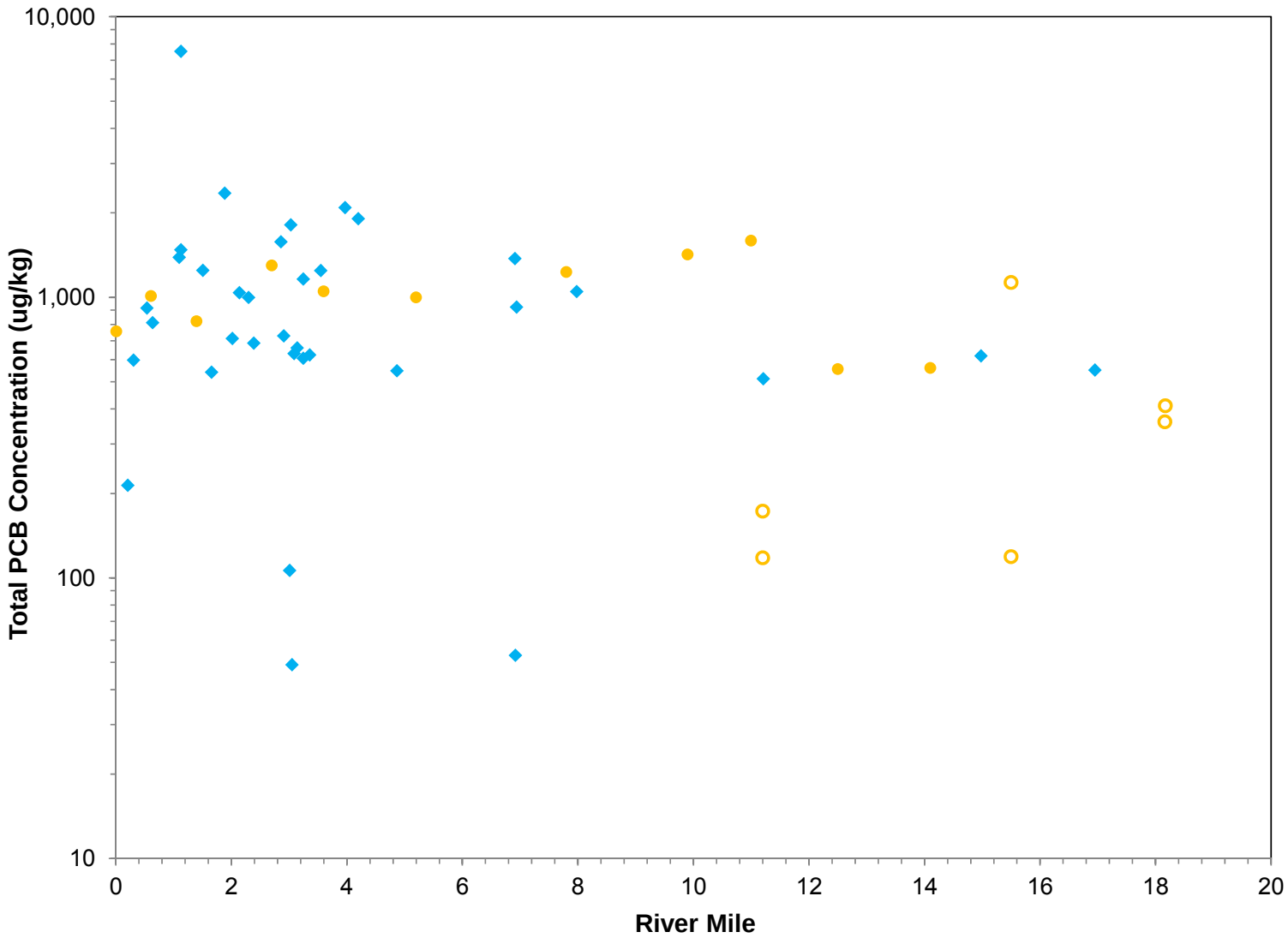
Total PCBs Concentration (0-6 inches) *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 3.1-4

2014

R2-0027124



Legend

- 1991-1993
- 2007-2008 EPA
- 2007-2008 EPA Tributary Above HoT

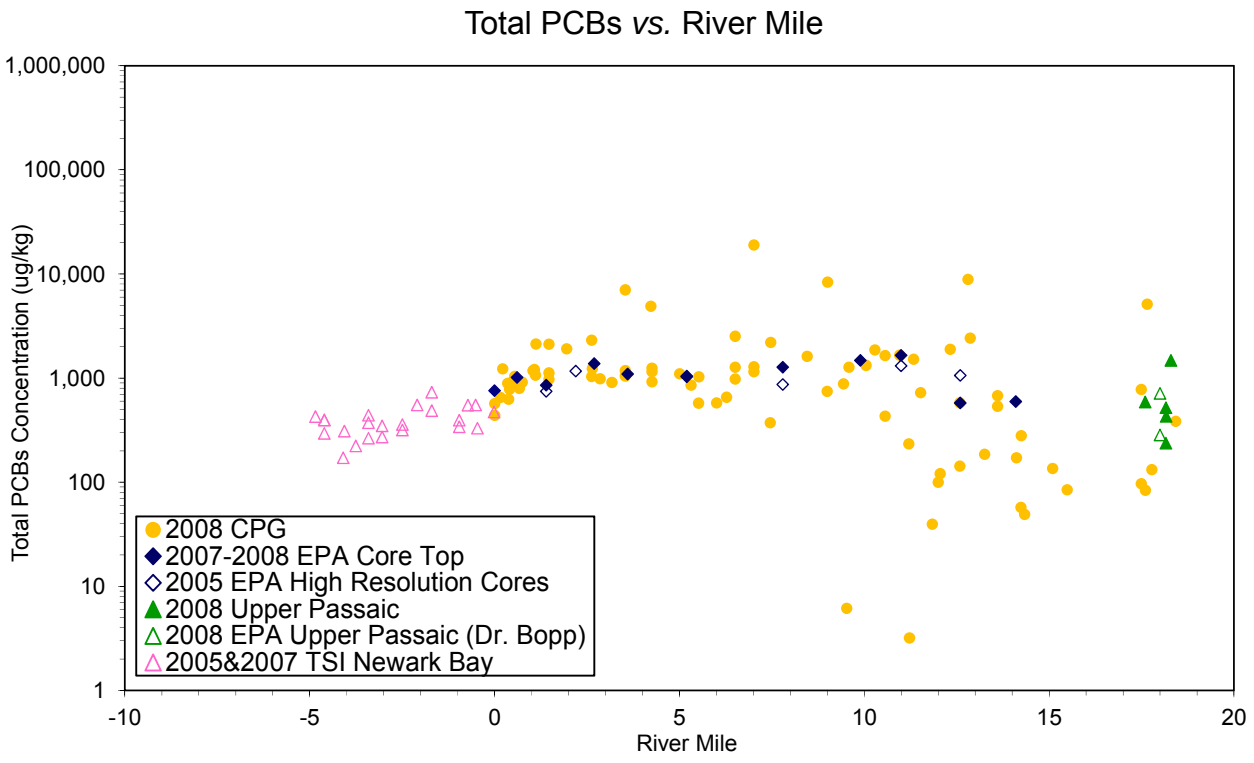
Total PCBs Concentration (0 - ≤2 inches) *vs.* River Mile

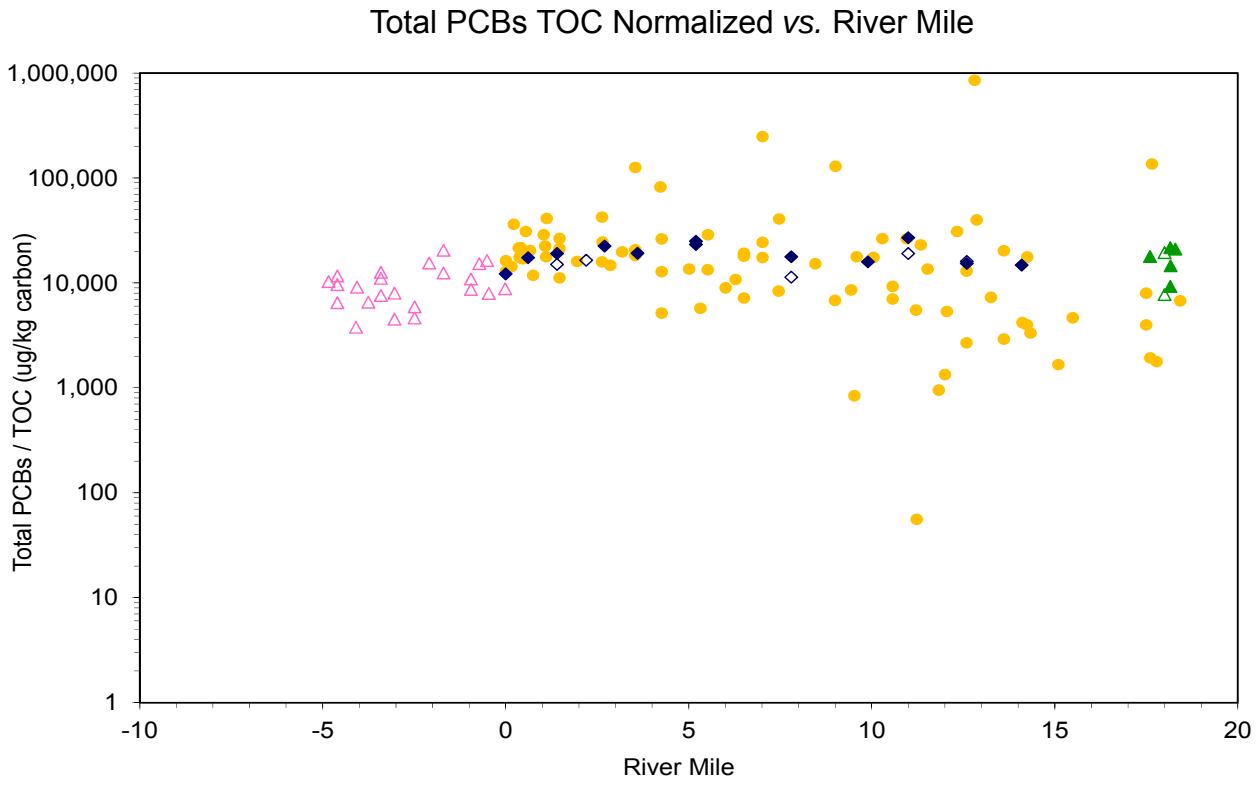
Lower Eight Miles of the Lower Passaic River

Figure 3.1-5

2014

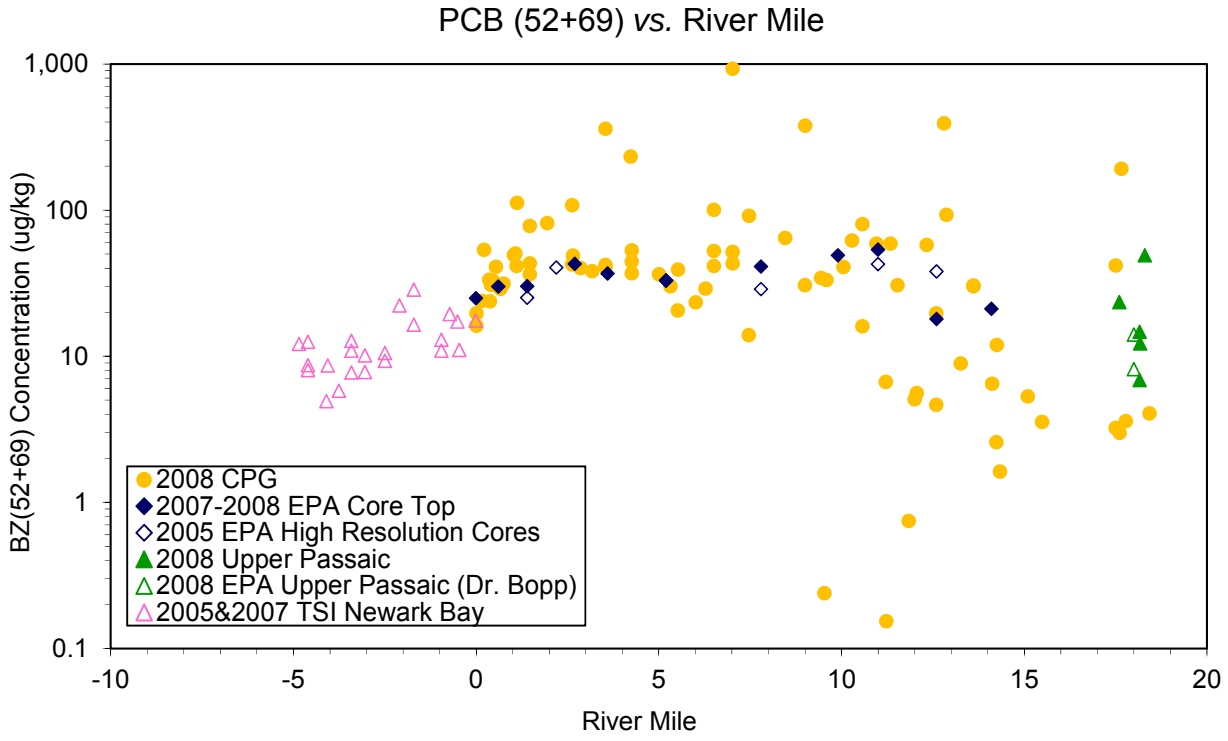
R2-0027125

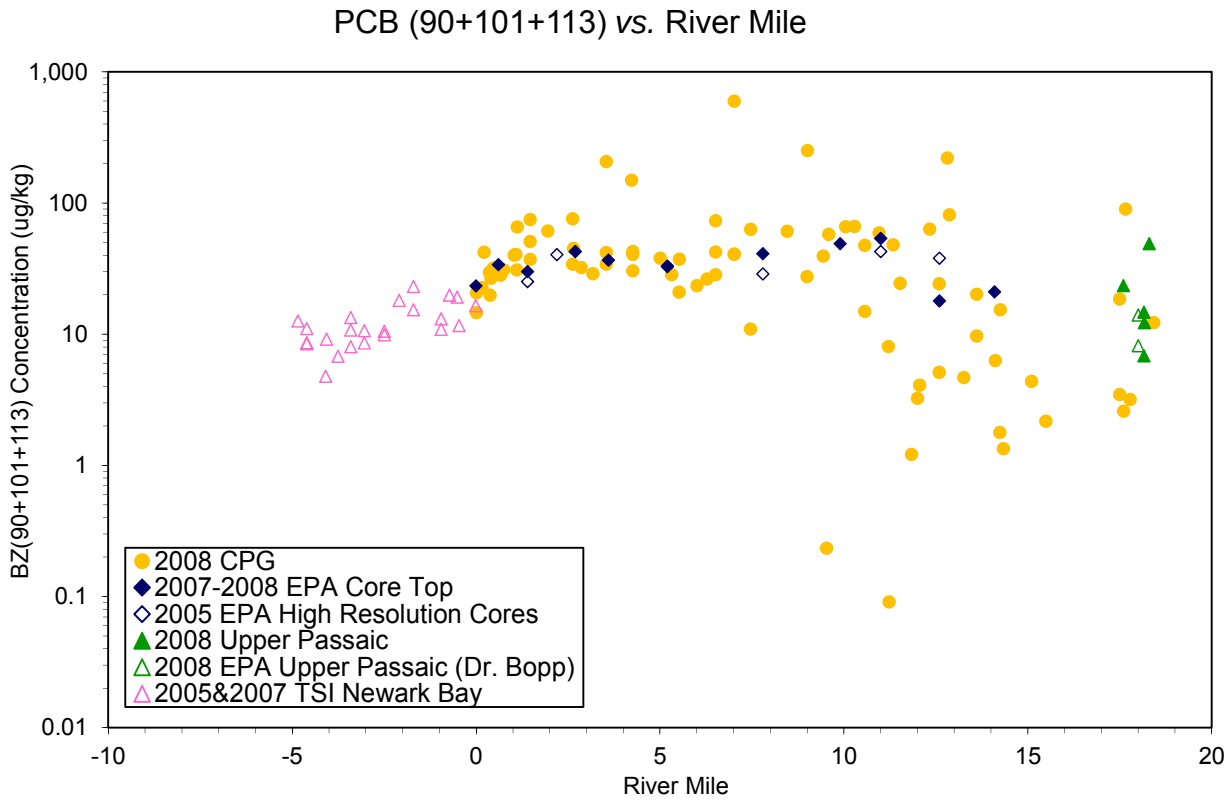




	Total PCBs in Recently-Deposited Sediments in the Lower Passaic River, Newark Bay and the Upper Passaic River *Lower Eight Miles of the Lower Passaic River*	**Figure 3.1-6** 2014

R2-0027126



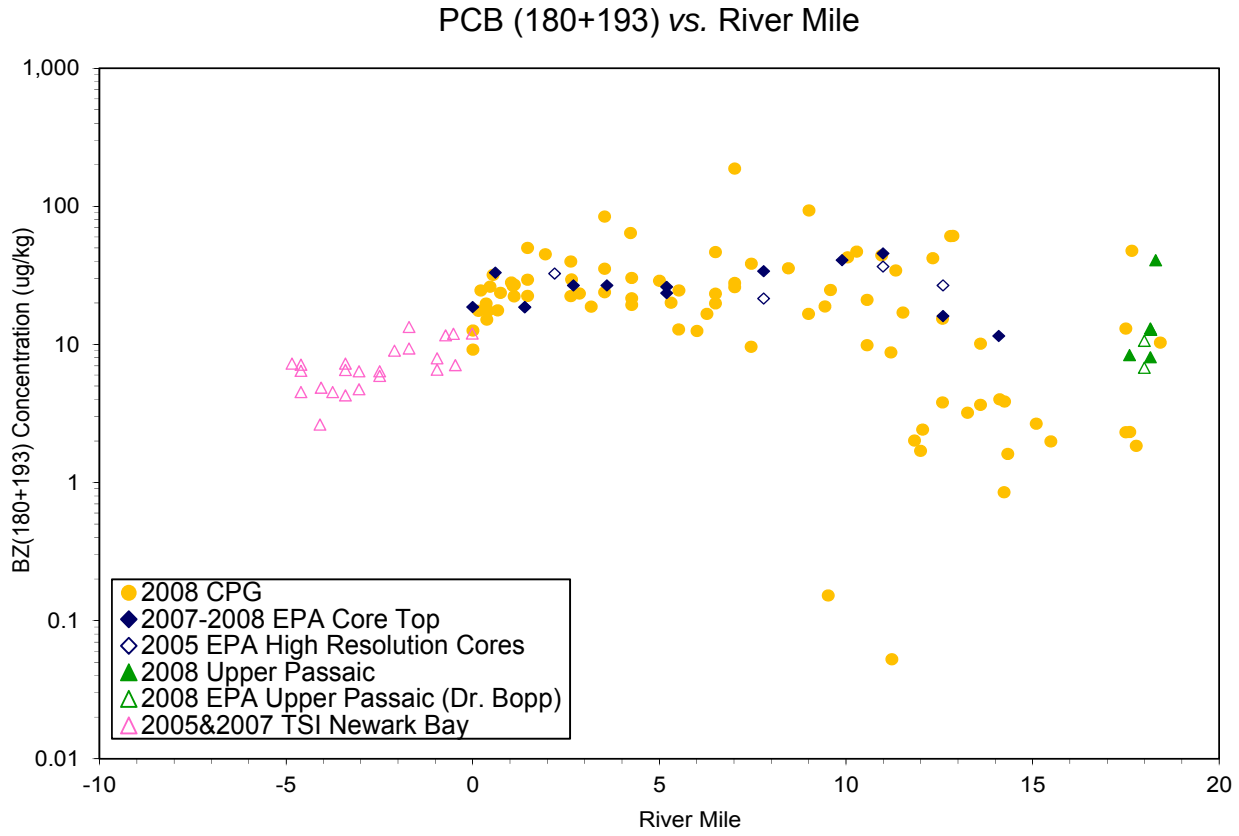


PCB (52+69) and PCB (90+101+113) in Recently-Deposited Sediments in the Lower Passaic River, Newark Bay and the Upper Passaic River

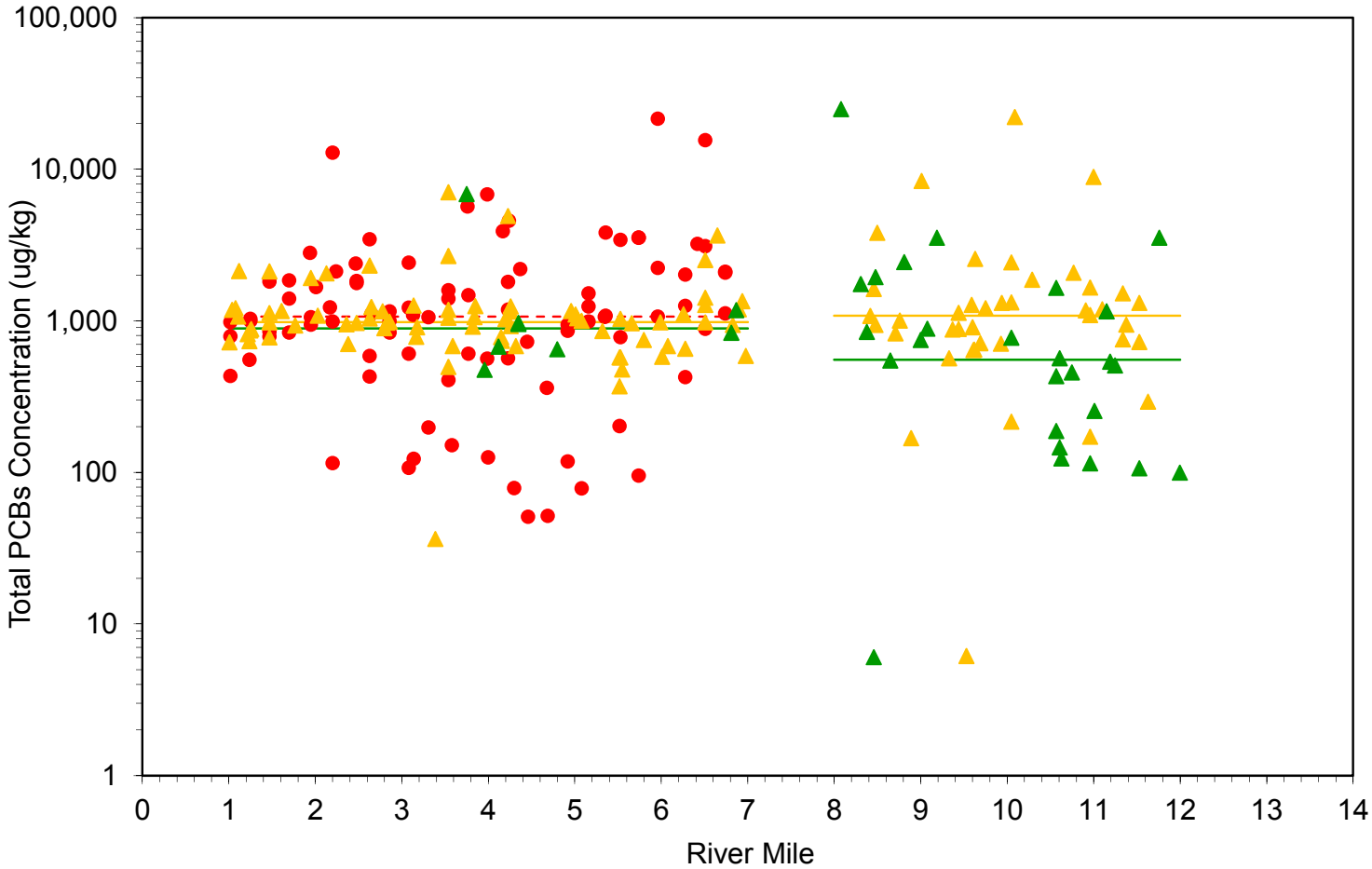
Lower Eight Miles of the Lower Passaic River

Figure 3.1-7a

2014



	PCB (180+193) in Recently-Deposited Sediments in the Lower Passaic River, Newark Bay and the Upper Passaic River *Lower Eight Miles of the Lower Passaic River*	**Figure 3.1-7b** 2014



Note: 2012 CPG data are not plotted since there are no PCB Aroclors data available, the CPG analyzed PCB congeners only.

Legend

- 2008-2010 Fine-Grained
- 2008-2010 Fine-Grained Median
- 2008-2010 Coarse-Grained
- 2008-2010 Coarse-Grained Median
- 1995
- 1995 Median

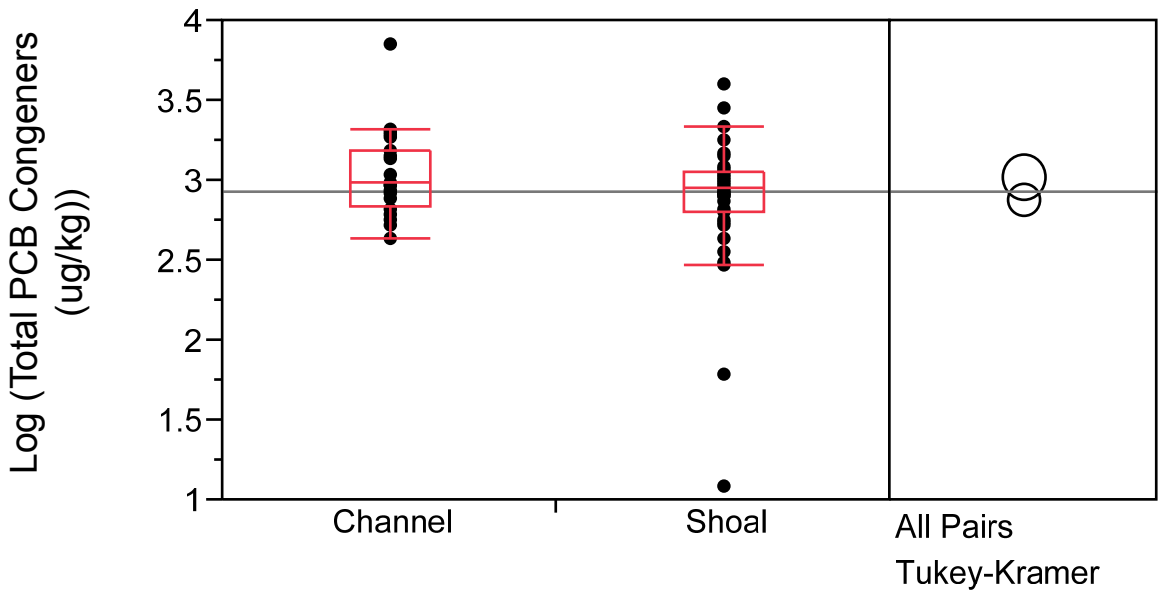
Comparison of Total PCB Aroclors Surface Concentration (0-6 inches)
RM1 to RM7 *vs.* RM8 to RM12

Lower Eight Miles of the Lower Passaic River

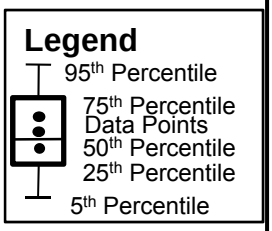
Figure 3.1-8

2014

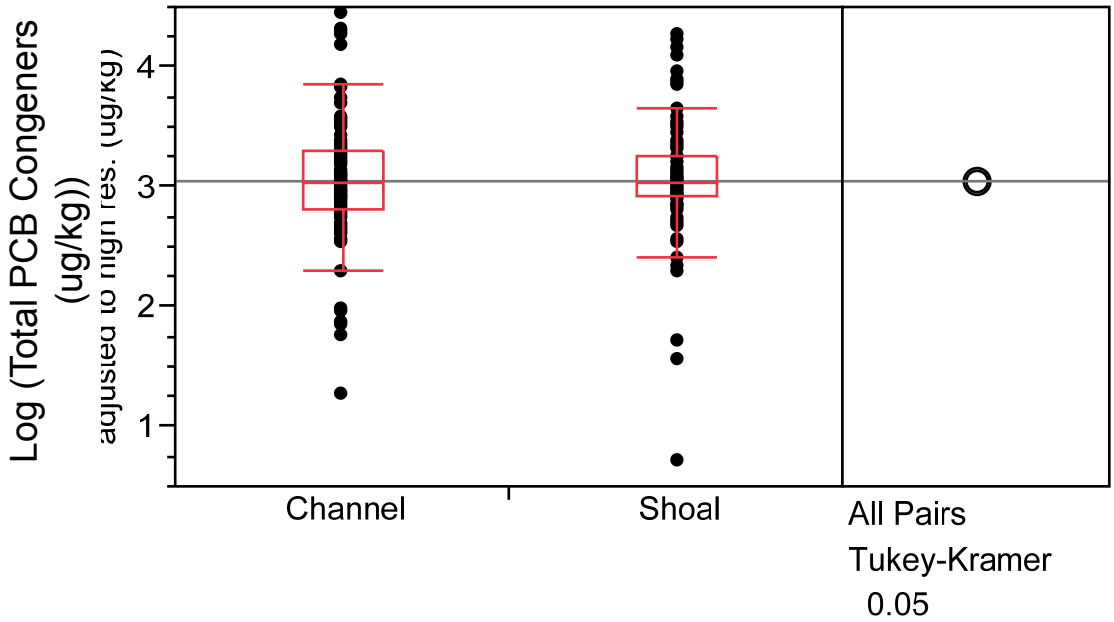
RM0 to RM2



Notes:
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 1995, 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.
3) A factor 1.25 was applied to the1995 TPCB concentrations based on matched pairs of congener and Aroclor analysis (see Data Evaluation No. 4 for further discussion).

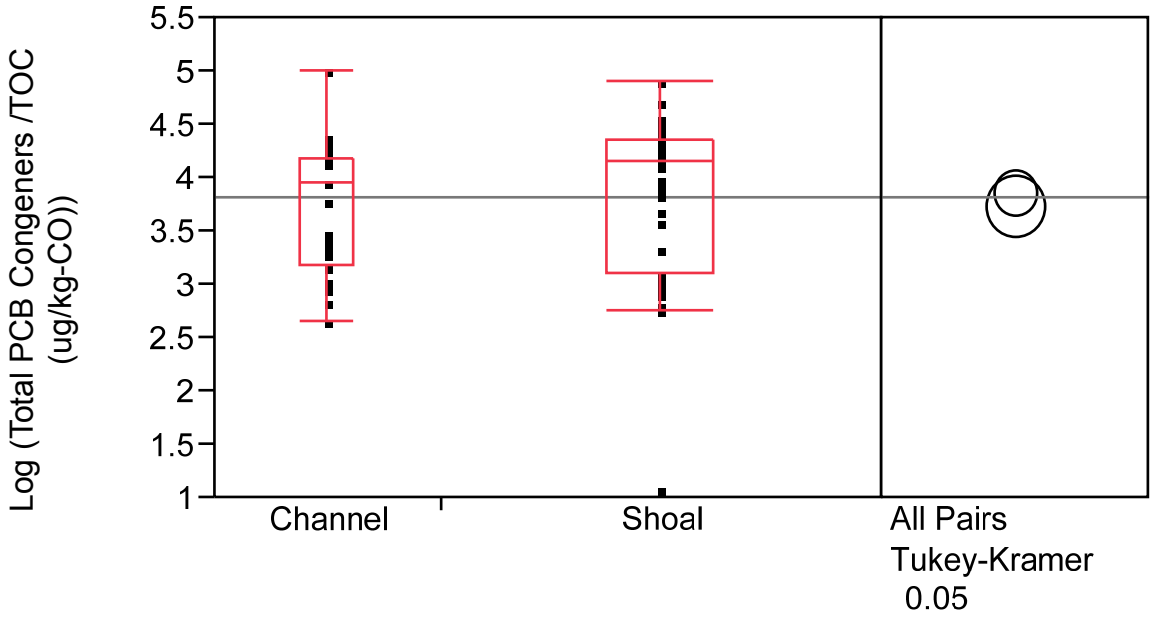


RM2 to RM8

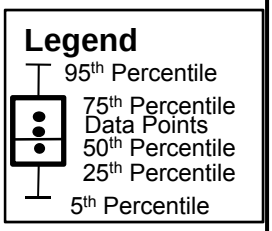


	Total PCBs (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.1-9a** 2014

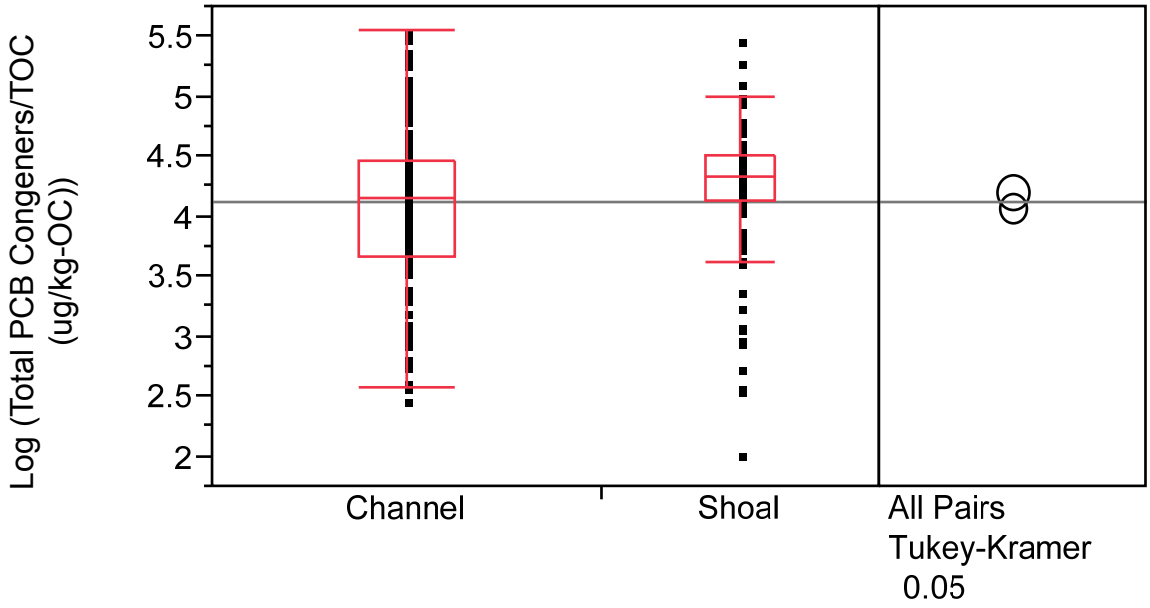
RM0 to RM2



Notes:
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 1995, 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.
3) A factor 1.25 was applied to the1995 TPCB concentrations based on matched pairs of congener and Aroclor analysis (see Data Evaluation No. 4 for further discussion).



RM2 to RM8



	TOC Normalized Total PCBs (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.1-9b** 2014

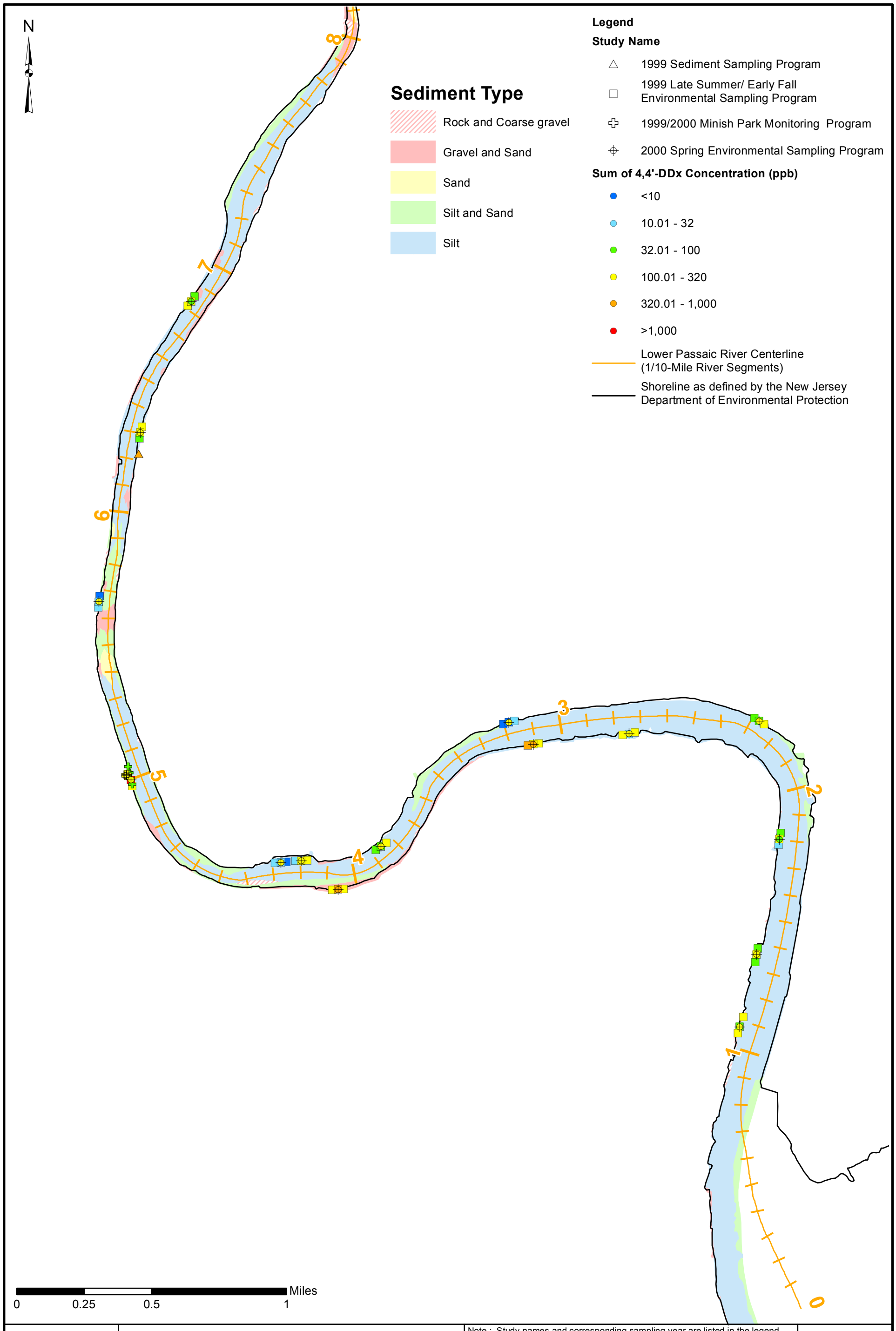
4,4'-DDE Surface Sediment Samples from 1991 to 1995

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.2-1

2014



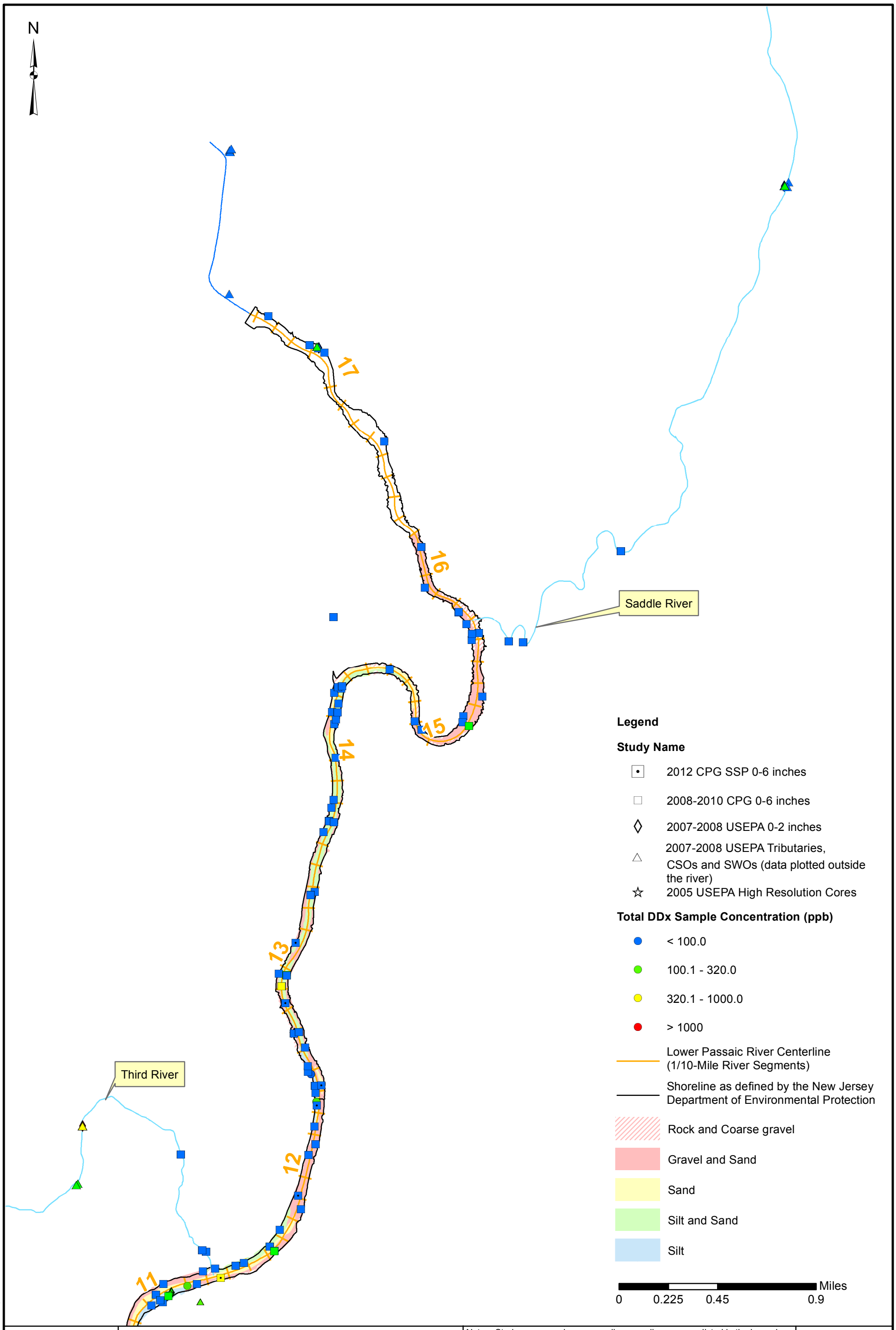
Total DDx Surface Sediment Samples from 1999 to 2000

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.2-2

2014



Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\HS mxd\44DDX_Surficial_Sed_2005_2012.mxd

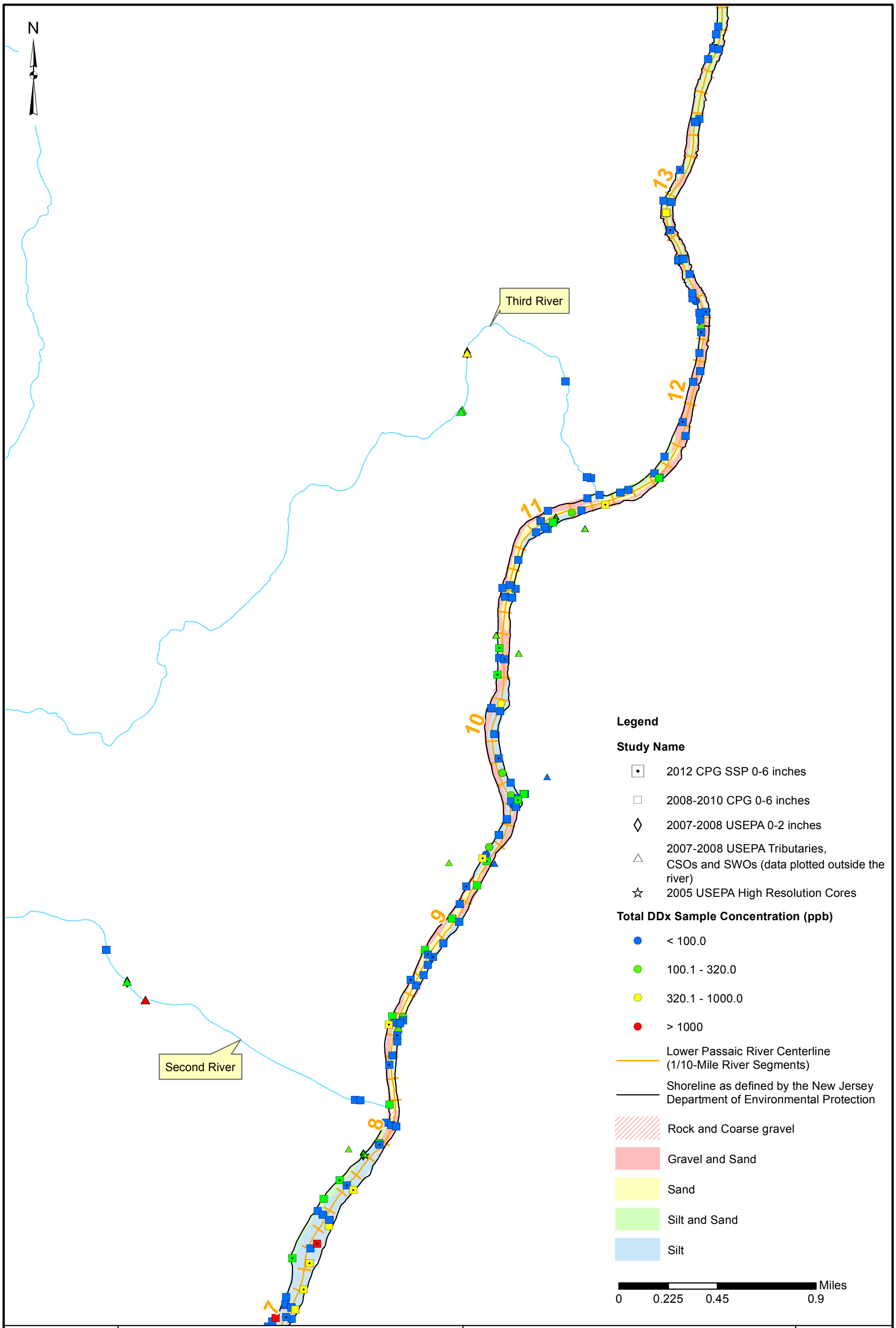
Total DDx Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.2-3a

2014



Total DDx Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.2-3b

2014

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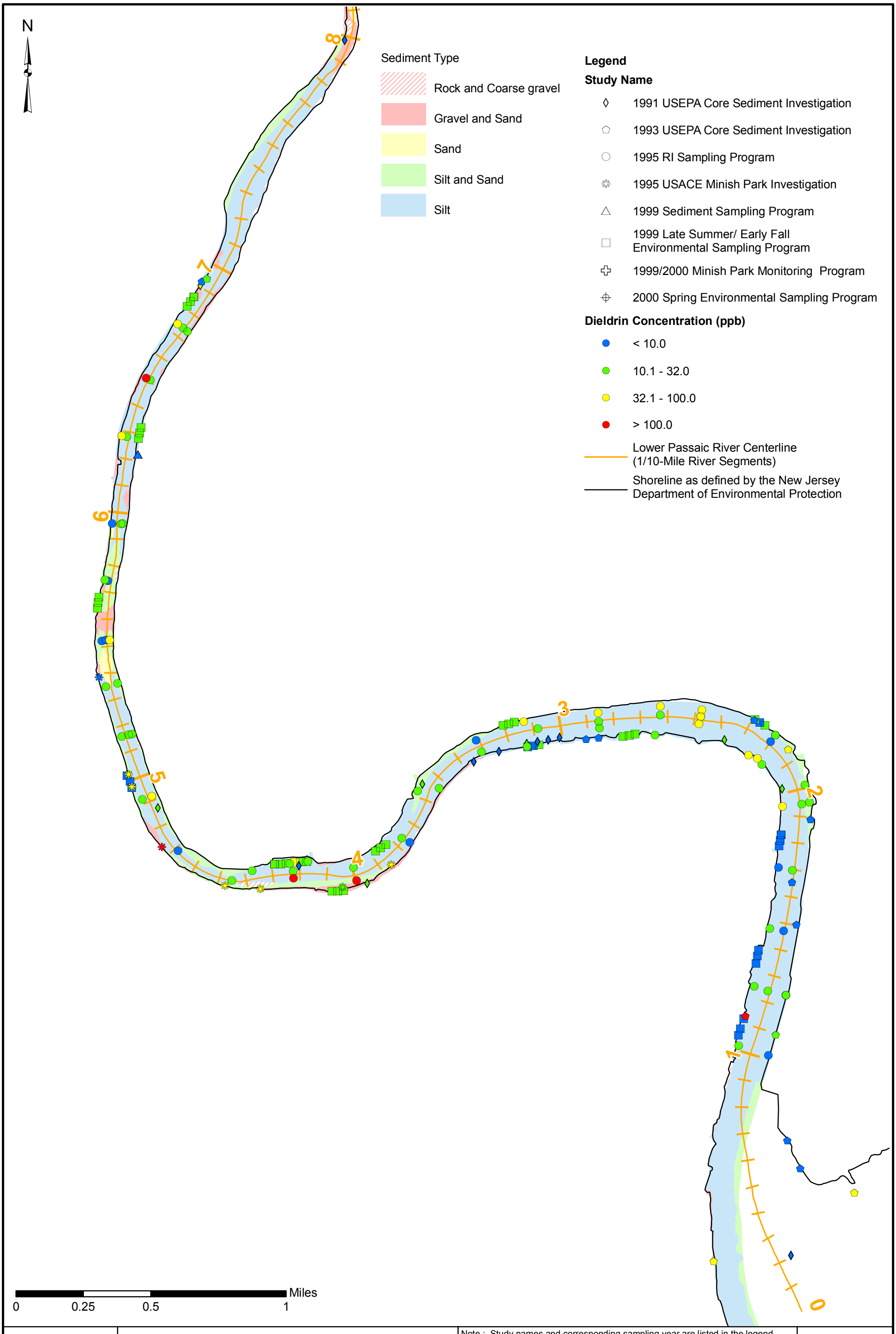
Total DDx Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.2-3c

2014



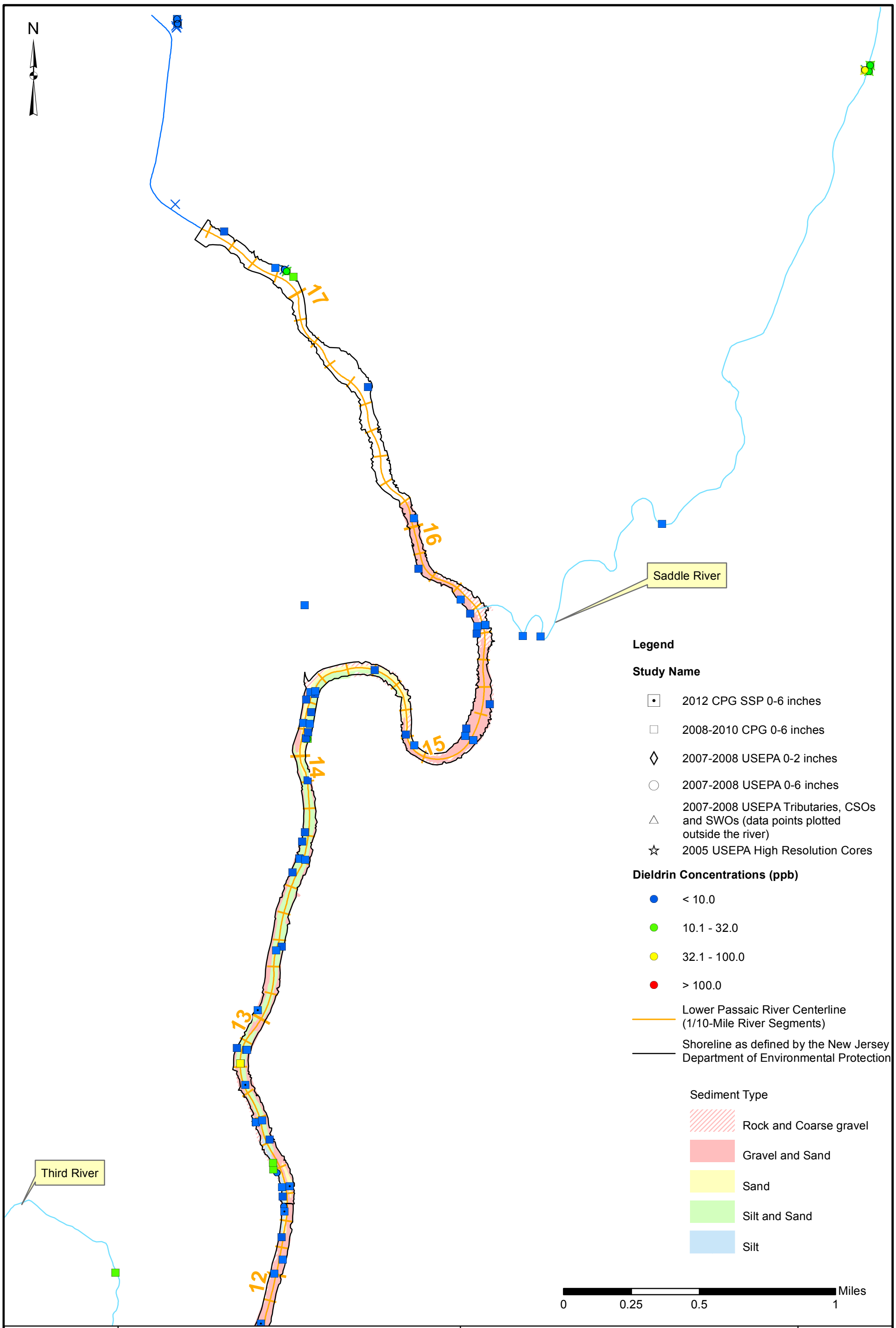
Dieldrin in Surface Sediment Samples from 1991 to 2000

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.2-4

2014



Dieldrin Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.2-5a

2014

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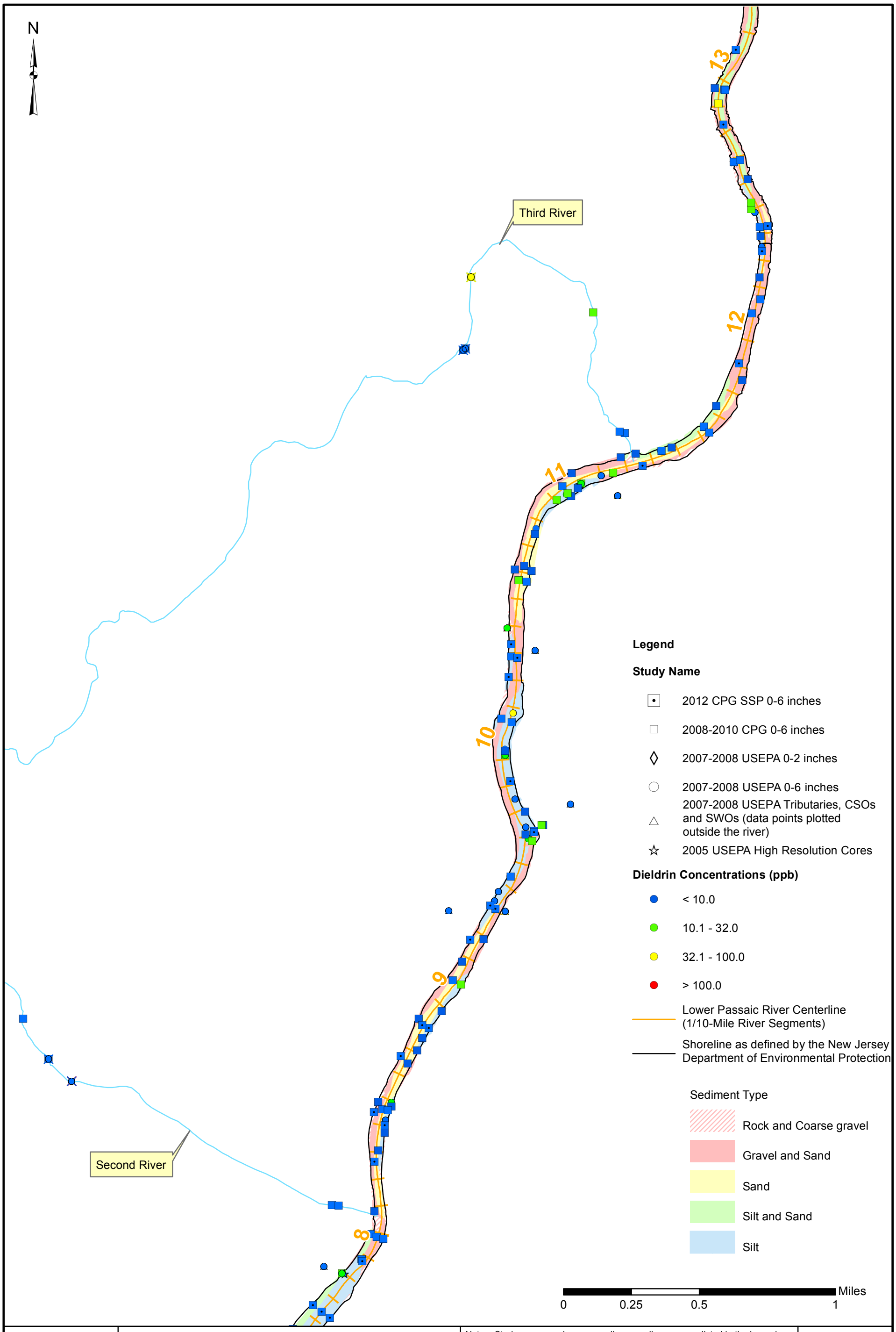

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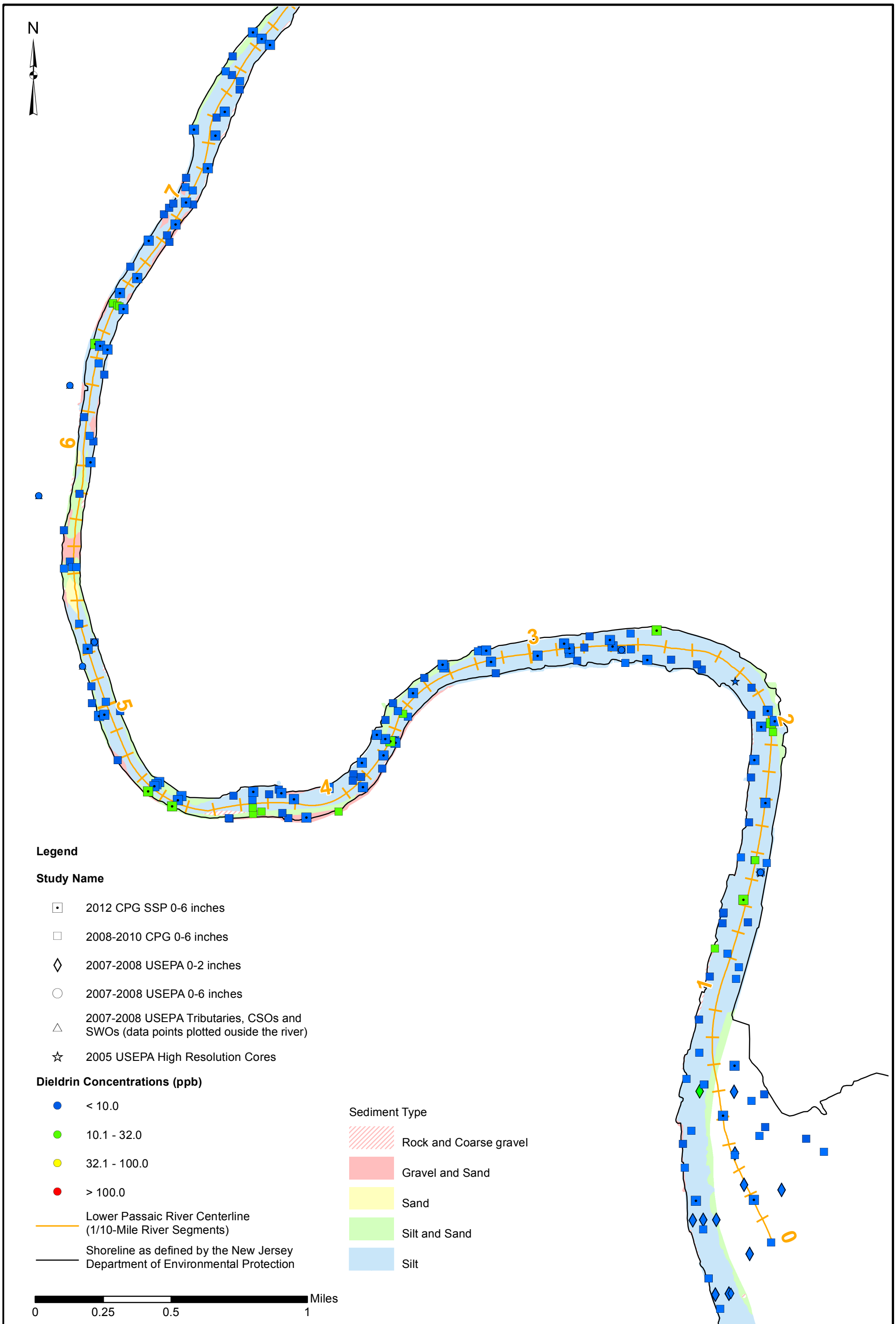
Dieldrin Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.2-5b

2014



Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\HS mxd\Dieldrin_Surficial_Sed_2007_2010RM12-DD_Fig14-3g1.mxd

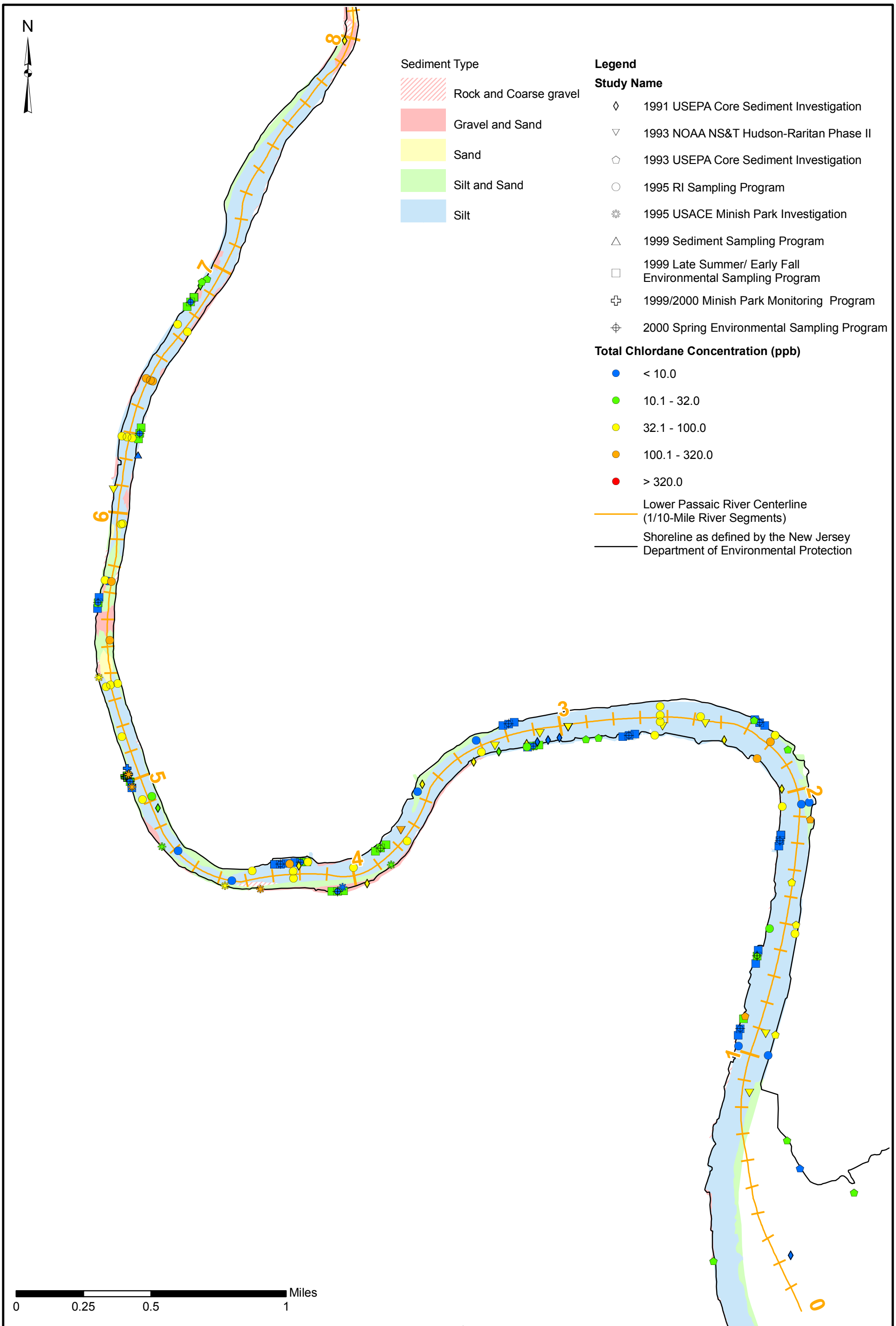
Dieldrin Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.2-5c

2014



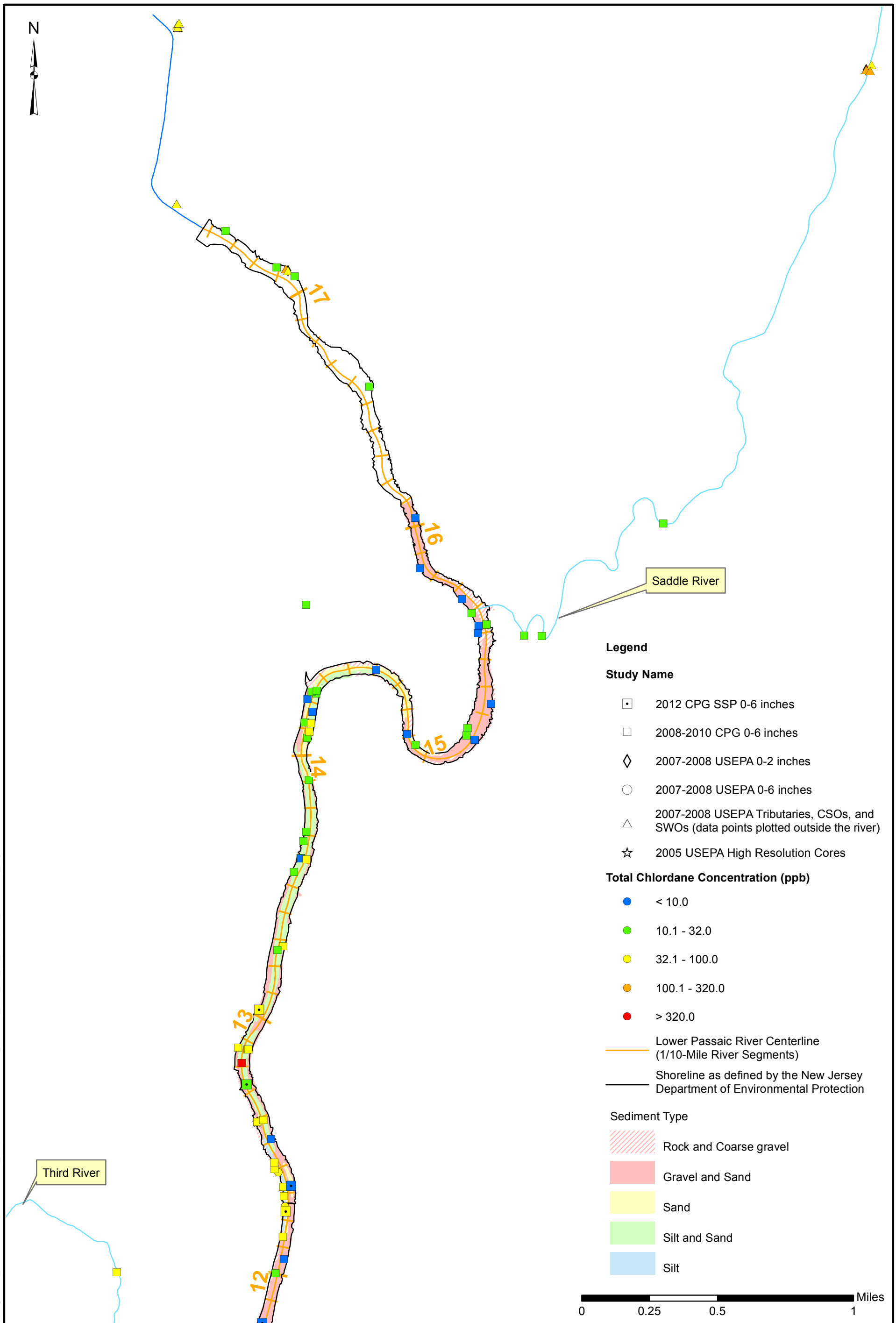
Total Chlordane Surface Sediment Samples from 1991 to 2000

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.2-6

2014



Total Chlordane Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.2-7a

2014

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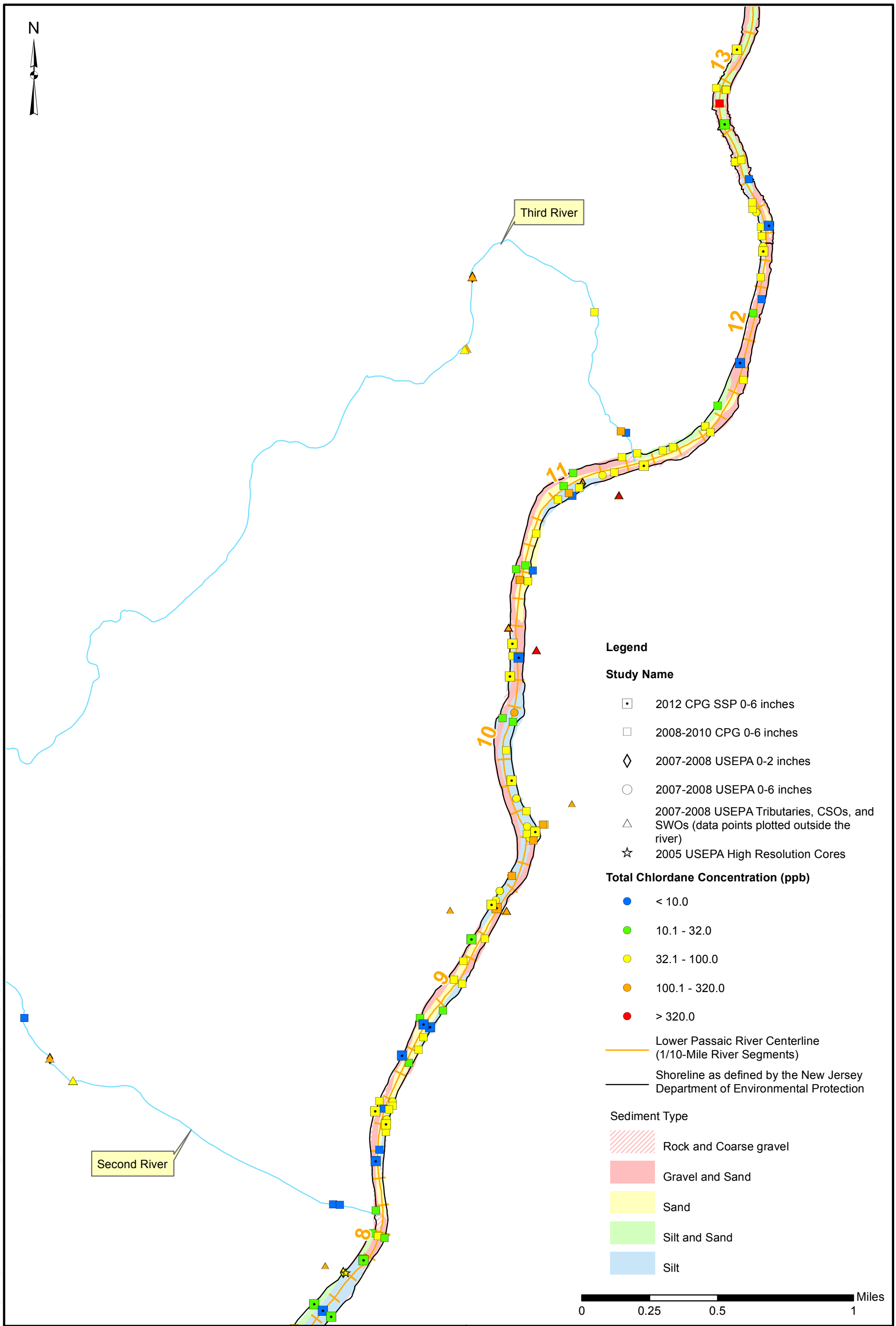

Total Chlordane Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.2-7b

2014

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Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\HS mxd\Chlordane_Surficial_Sed_07_10_Samples_RM12-DD_Fig14-3f1.mxd

Total Chlordane Surface Sediment Samples from 2005 to 2012

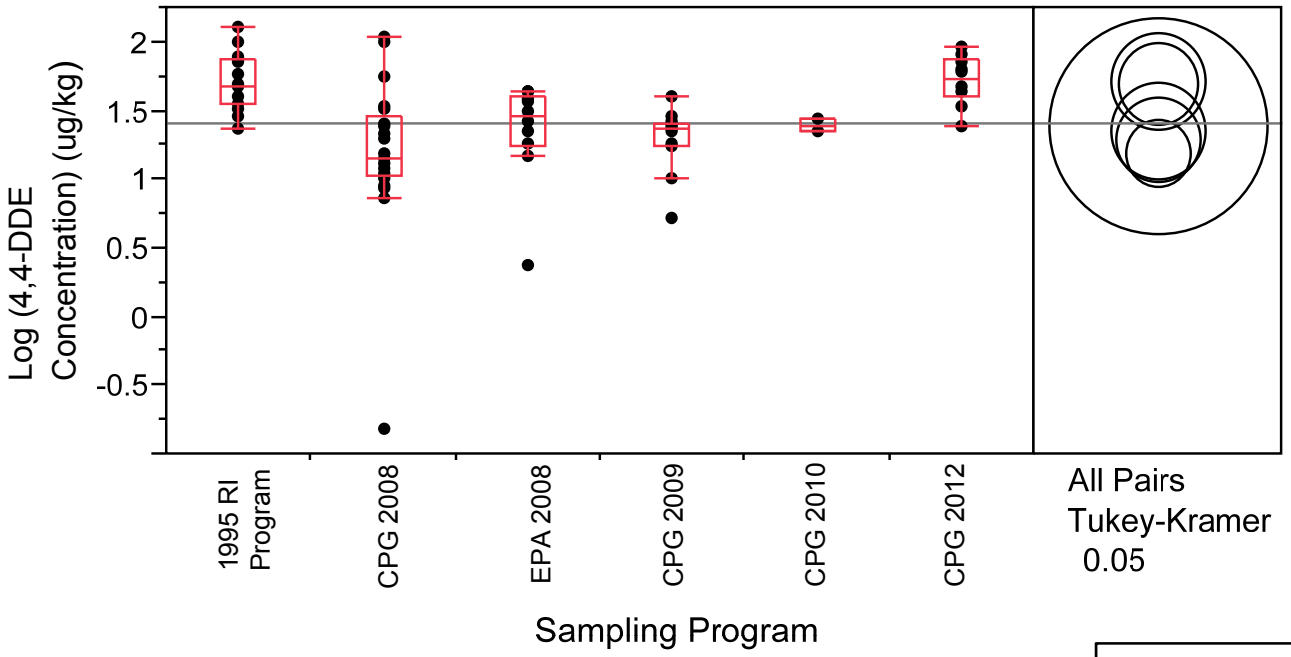
Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

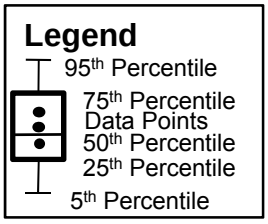
Figure 3.2-7c

2014

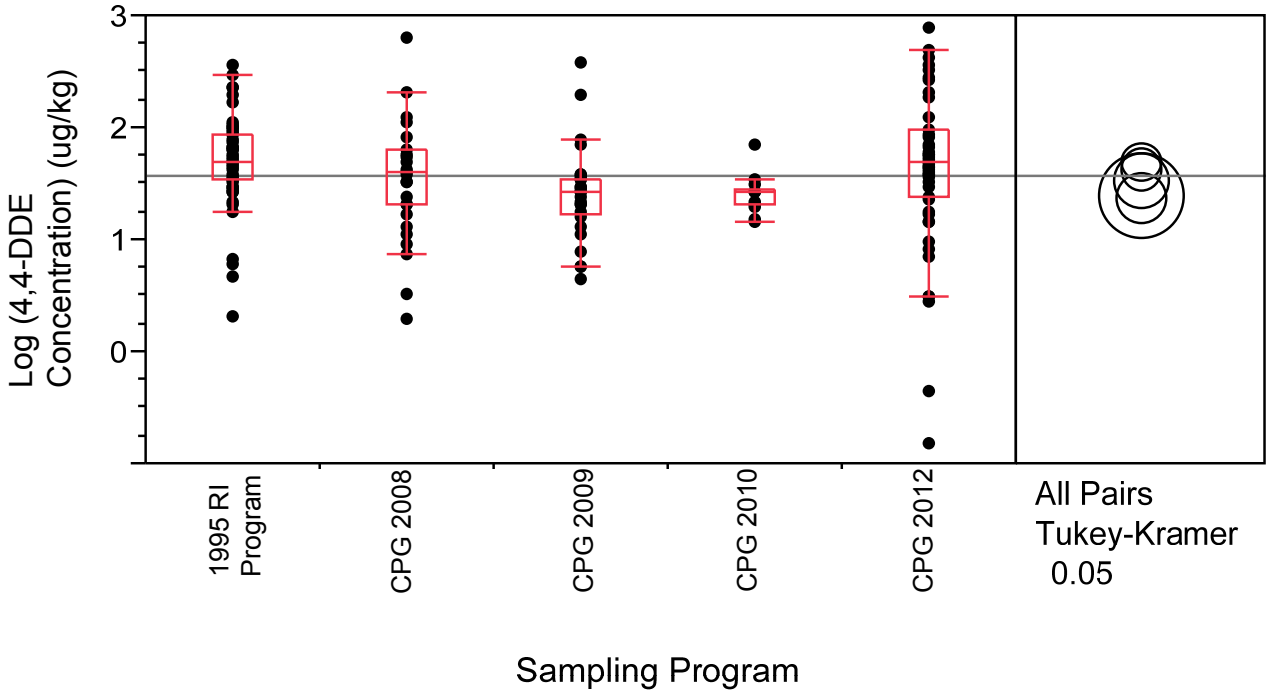
RM0 to RM2



Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.

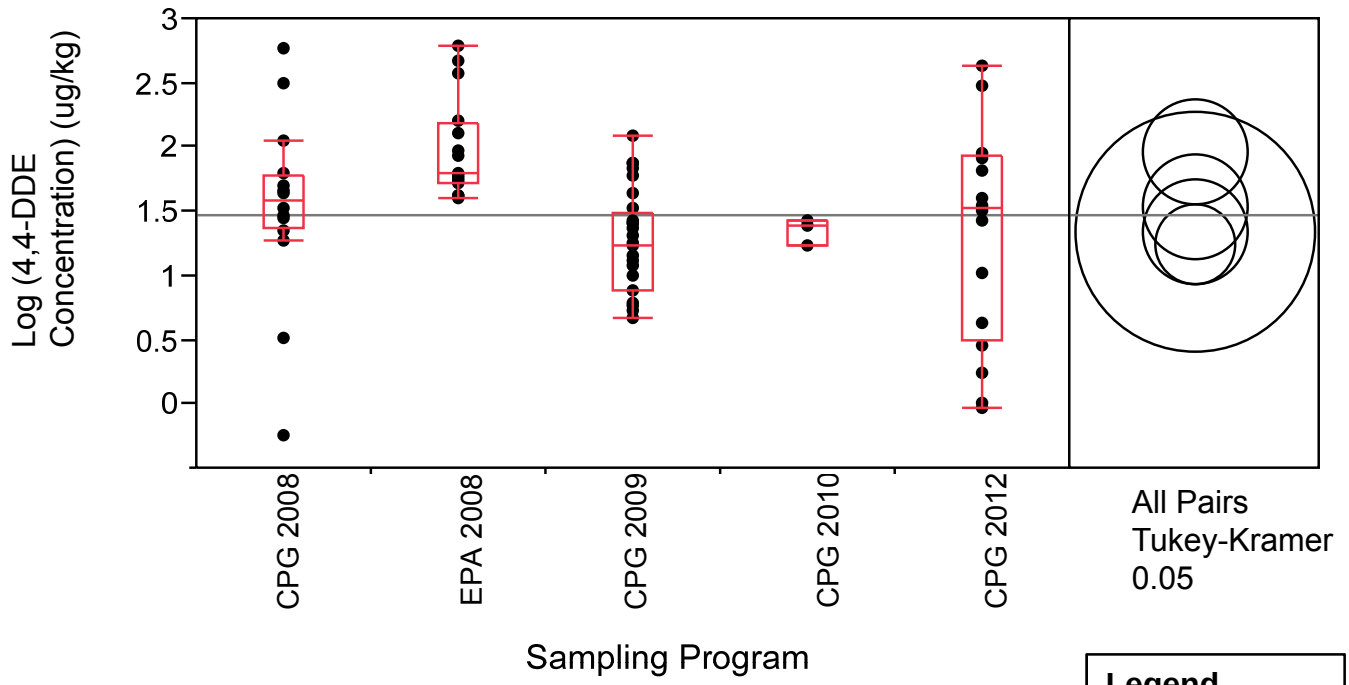


RM2 to RM8

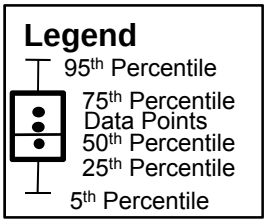


	4,4'-DDE (0-6 inch) by Sampling Program at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.2-8a** 2014

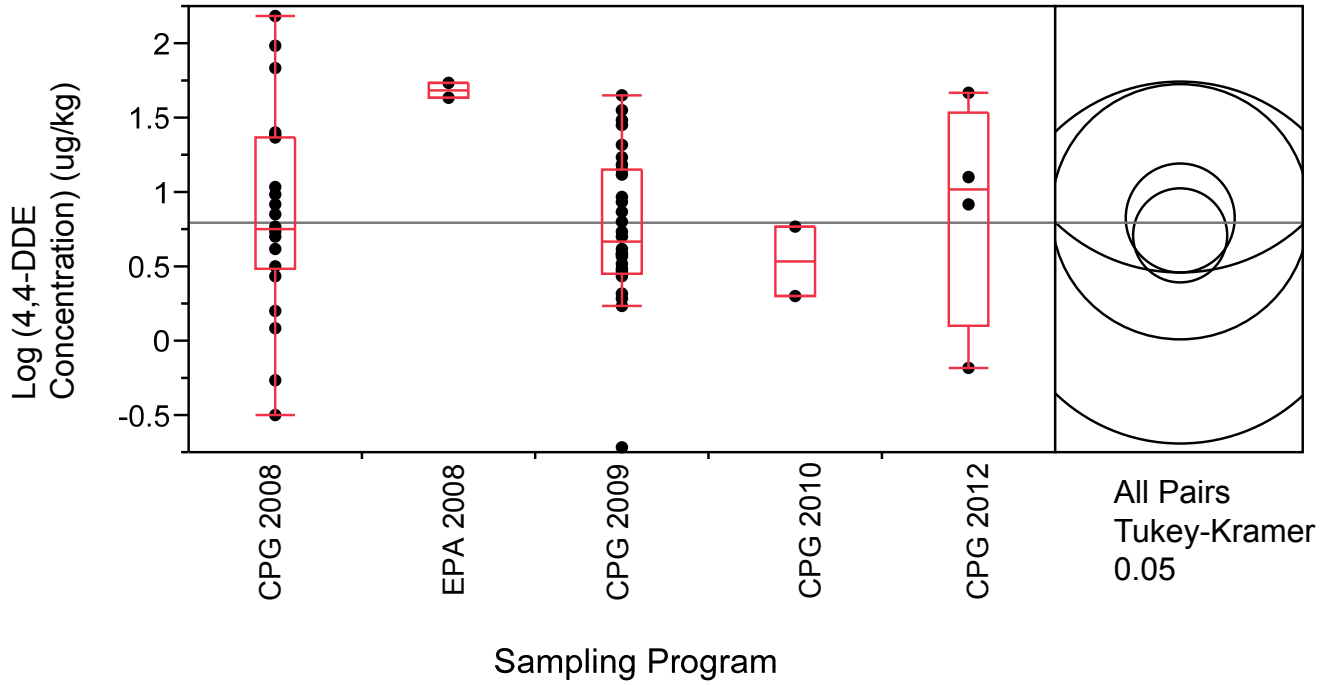
RM8 to RM12



Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.

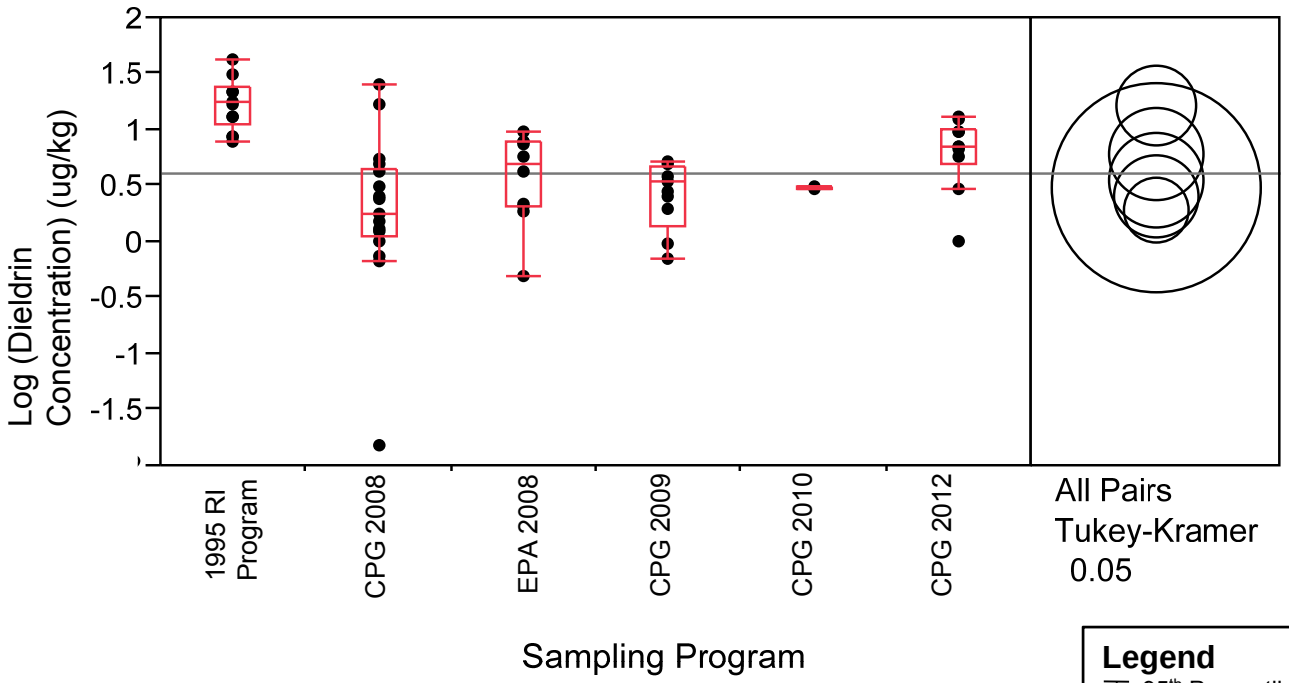


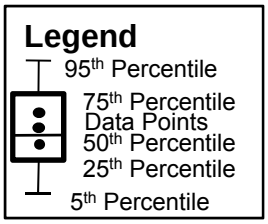
RM12 to RM17.4



	4,4'-DDE (0-6 inch) by Sampling Program at RM8 to RM12 and RM12 to RM17.4 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.2-8b** 2014

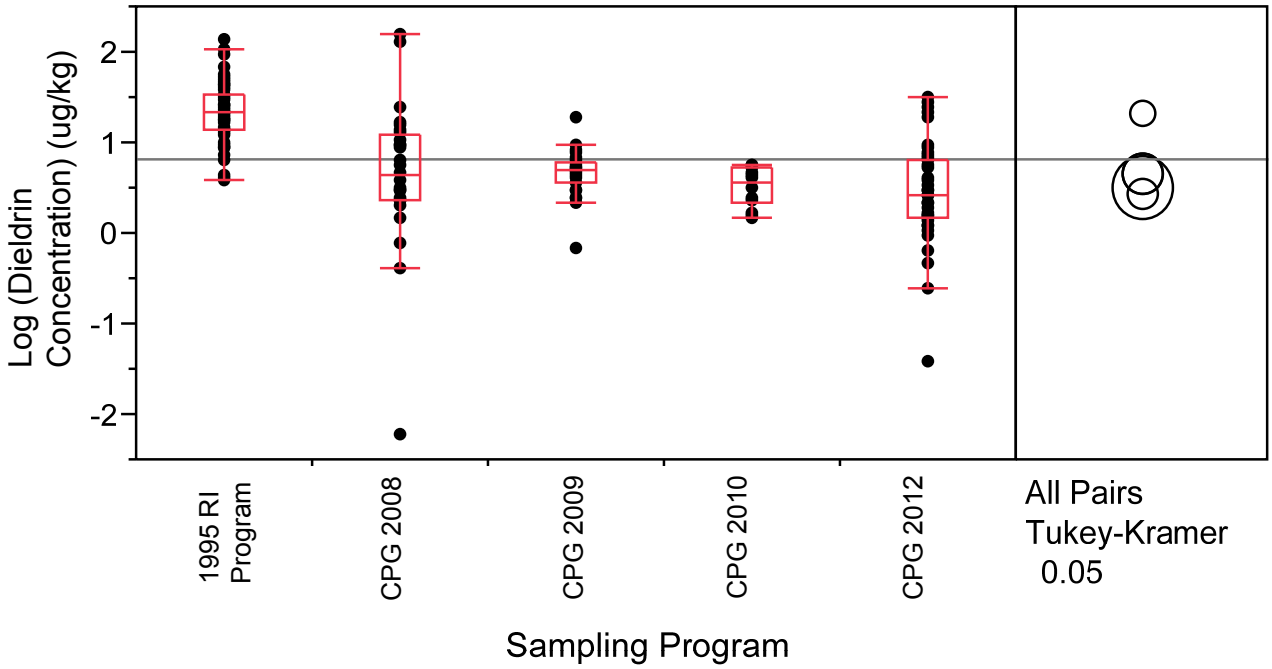
RM0 to RM2





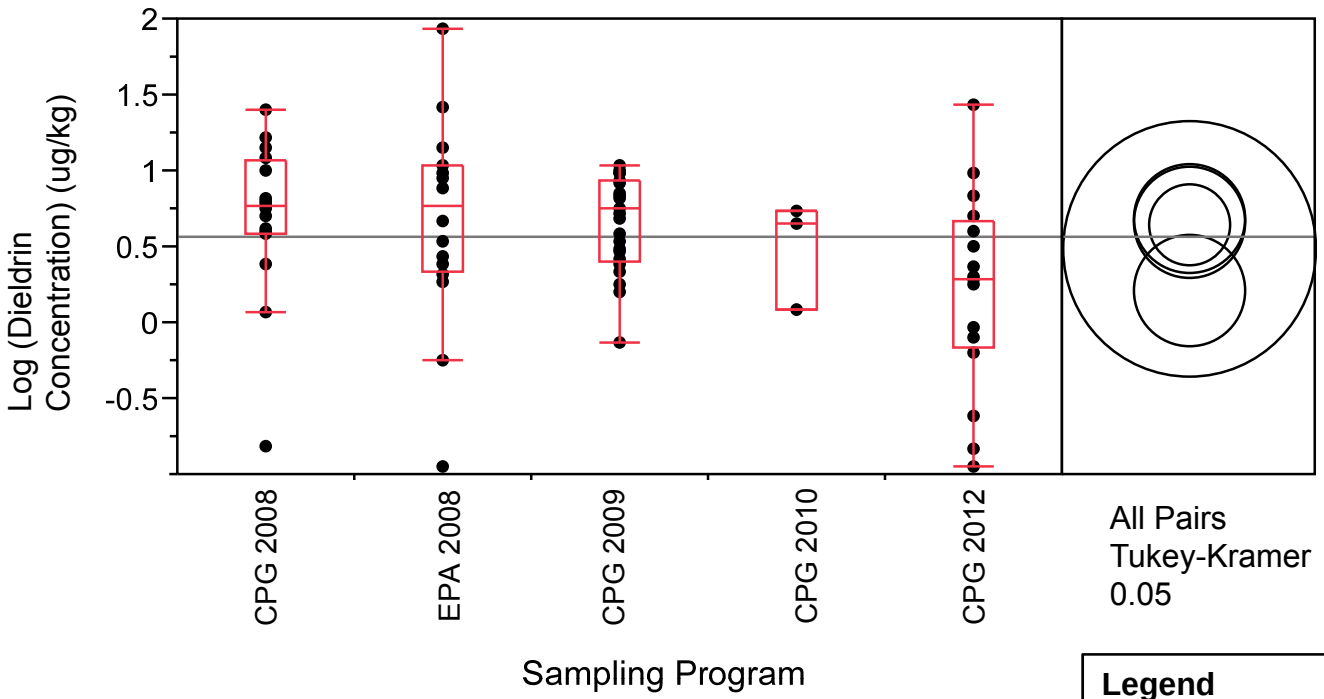
Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.

RM2 to RM8

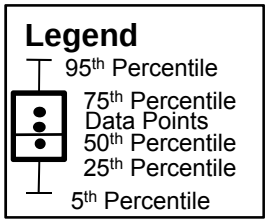


	Dieldrin (0-6 inch) by Sampling Program at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.2-9a** 2014

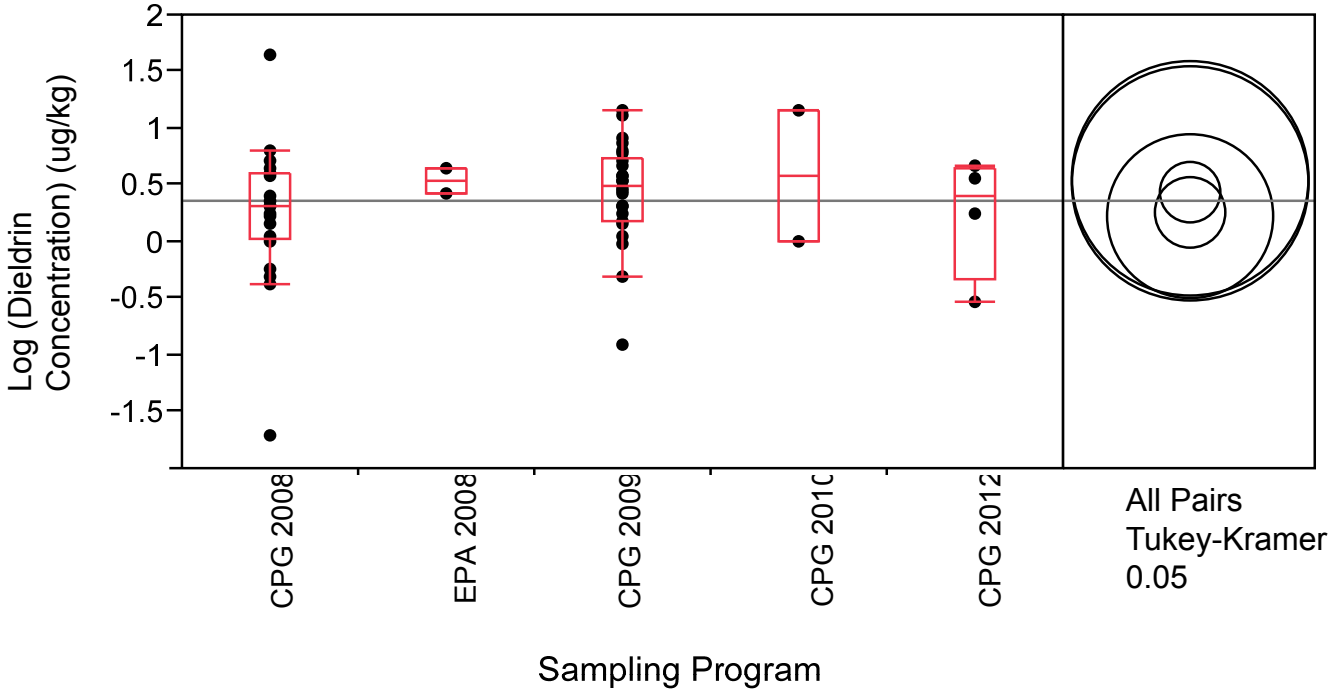
RM8 to RM12



Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.



RM12 to RM17.4



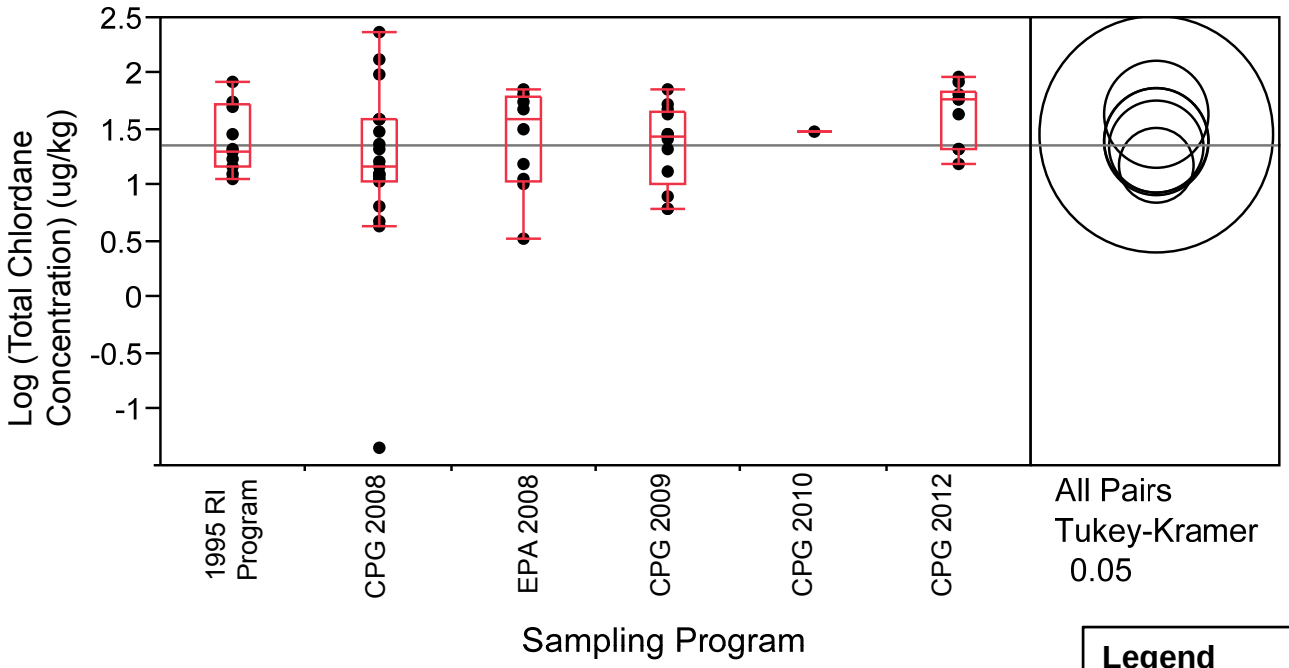
Dieldrin (0-6 inch) by Sampling Program at RM8 to RM12 and RM12 to RM17.4

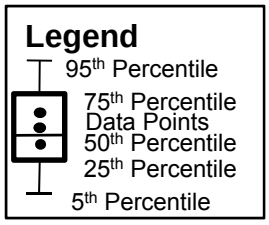
Lower Eight Miles of the Lower Passaic River

Figure 3.2-9b

2014

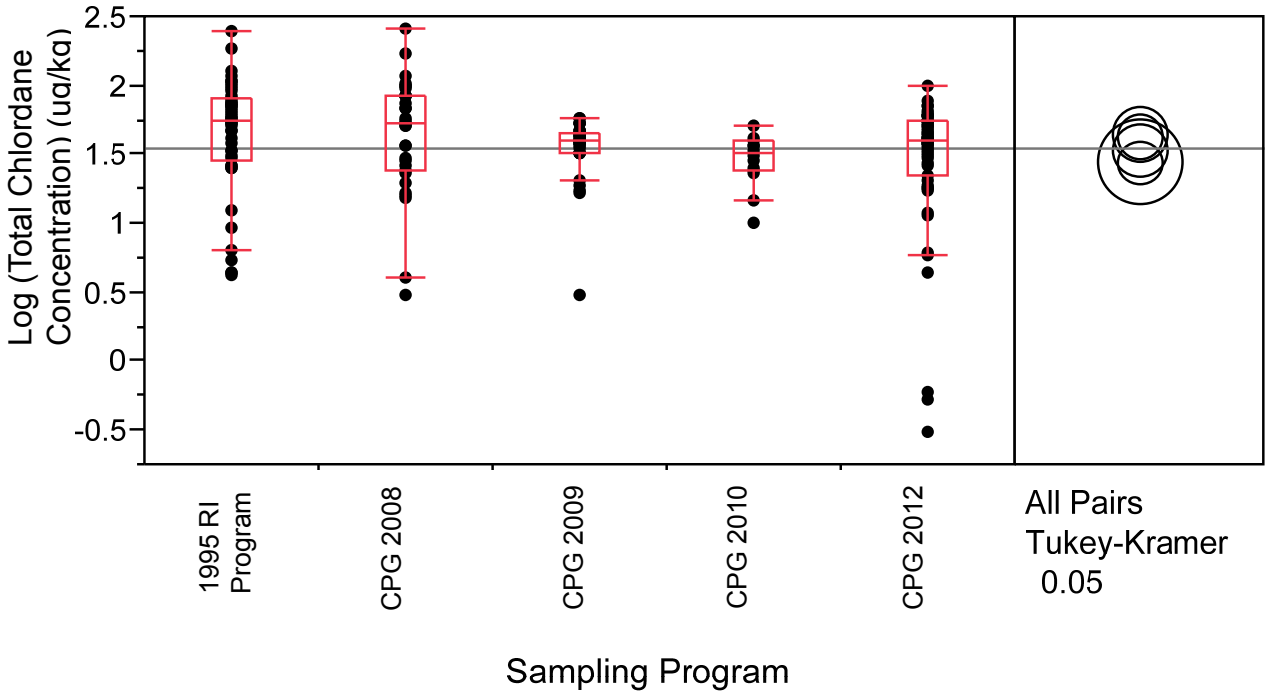
RM0 to RM2





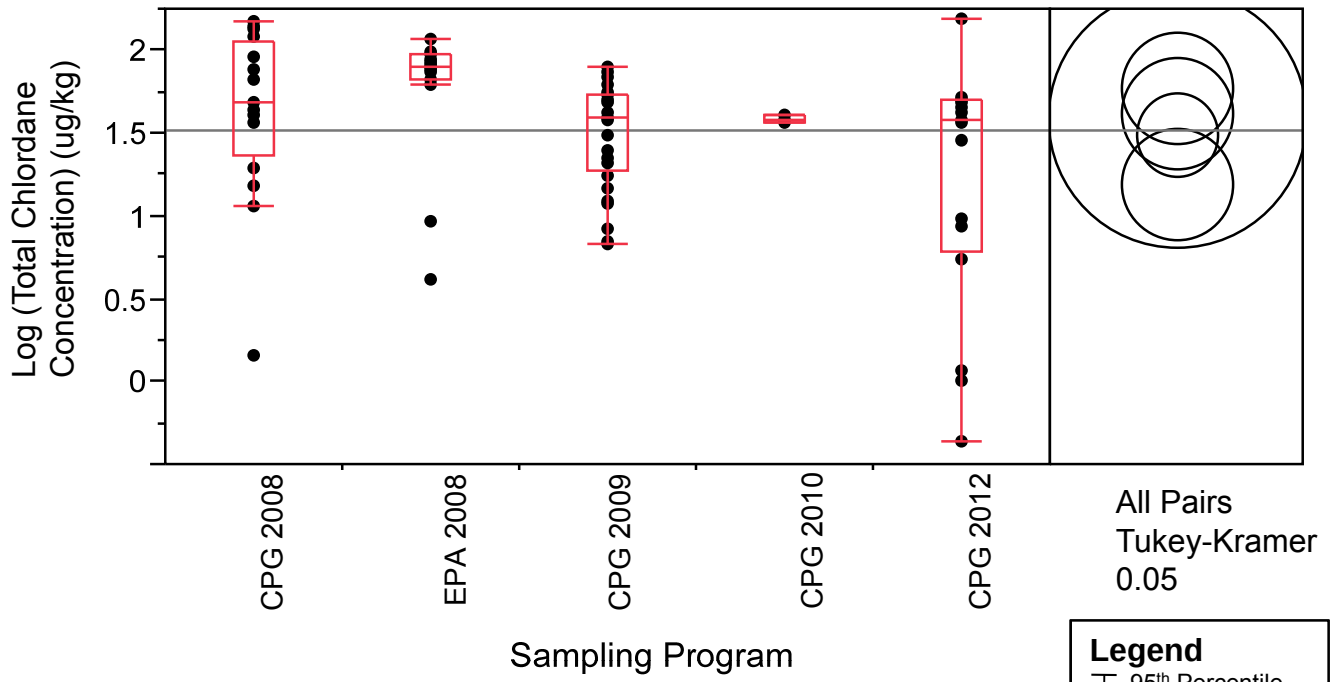
Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.

RM2 to RM8

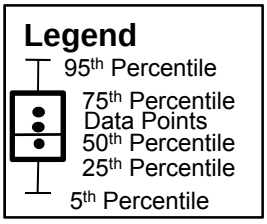


	Total Chlordane (0-6 inch) by Sampling Program at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.2-10a** 2014

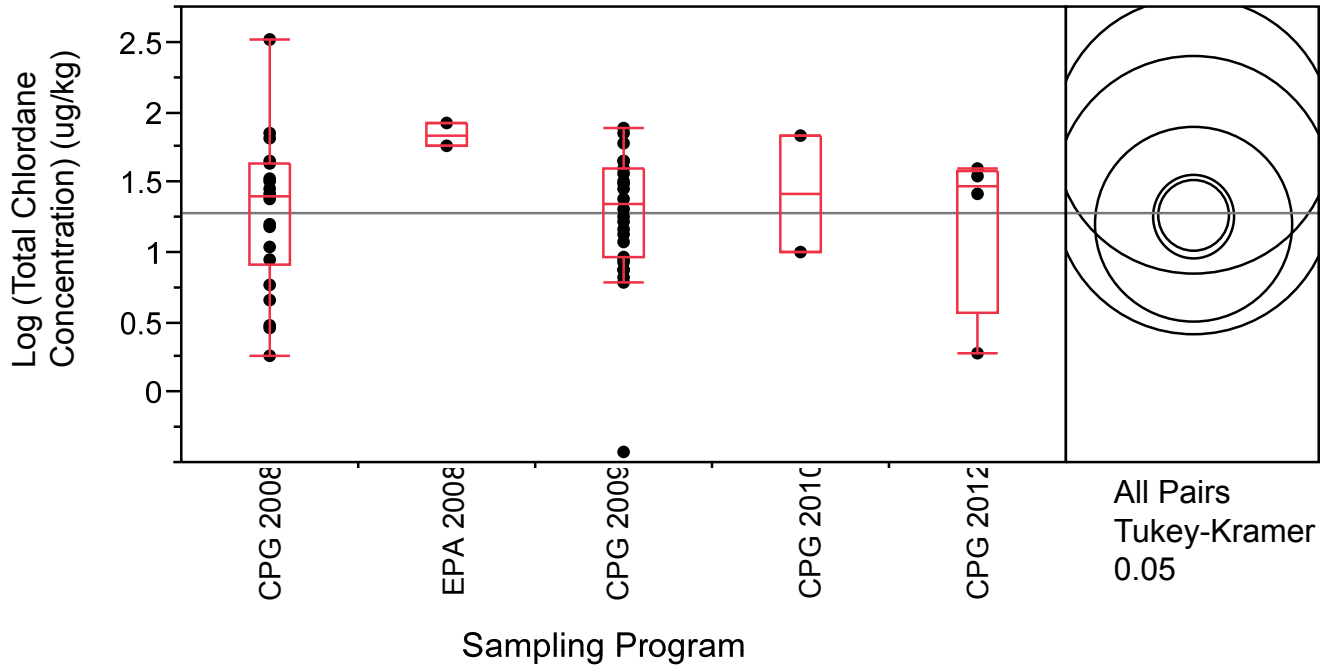
RM8 to RM12



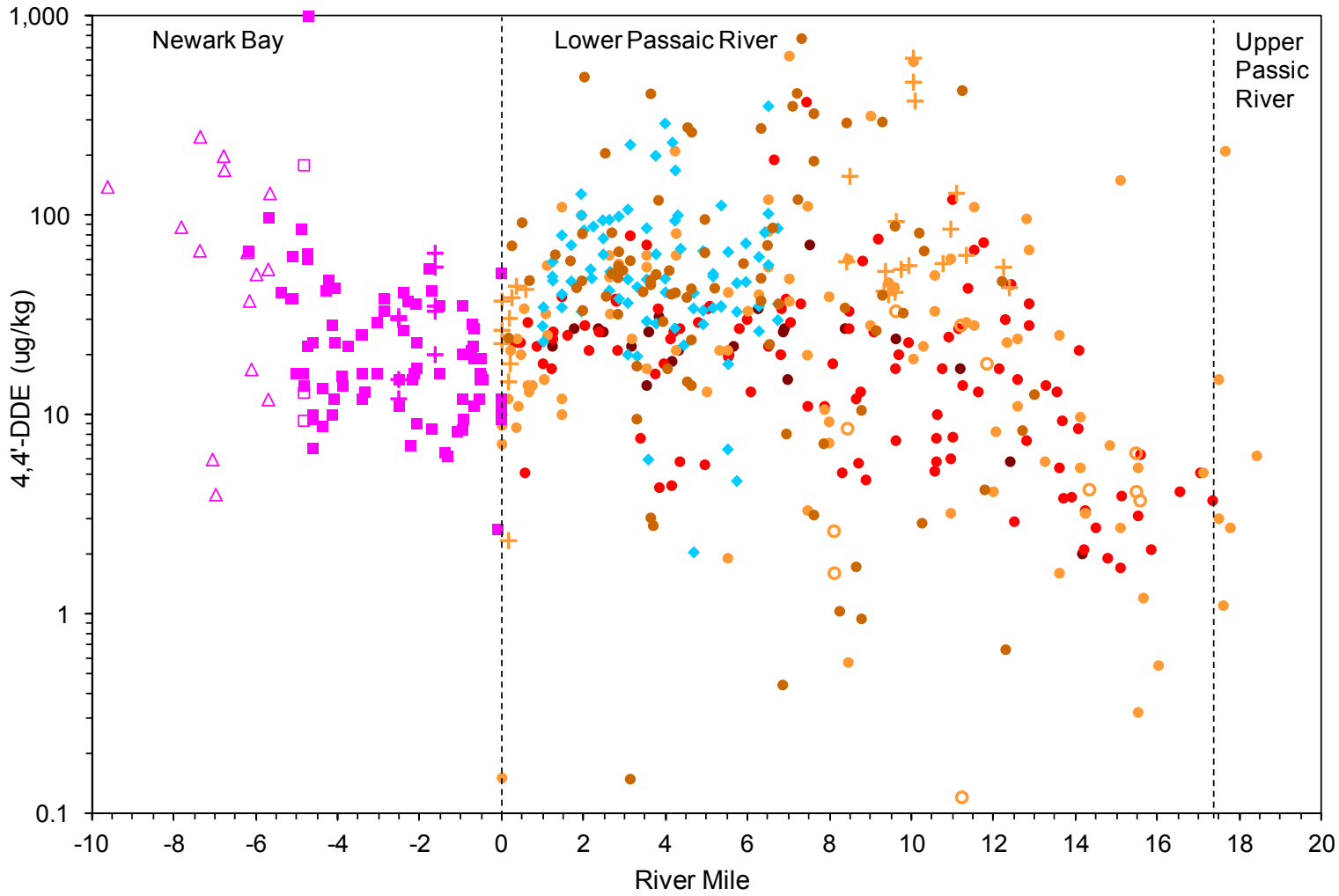
Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.



RM12 to RM17.4



	Total Chlordane (0-6 inch) by Sampling Program at RM8 to RM12 and RM12 to RM17.4 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.2-10b** 2014



Legend

- 2012 CPG
- 2010 CPG
- 2009 CPG
- 2008 CPG
- 2008 CPG Tributary Below HoT
- 2008 EPA
- 2005&2007 Newark Bay
- 2005&2007 Shooters Island & Arthur Kill
- 2005&2007 Kill Van Kull
- 2005&2007 Port Elizabeth & Newark
- 1995 TSI

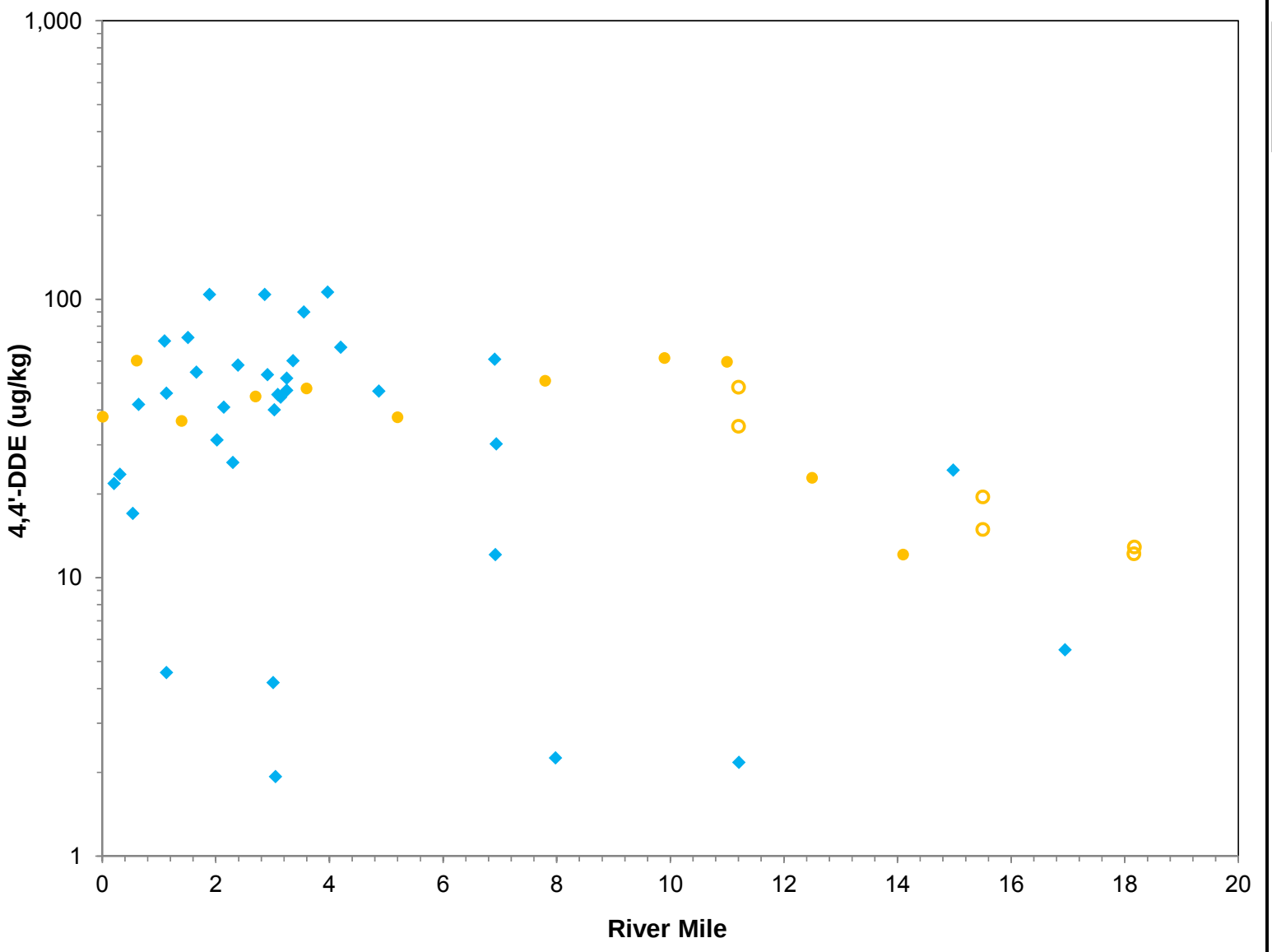
4,4'-DDE Concentration (0-6 inches) *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 3.2-11

2014

R2-0027151



Legend

- 1991-1993
- 2007-2008 EPA
- 2007-2008 EPA Tributary Above HoT

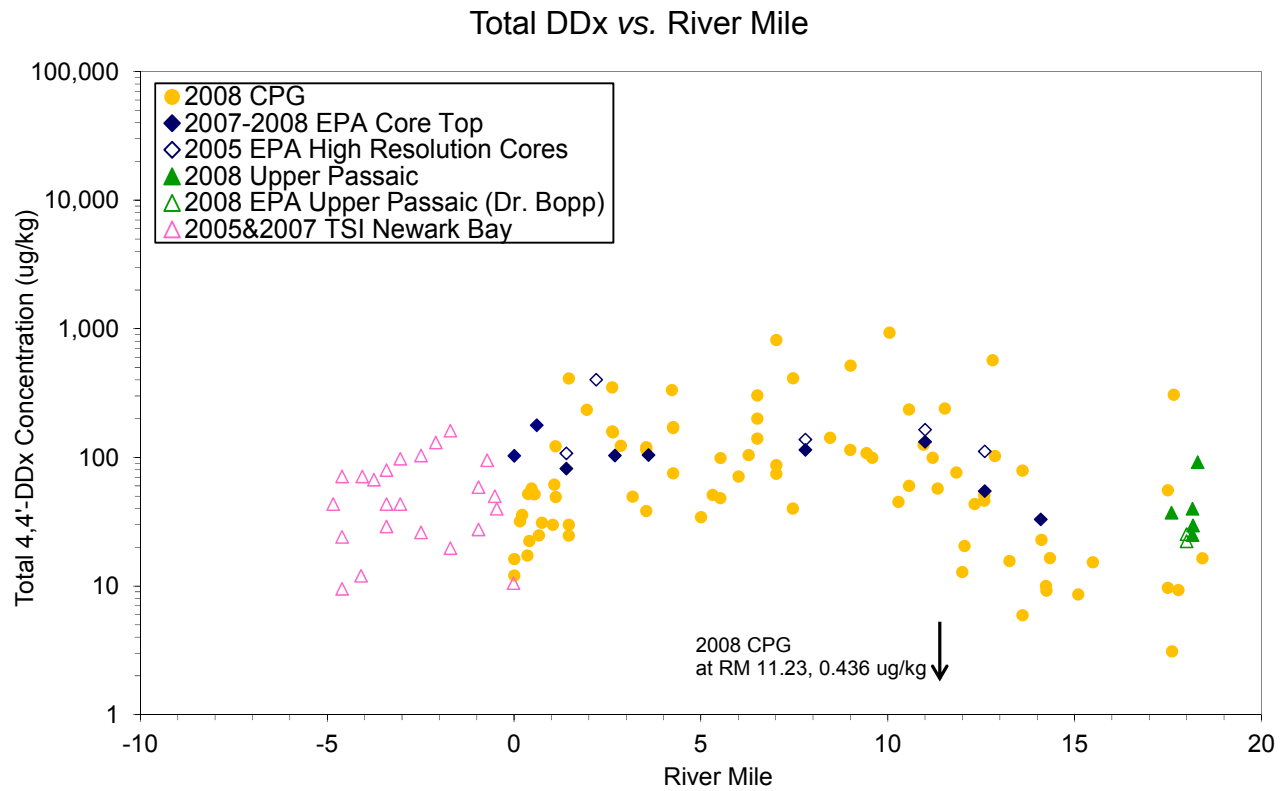
4,4'-DDE Concentration (0 - ≤2 inches) *vs.* River Mile

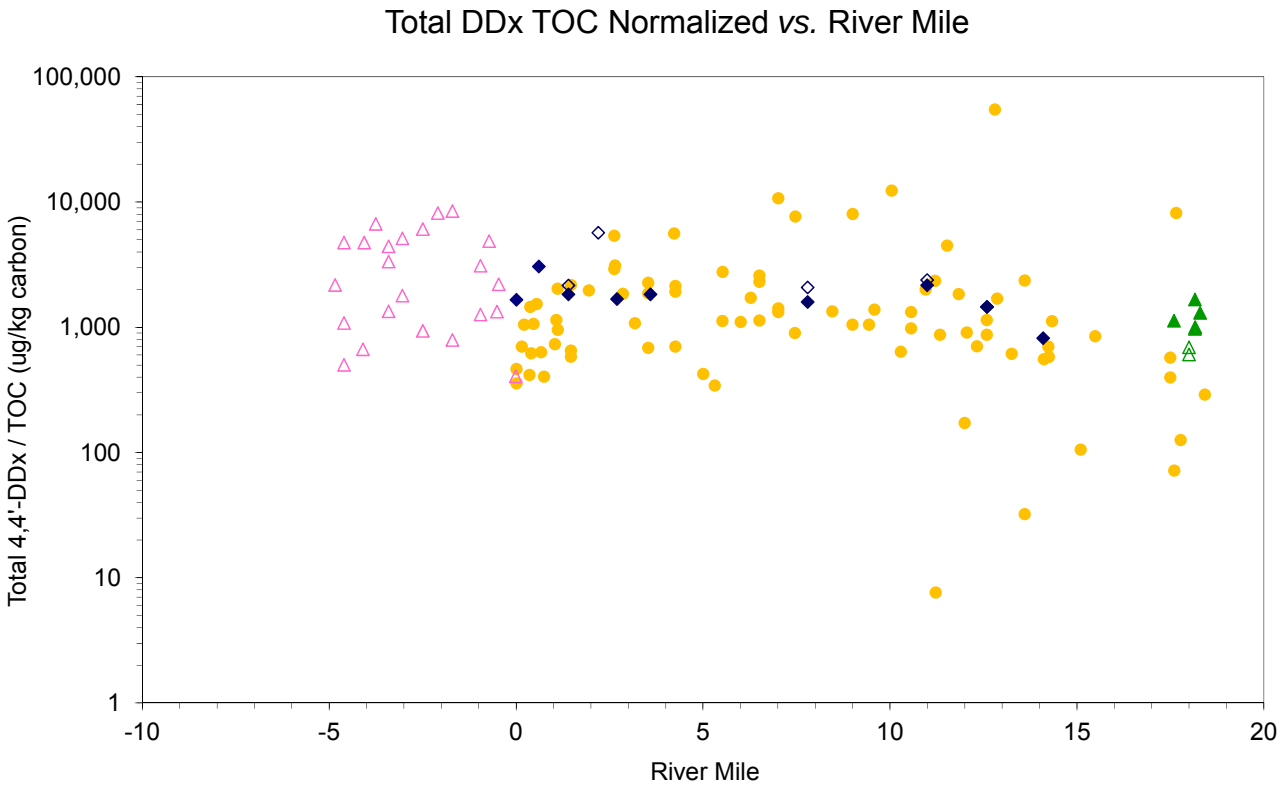
Lower Eight Miles of the Lower Passaic River

Figure 3.2-12

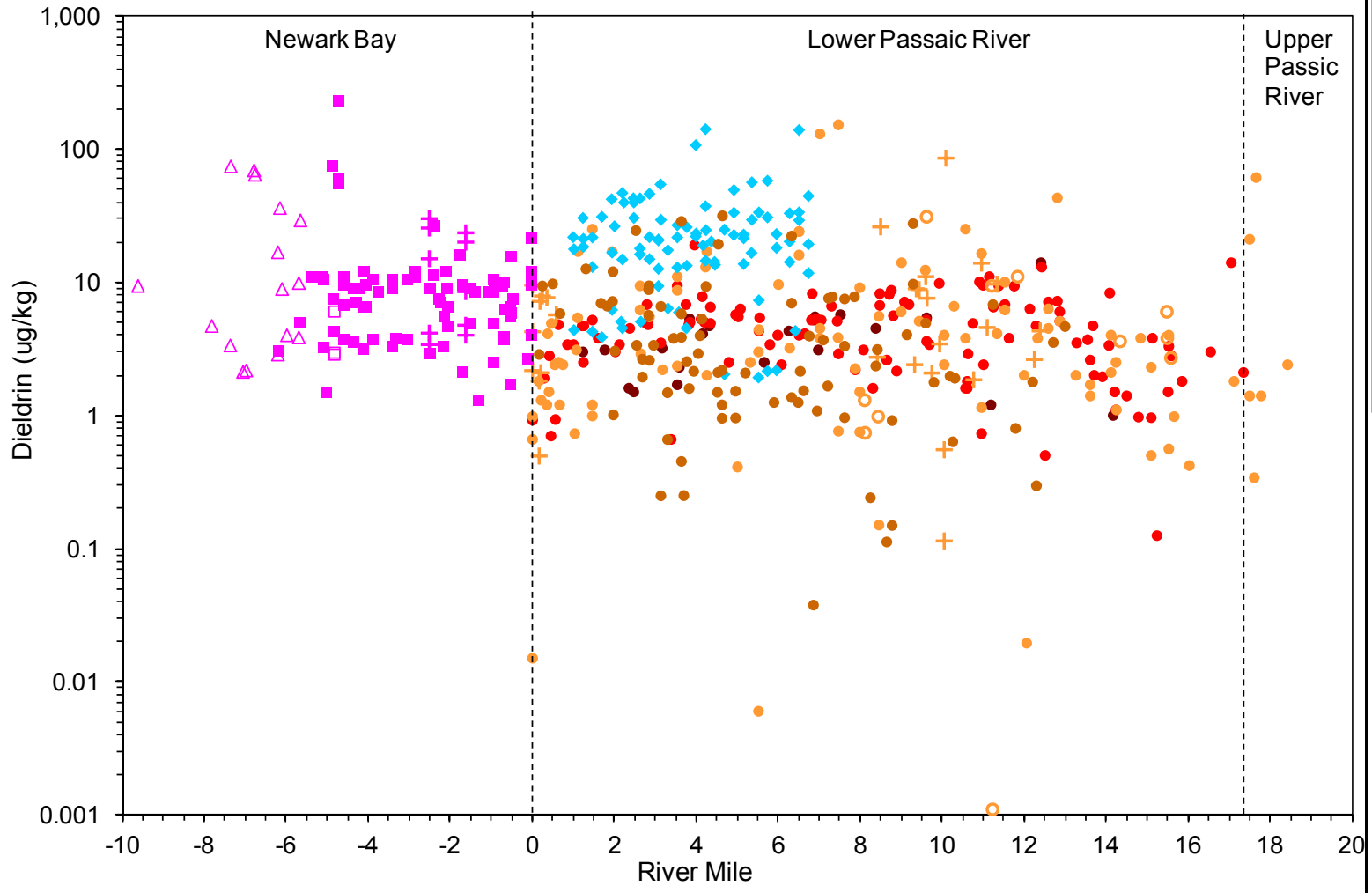
2014

R2-0027152





	Total DDx in Recently-Deposited Sediments in the Lower Passaic River, Newark Bay and the Upper Passaic River *Lower Eight Miles of the Lower Passaic River*	**Figure 3.2-13** 2014



Legend

- 2012 CPG
- 2010 CPG
- 2009 CPG
- 2008 CPG
- 2008 CPG Tributary Below HoT
- 2008 EPA
- 2005&2007 Newark Bay
- 2005&2007 Shooters Island & Arthur Kill
- 2005&2007 Kill Van Kull
- 2005&2007 Port Elizabeth & Newark
- 1995 TSI

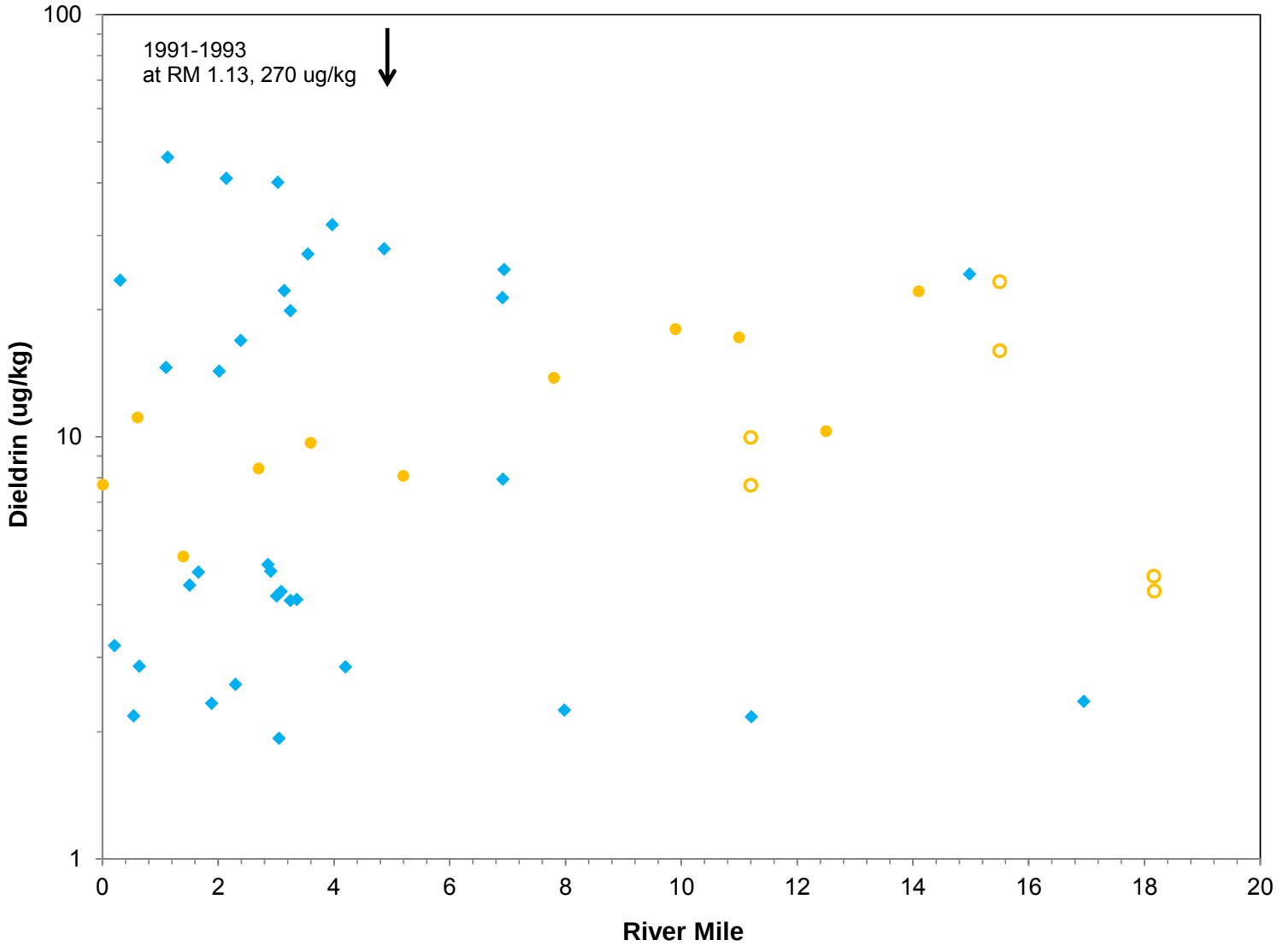
Dieldrin Concentration (0-6 inches) *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 3.2-14

2014

R2-0027154



Legend

- 1991-1993
- 2007-2008 EPA
- 2007-2008 EPA Tributary Above HoT

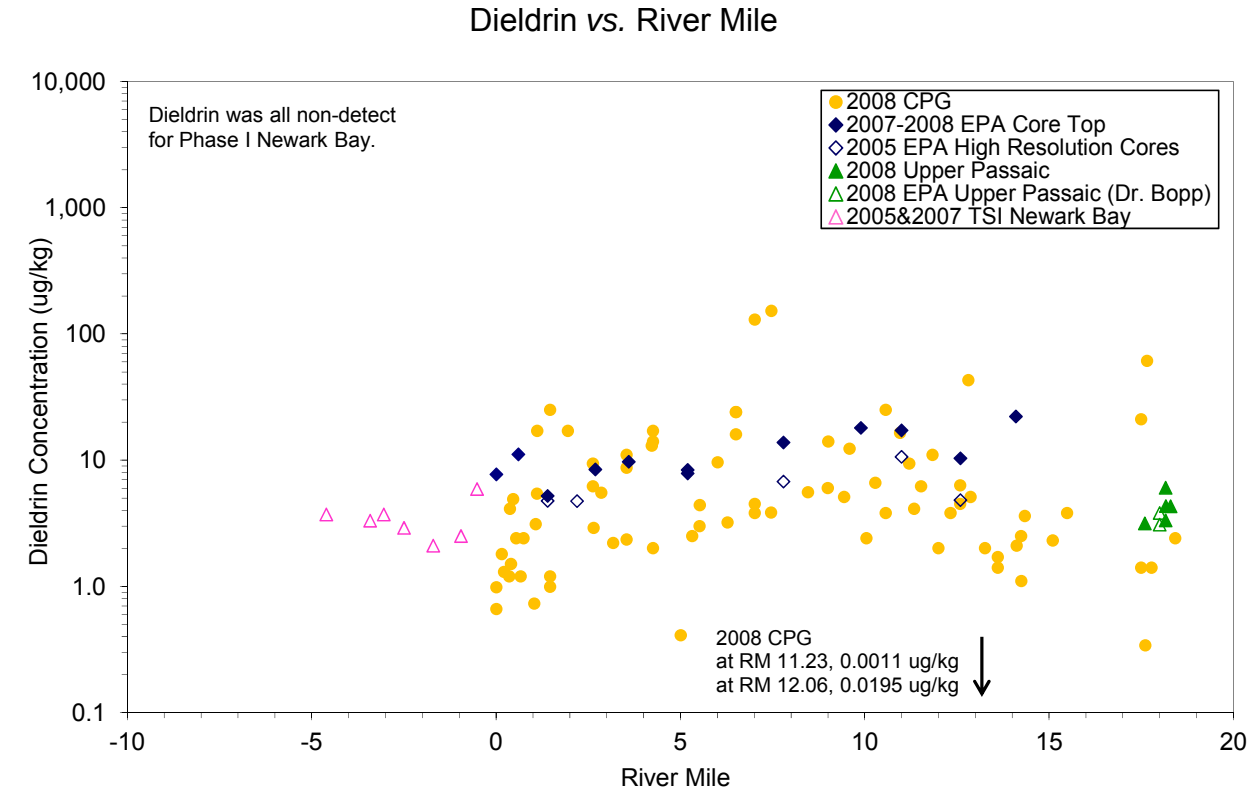
Dieldrin Concentration (0 - ≤2 inches) *vs.* River Mile

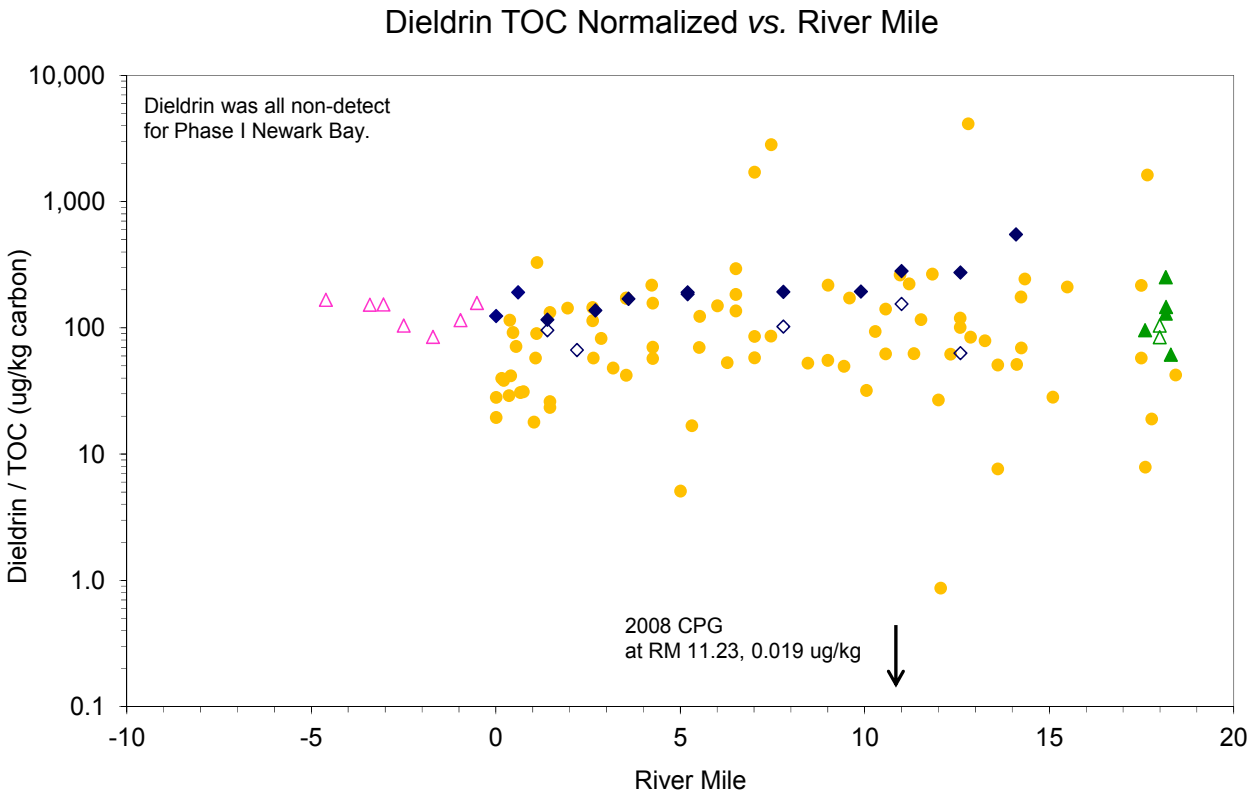
Lower Eight Miles of the Lower Passaic River

Figure 3.2-15

2014

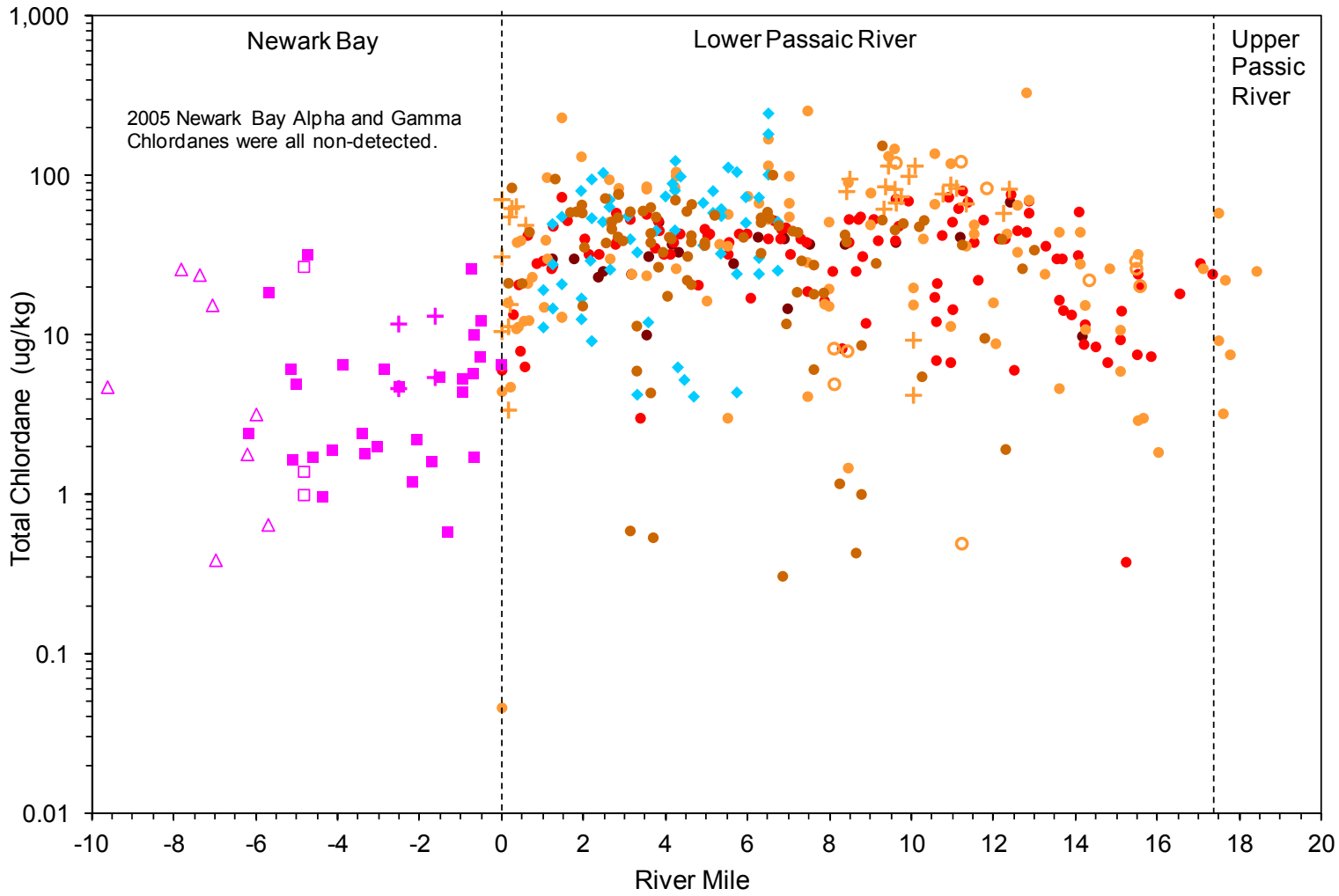
R2-0027155





	Dieldrin in Recently-Deposited Sediments in the Lower Passaic River, Newark Bay and the Upper Passaic River *Lower Eight Miles of the Lower Passaic River*	**Figure 3.2-16** 2014

R2-0027156



Legend

- 2012 CPG
- 2010 CPG
- 2009 CPG
- 2008 CPG
- 2008 CPG Tributary Below HoT
- 2008 EPA
- 2005&2007 Newark Bay
- 2005&2007 Shooters Island & Arthur Kill
- 2005&2007 Kill Van Kull
- 2005&2007 Port Elizabeth & Newark
- 1995 TSI

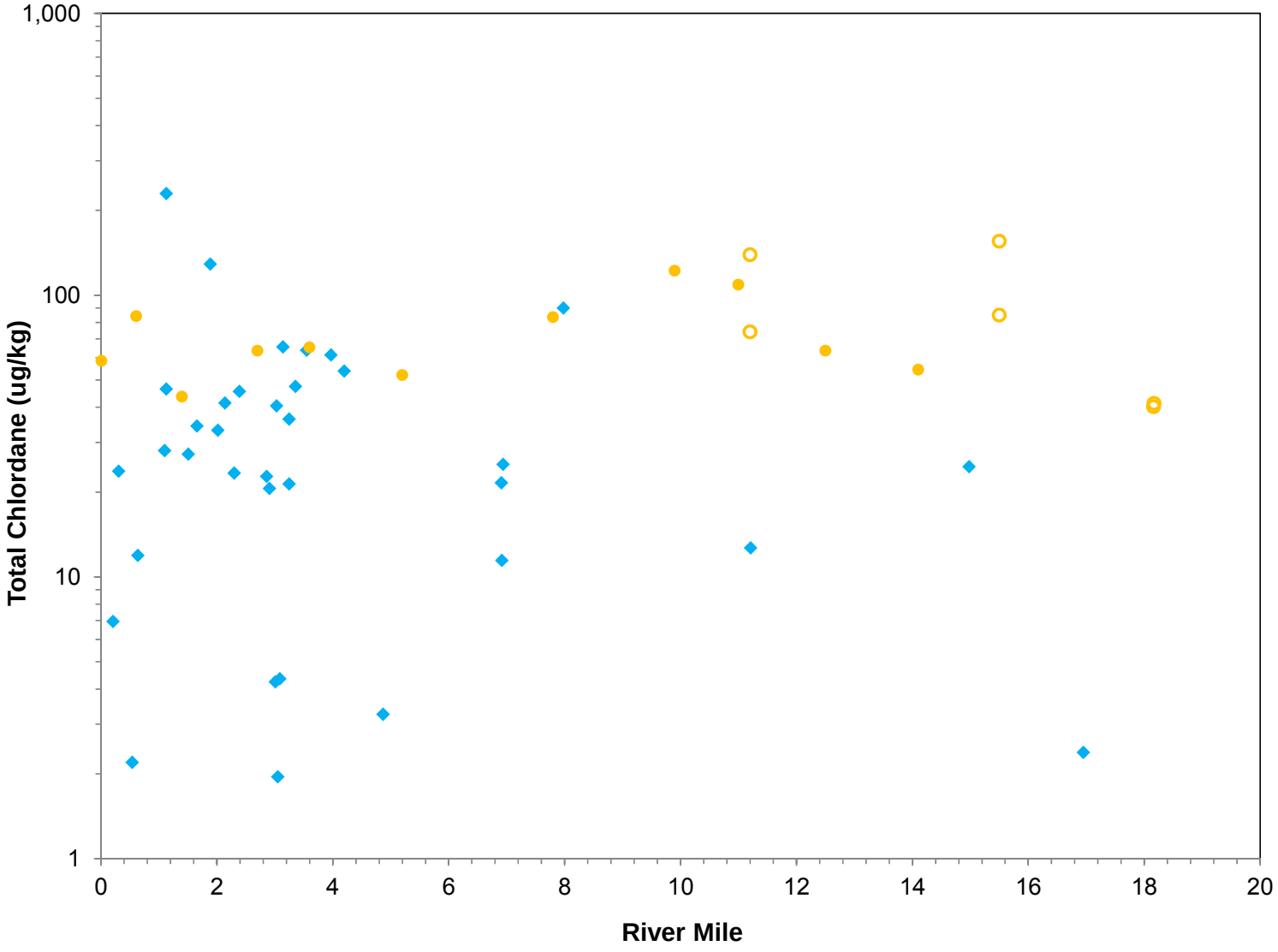
Total Chlordane Concentration (0-6 inches) *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 3.2-17

2014

R2-0027157



Legend

- 1991-1993
- 2007-2008 EPA
- 2007-2008 EPA Tributary Above HoT

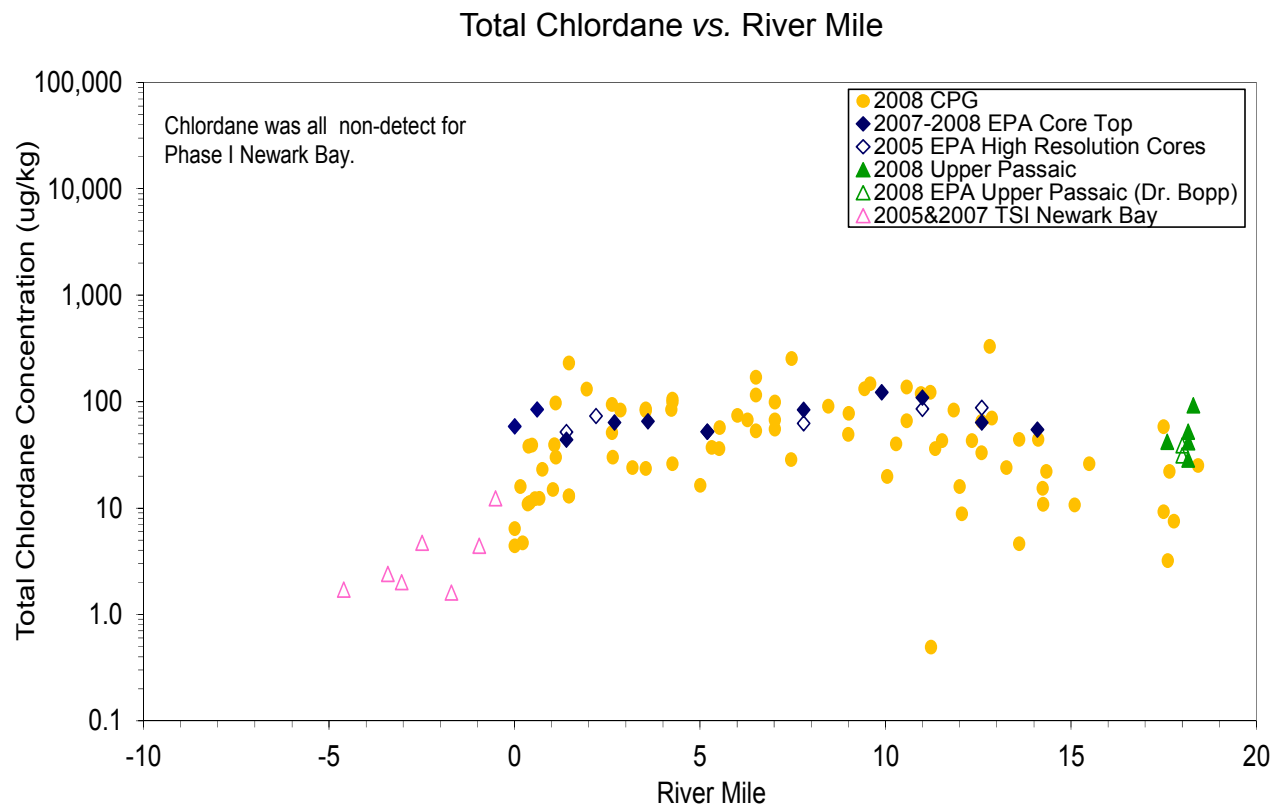
Total Chlordane Concentration (0 - ≤2 inches) *vs.* River Mile

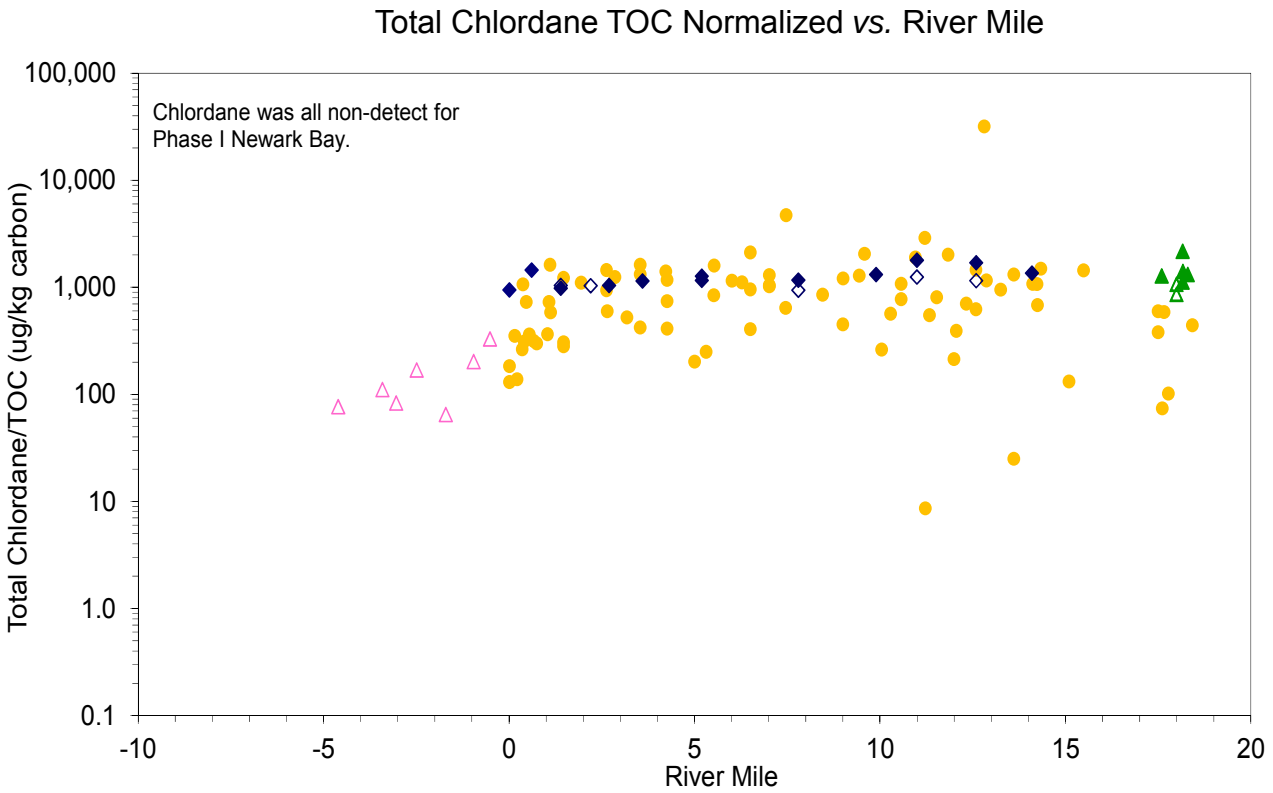
Lower Eight Miles of the Lower Passaic River

Figure 3.2-18

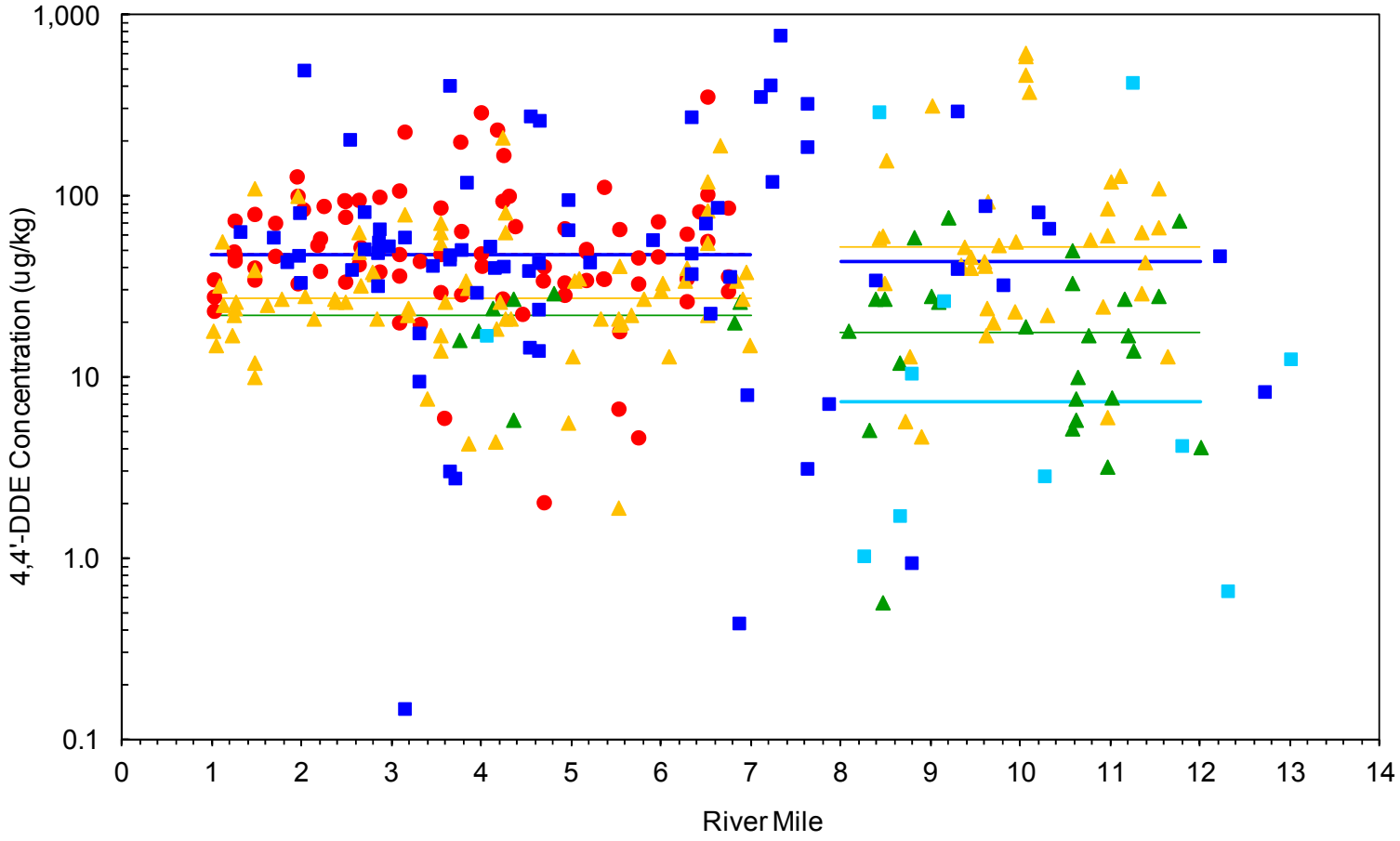
2014

R2-0027158





	Total Chlordane in Recently-Deposited Sediments in the Lower Passaic River, Newark Bay and the Upper Passaic River *Lower Eight Miles of the Lower Passaic River*	**Figure 3.2-19** 2014



Legend

- 2012 Fine-Grained
- 2012 Fine-Grained Median
- 2012 Coarse-Grained
- 2012 Coarse-Grained Median
- 2008-2010 Fine-Grained
- 2008-2010 Fine-Grained Median
- 2008-2010 Coarse-Grained
- 2008-2010 Coarse-Grained Median
- 1995
- 1995 Median

Comparison of 4,4'-DDE Surface Concentration (0-6 inches)
RM1 to RM7 *vs.* RM8 to 12

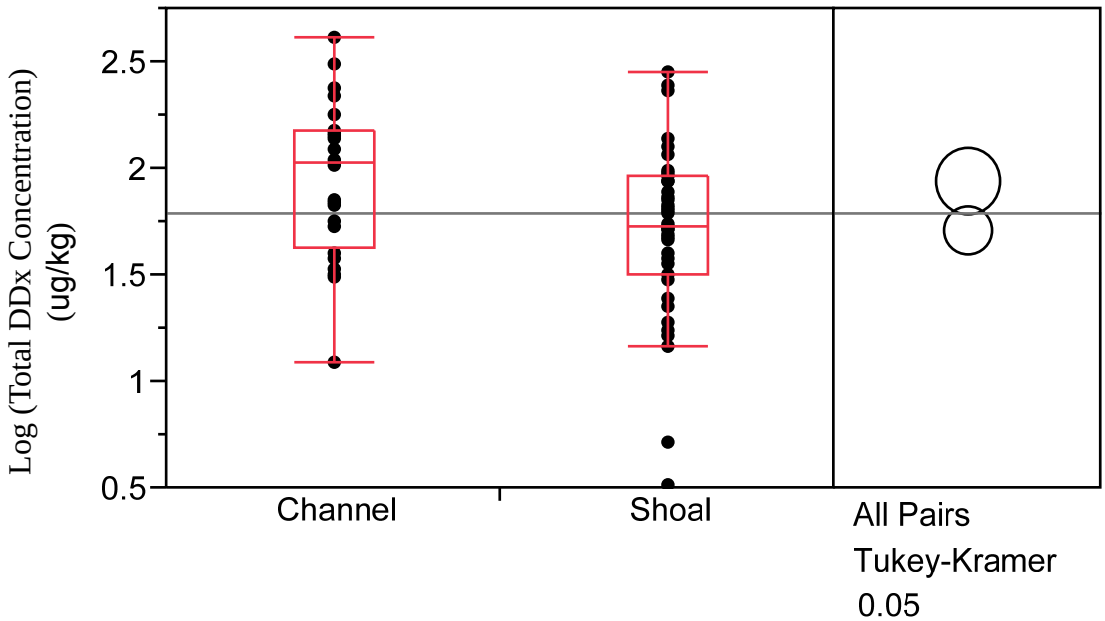
Lower Eight Miles of the Lower Passaic River

Figure 3.2-20

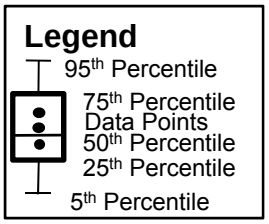
2014

R2-0027160

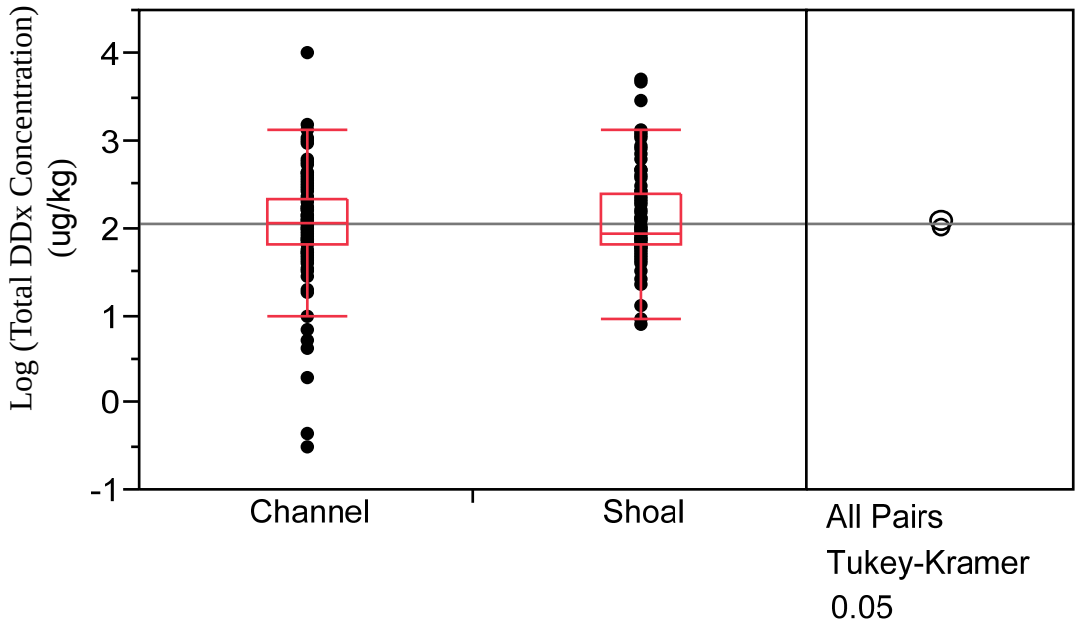
RM0 to RM2



Notes:
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.

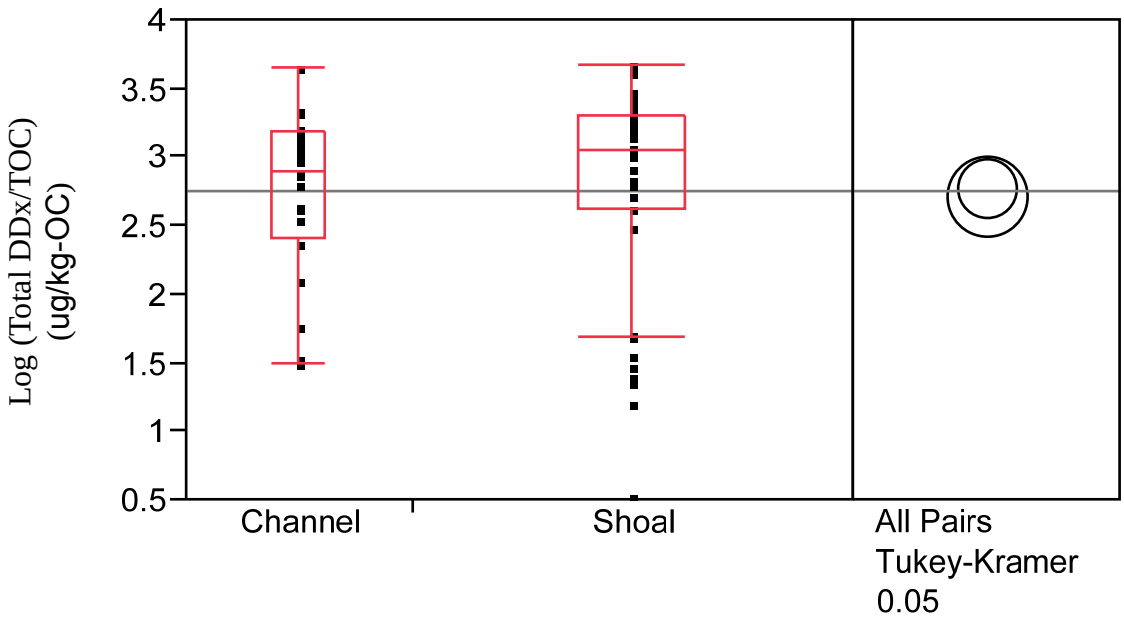


RM2 to RM8

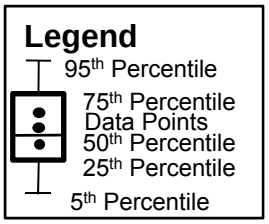


	Total DDx (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.2-21a** 2014

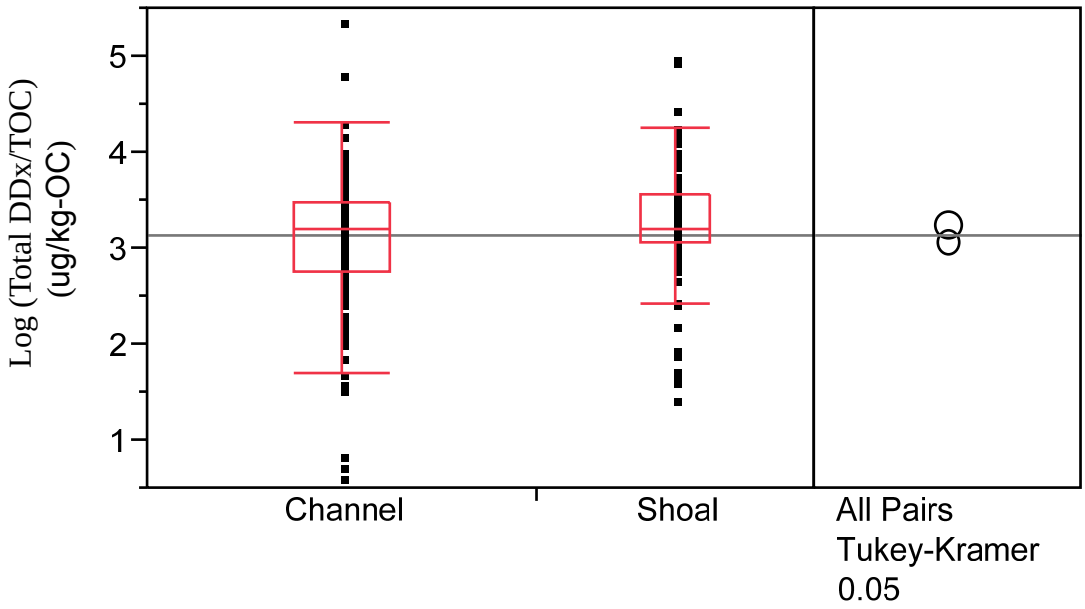
RM0 to RM2



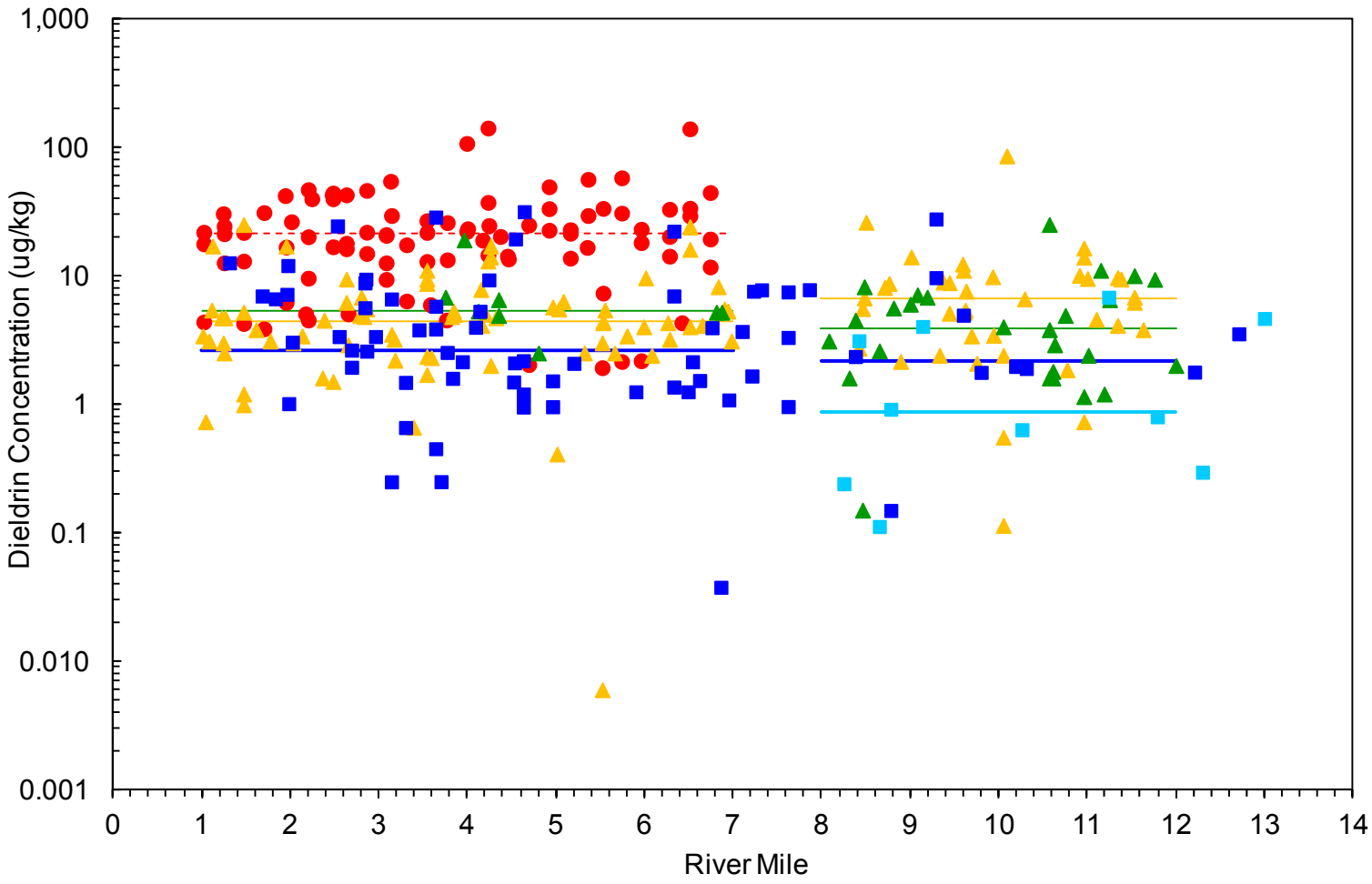
Notes:
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.



RM2 to RM8



	TOC Normalized Total DDx (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.2-21b** 2014



Legend

- 2012 Fine-Grained
- 2012 Fine-Grained Median
- 2012 Coarse-Grained
- 2012 Coarse-Grained Median
- 2008-2010 Fine-Grained
- 2008-2010 Fine-Grained Median
- 2008-2010 Coarse-Grained
- 2008-2010 Coarse-Grained Median
- 1995
- 1995 Median

Comparison of Dieldrin Surface Concentration (0-6 inches)
RM1 to RM7 *vs.* RM8 to 12

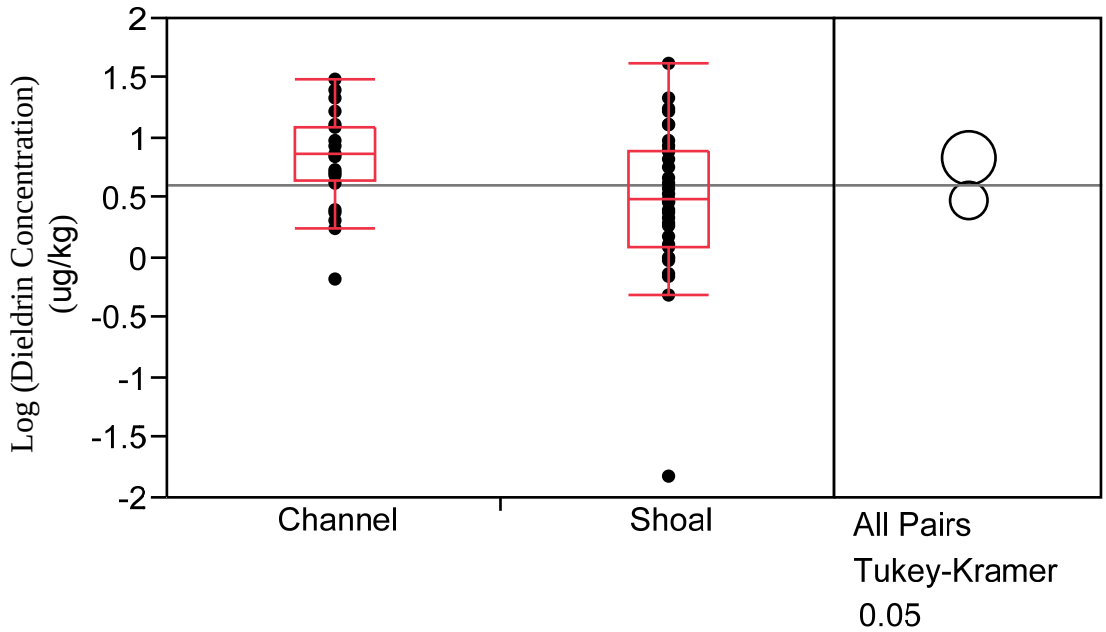
Lower Eight Miles of the Lower Passaic River

Figure 3.2-22

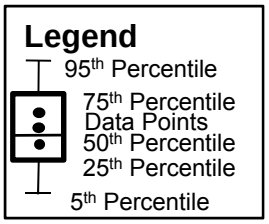
2014

R2-0027163

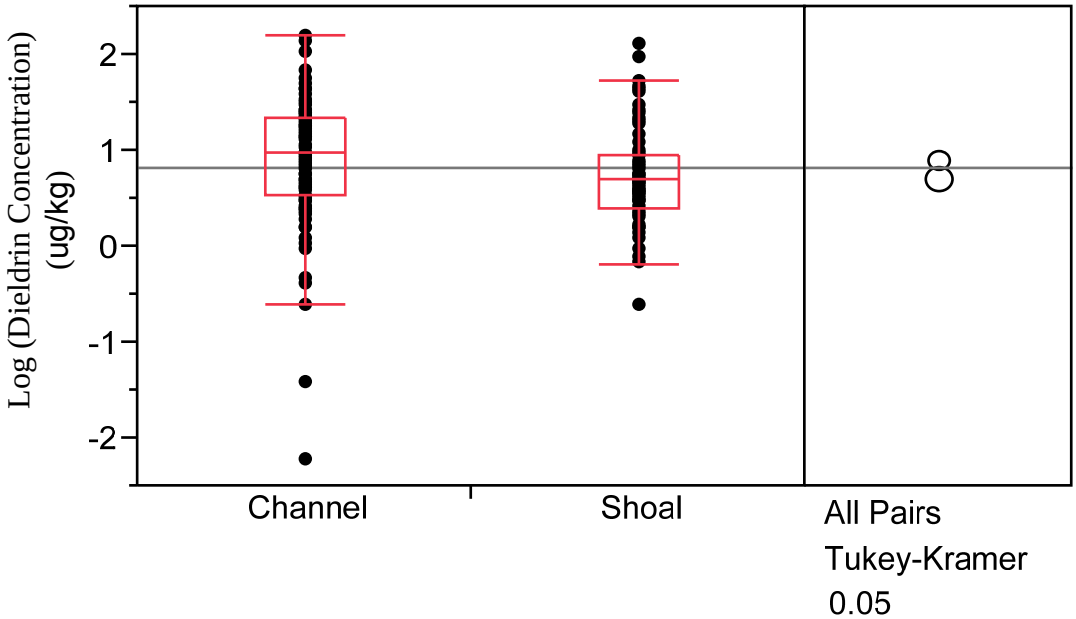
RM0 to RM2



Notes:
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.

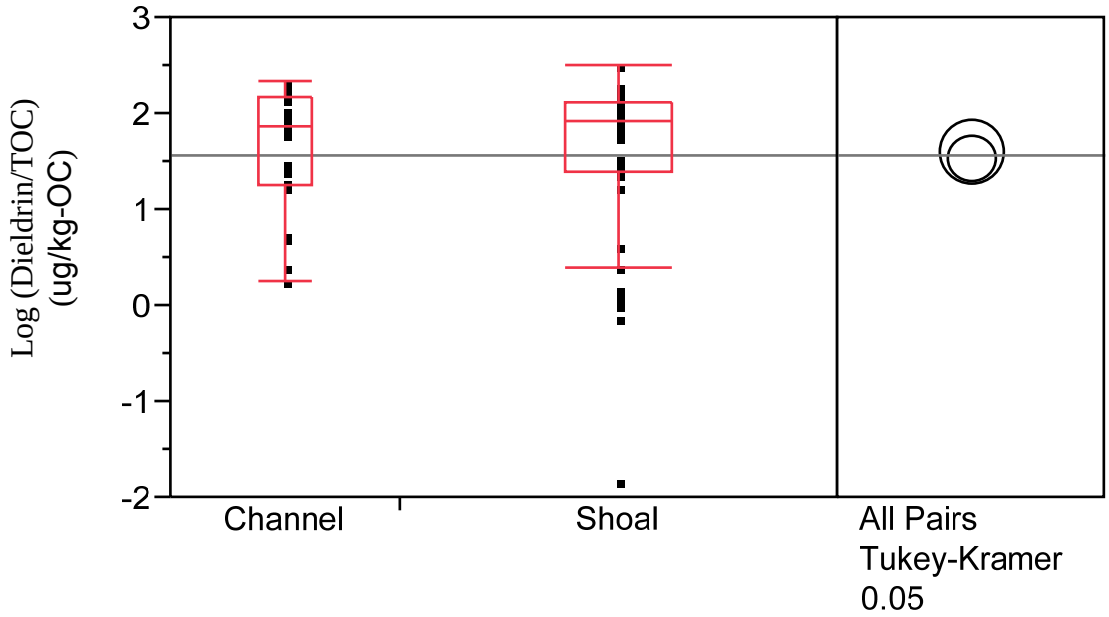


RM2 to RM8

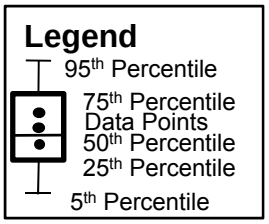


	Dieldrin by (0-6 inch) Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.2-23a** 2014

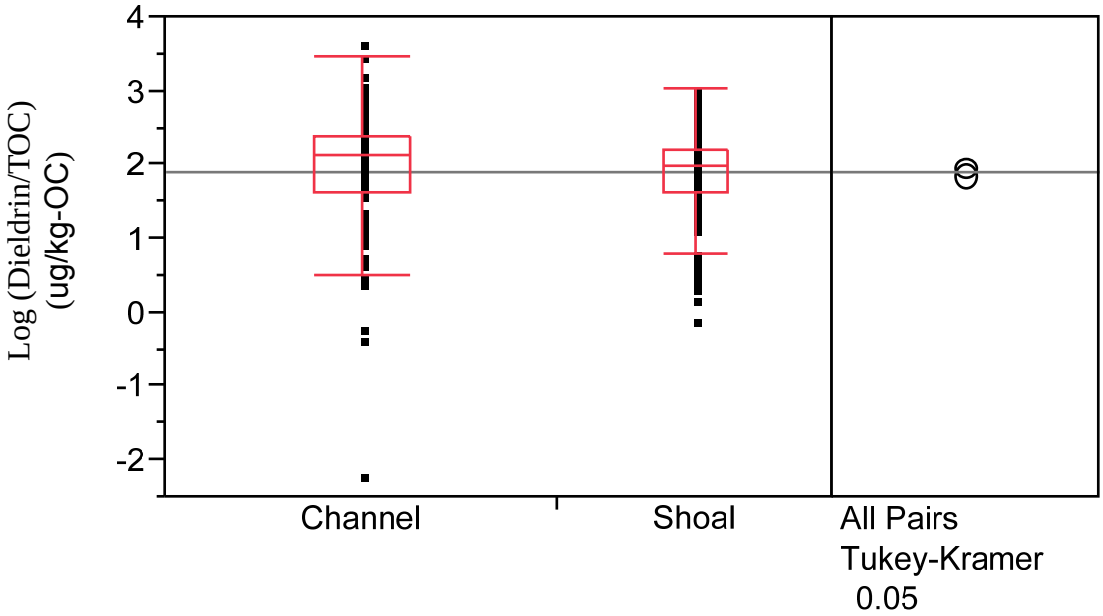
RM0 to RM2



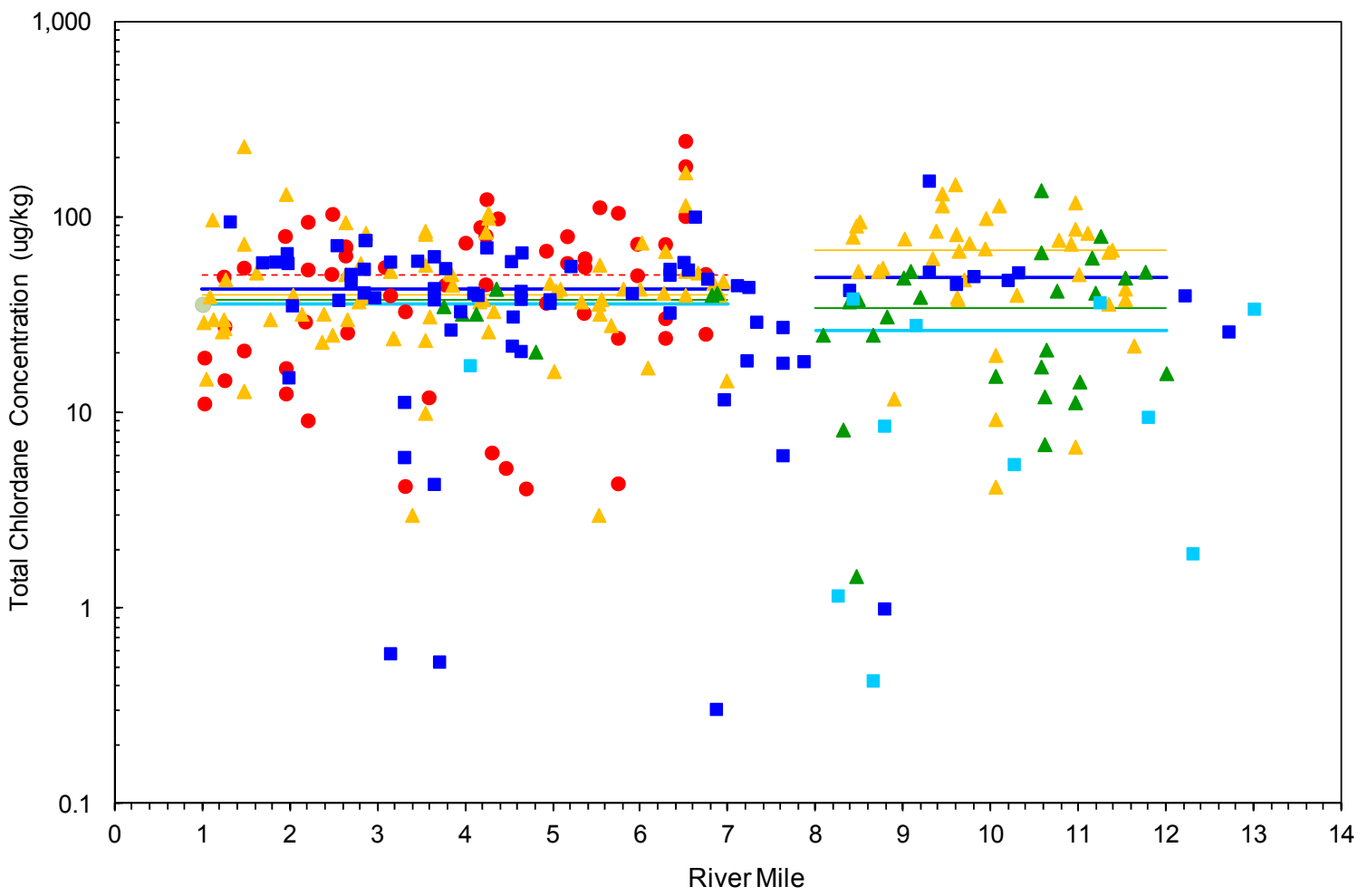
Notes:
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.



RM2 to RM8



	TOC Normalized Dieldrin (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.2-23b** 2014



Legend

- 2012 Fine-Grained
- 2012 Fine-Grained Median
- 2012 Coarse-Grained
- 2012 Coarse-Grained Median
- 2008-2010 Fine-Grained
- 2008-2010 Fine-Grained Median
- 2008-2010 Coarse-Grained
- 2008-2010 Coarse-Grained Median
- 1995
- 1995 Median

Comparison of Total Chlordane Surface Concentration (0-6 inches)
RM1 to RM7 *vs.* RM8 to 12

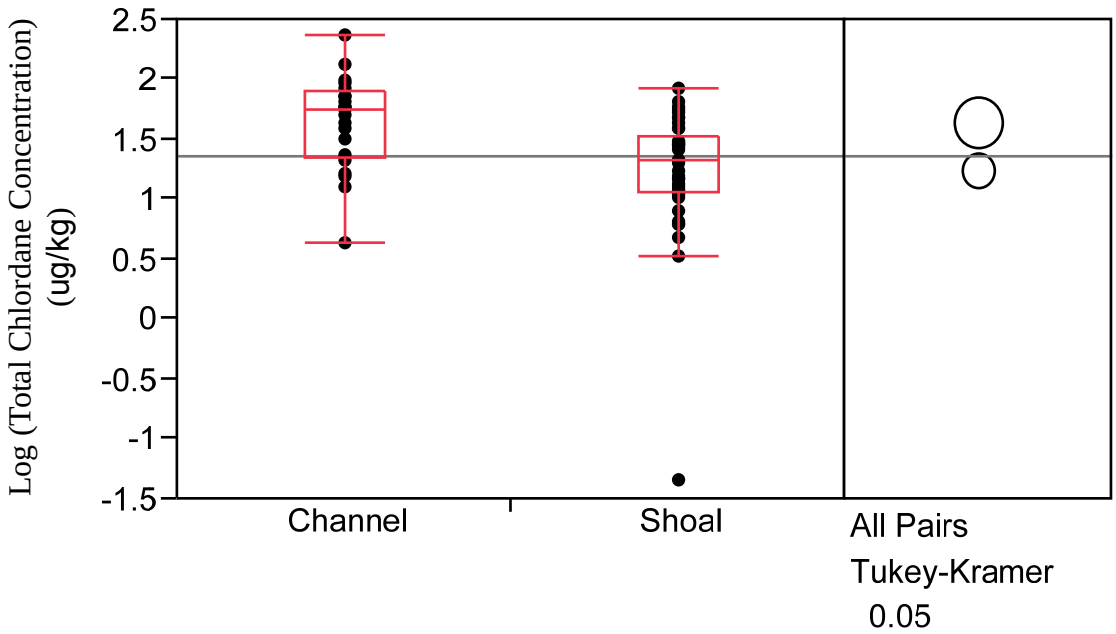
Lower Eight Miles of the Lower Passaic River

Figure 3.2-24

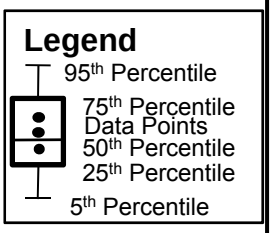
2014

R2-0027166

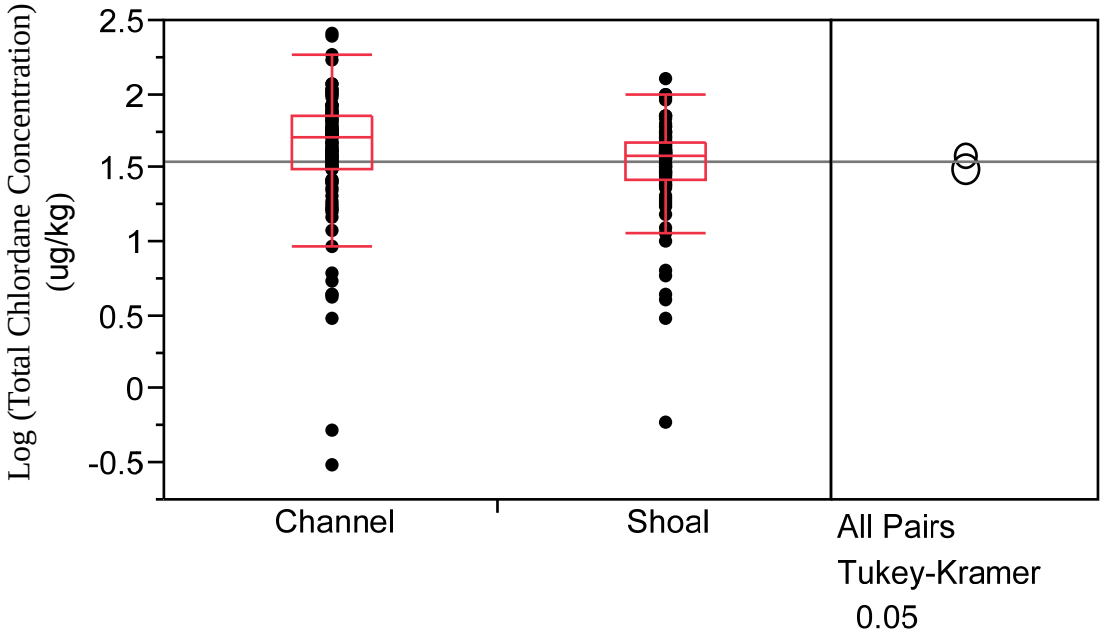
RM0 to RM2



Notes:
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 1995, 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.

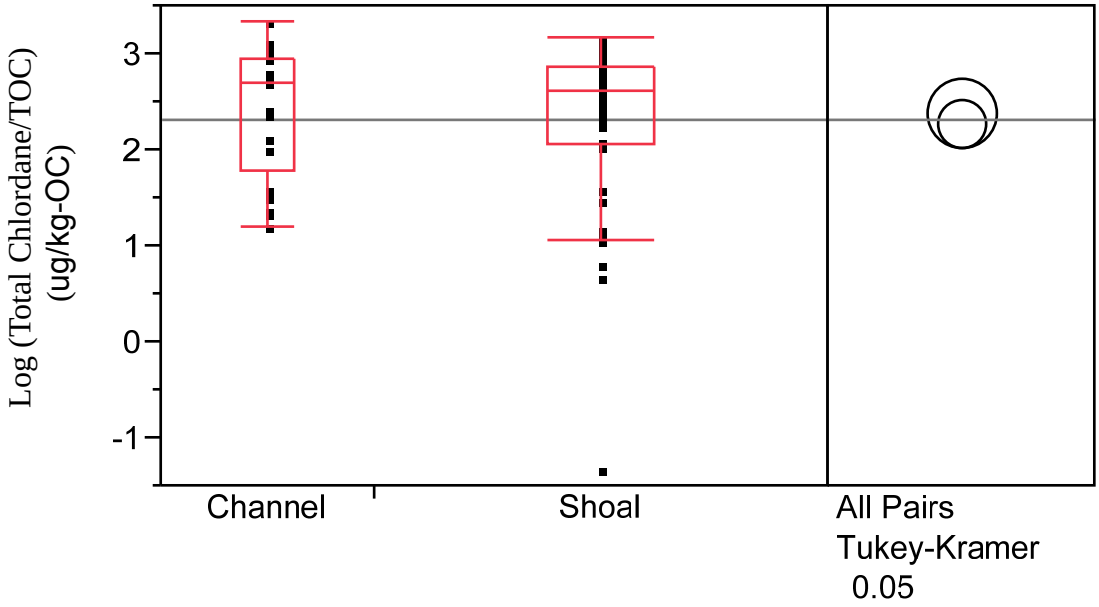


RM2 to RM8

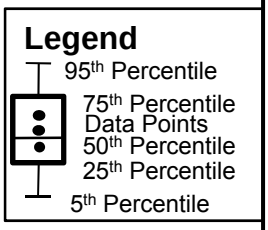


	Total Chlordane (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.2-25a** 2014

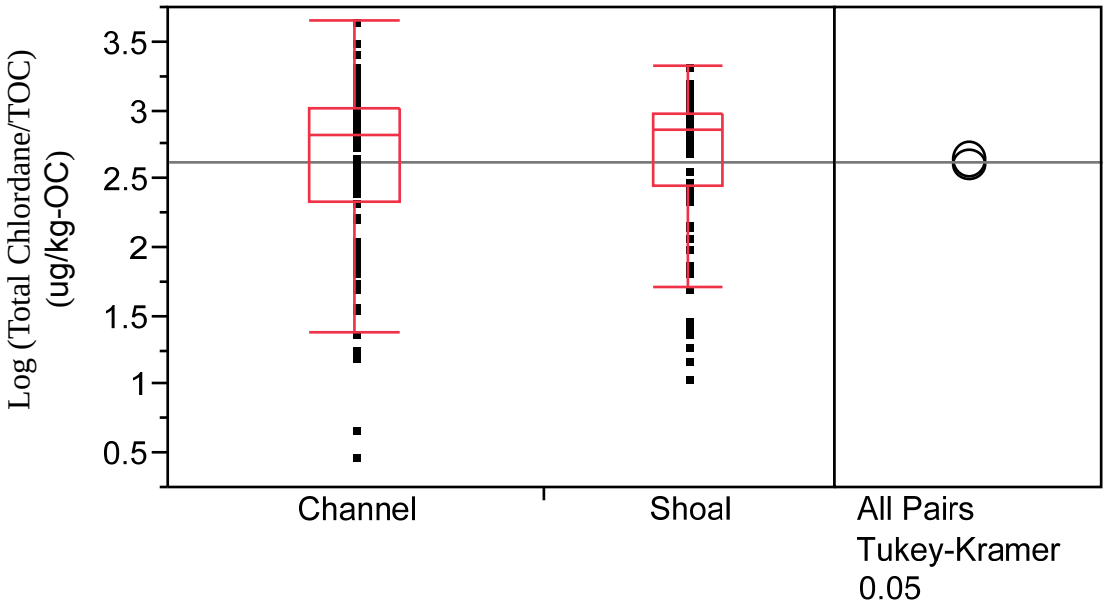
RM0 to RM2



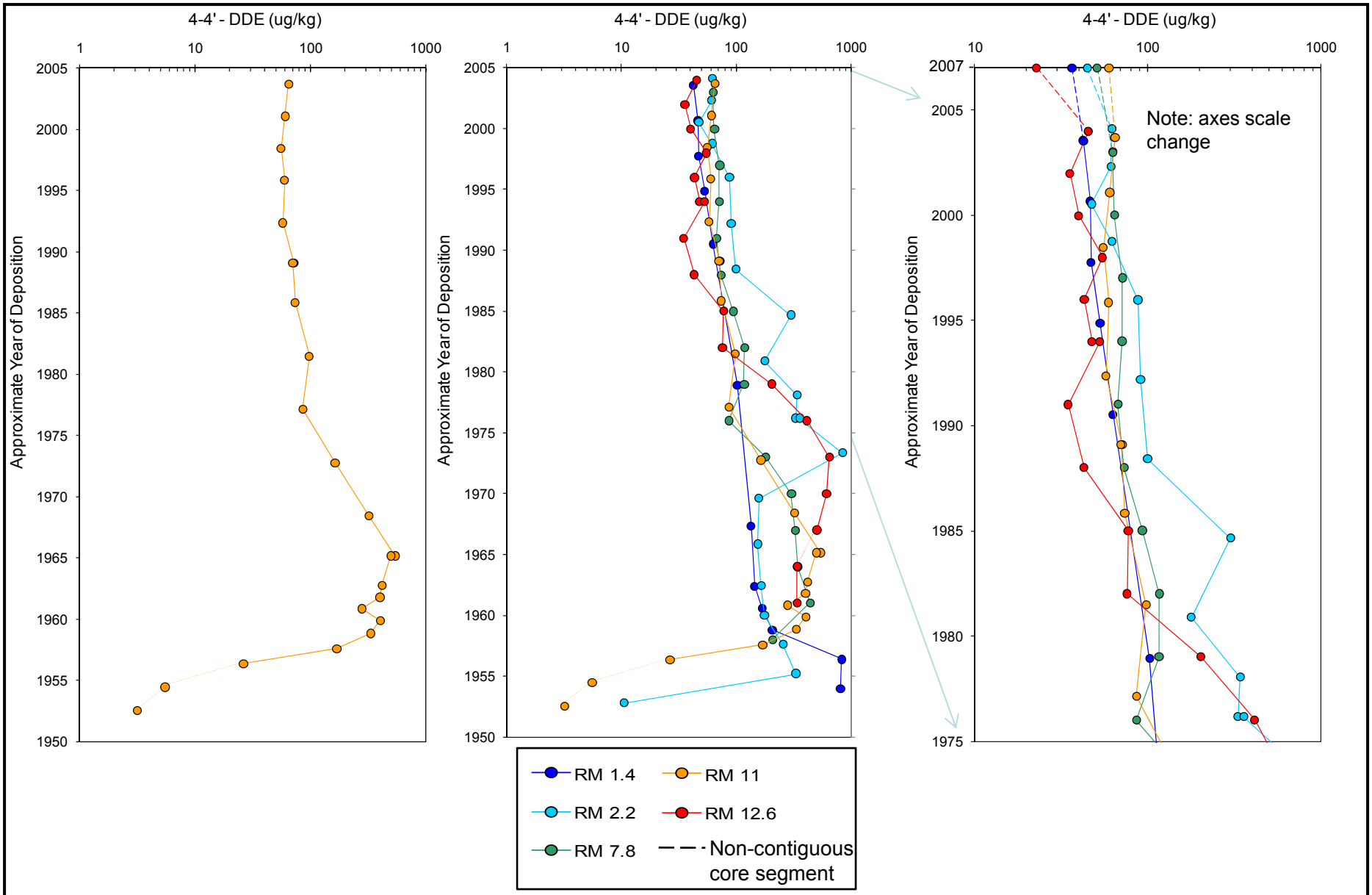
Notes:
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 1995, 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.



RM2 to RM8



	TOC Normalized Total Chlordane (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.2-25b** 2014



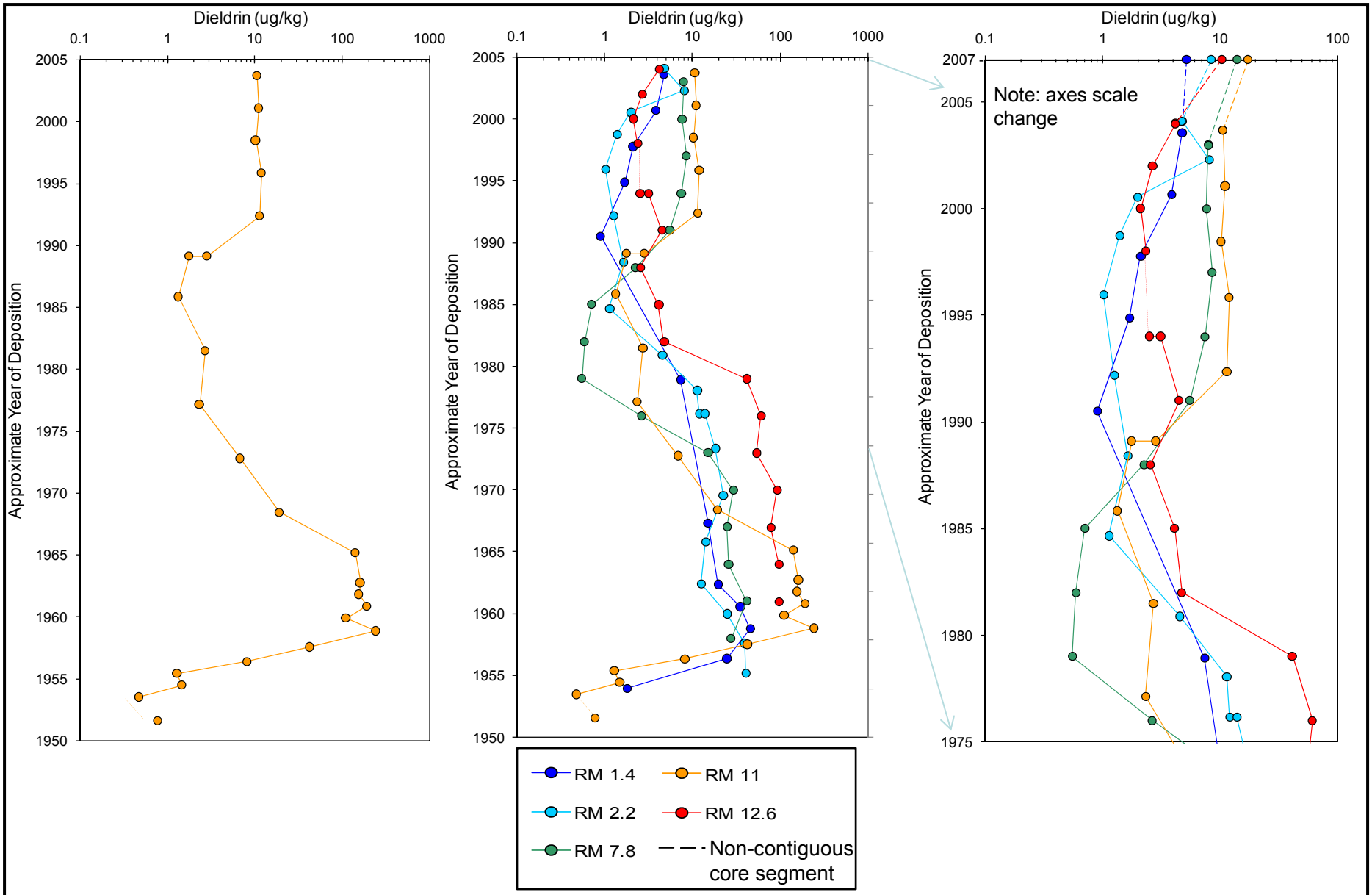
Dated Sediment Core Profile for 4,4'-DDE:
2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3.2-26

2014

R2-0027169



Dated Sediment Core Profile for Dieldrin:
2005 High Resolution Cores and 2007 Surface Samples

Lower Eight Miles of the Lower Passaic River

Figure 3.2-27

2014

R2-0027170

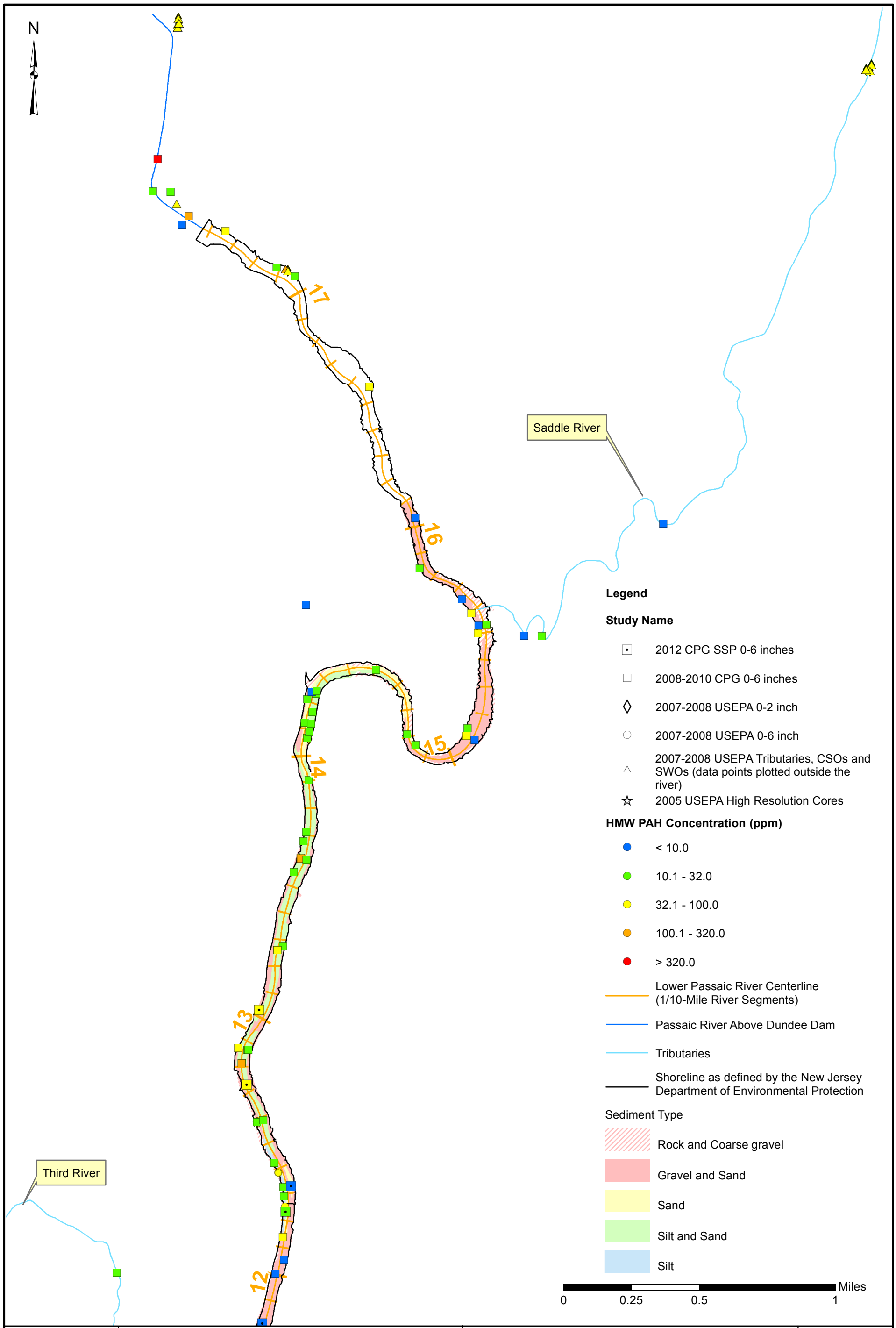
Total HMW PAH Surface Sediment Samples from 1991 to 2000

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.3-1

2014



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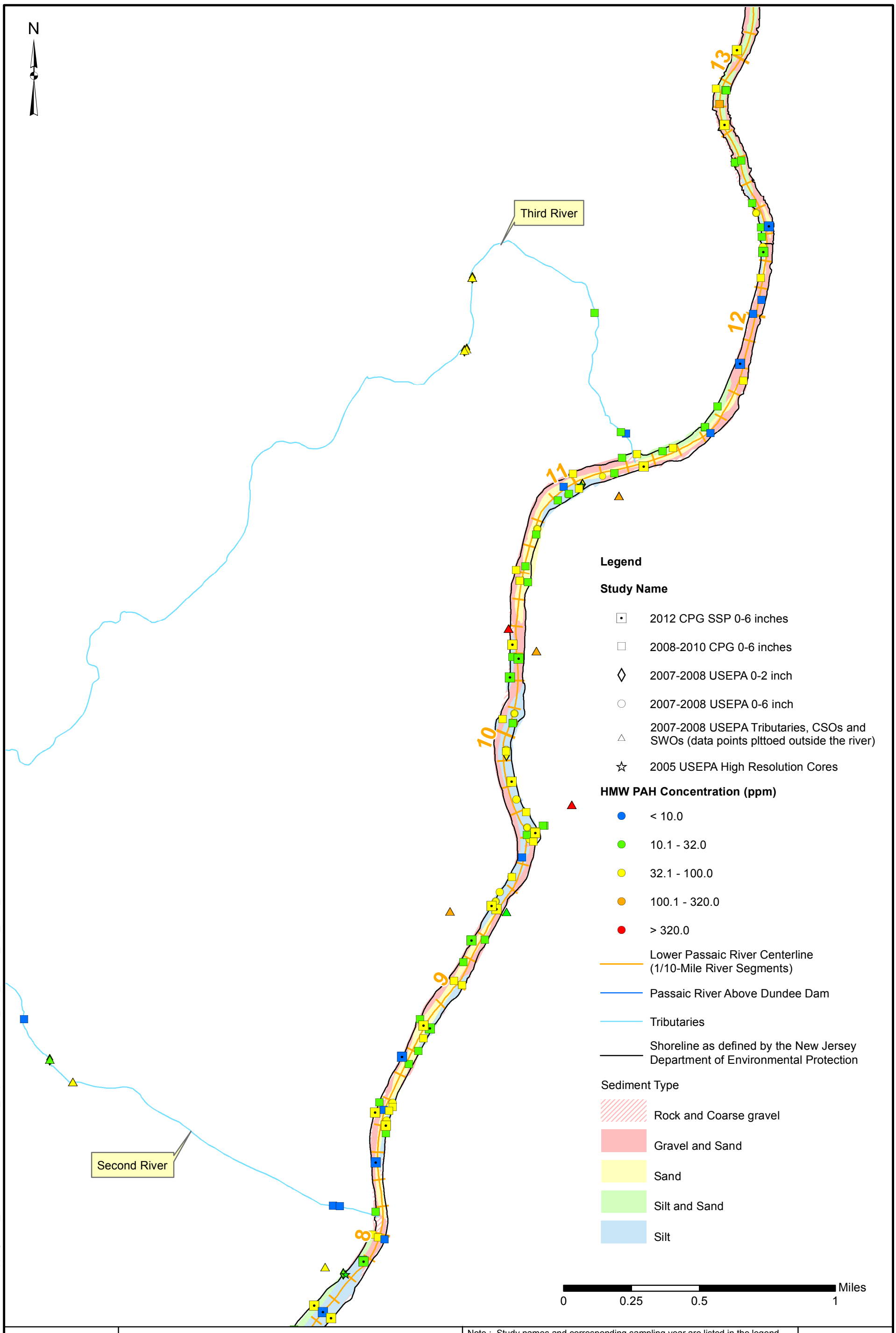
Total HMW PAH Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.3-2a

2014



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Total HMW PAH Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.3-2b

2014

Total HMW PAH Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.3-2c

2014

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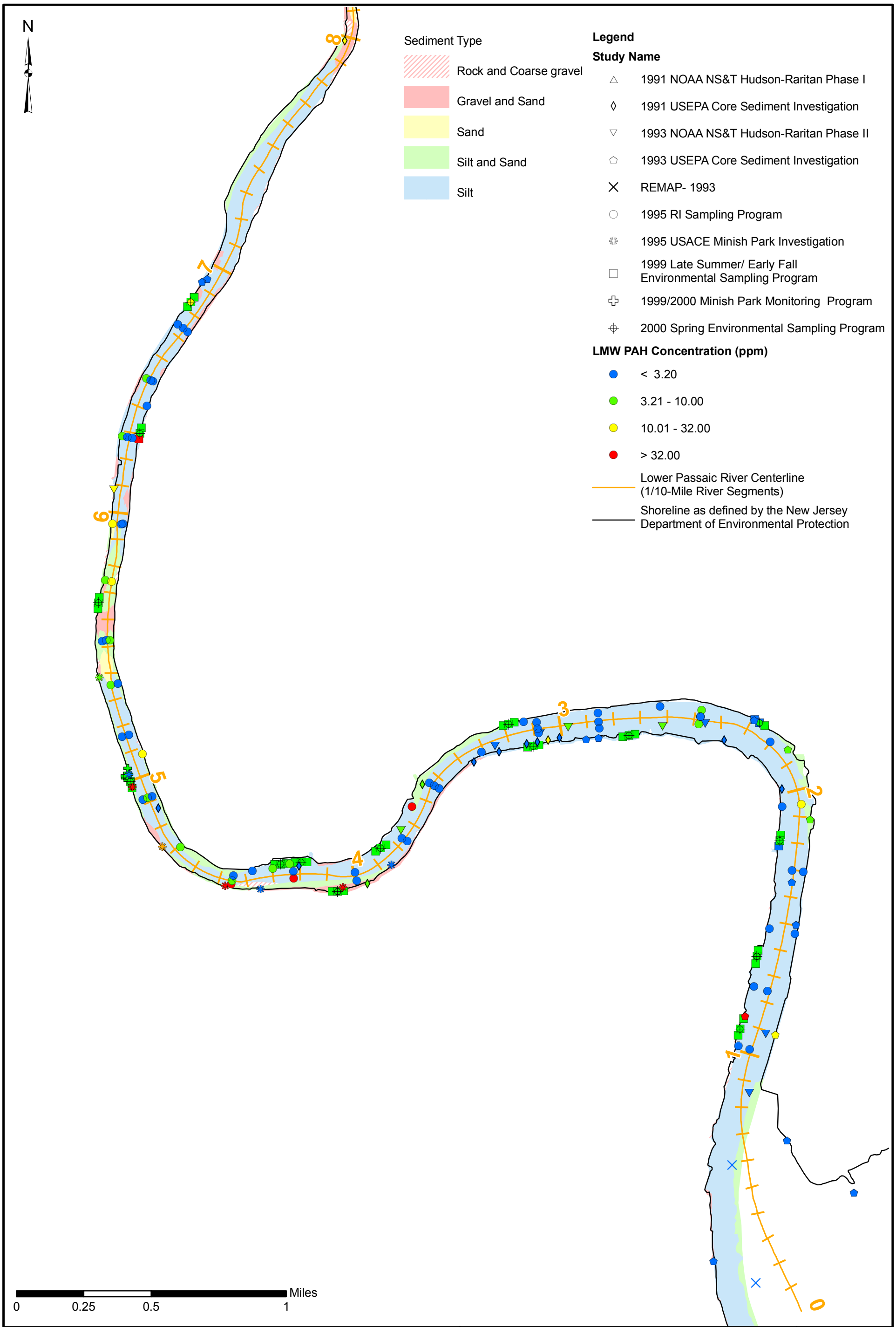


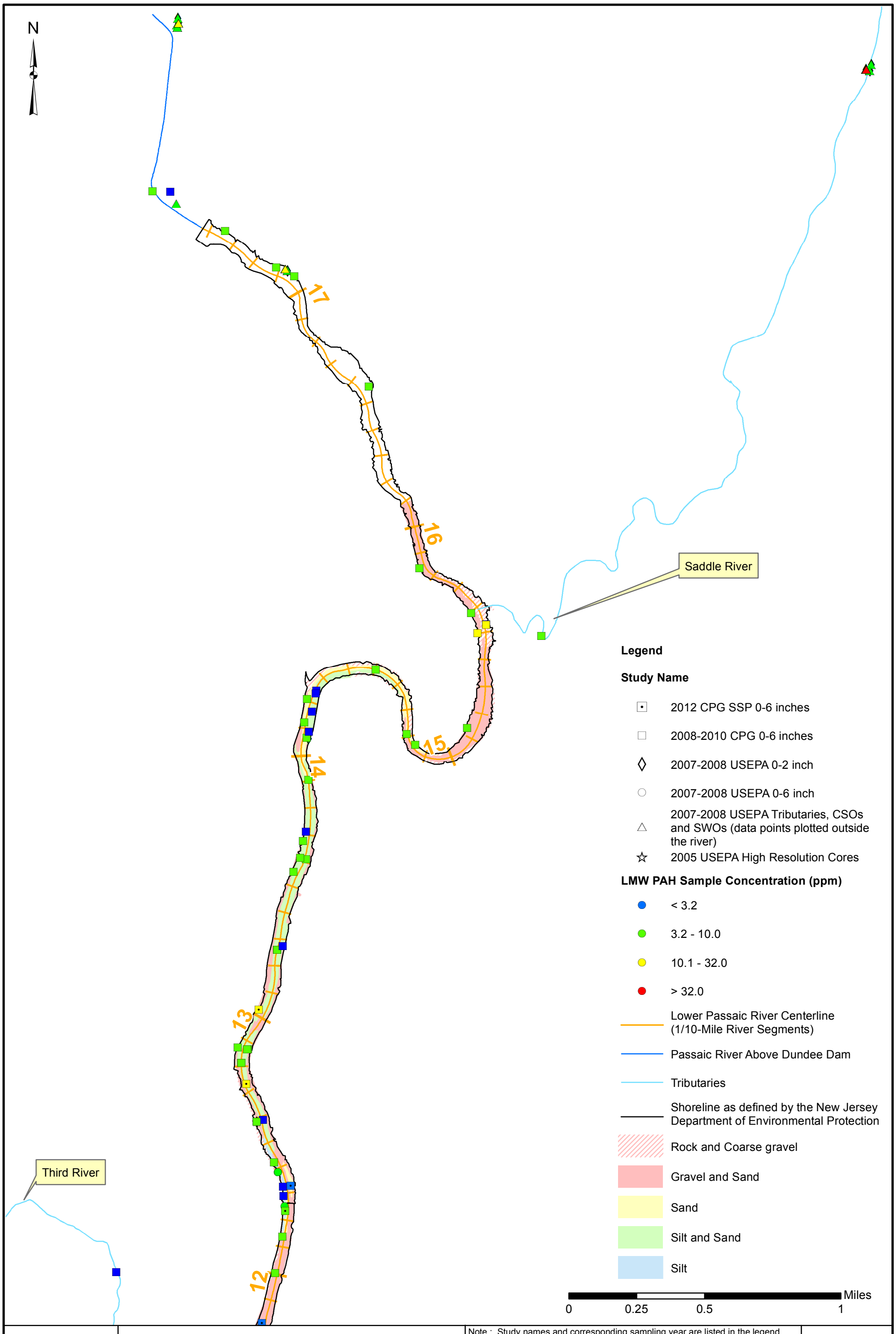
Total LMW PAH Surface Sediment Samples from 1991 to 2000

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.3-3

2014



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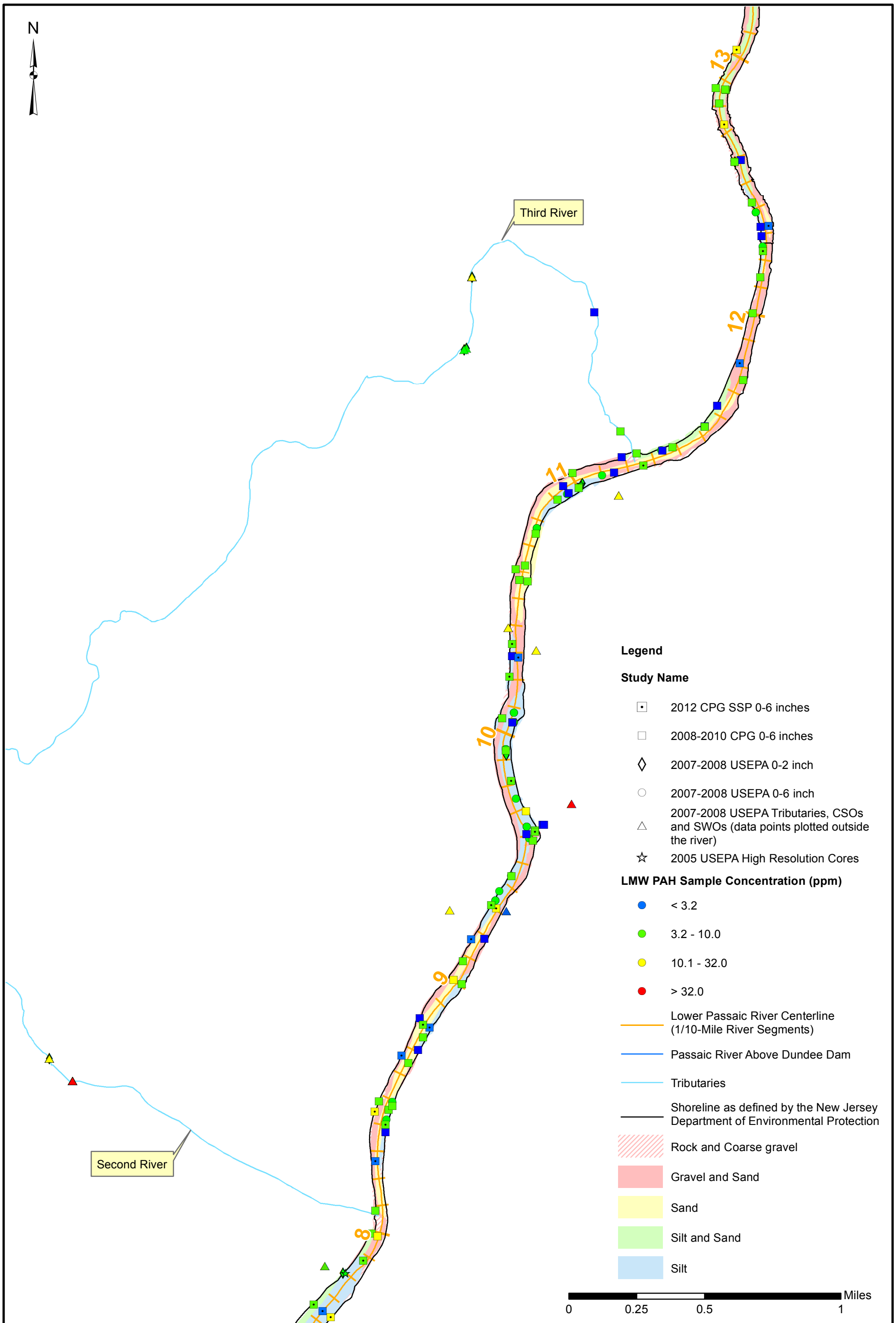
Total LMW PAH Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.3-4a

2014



Total LMW PAH Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.3-4b

2014

Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\HS mxd\LMW_PAH_Surficial_Sed_2005_2012.mxd

Total LMW PAH Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.3-4c

2014

Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\HS mxd\LMW_PAH_Surficial_Sed_2005_2012.mxd

Total PAH Surface Sediment Samples from 1991 to 2000

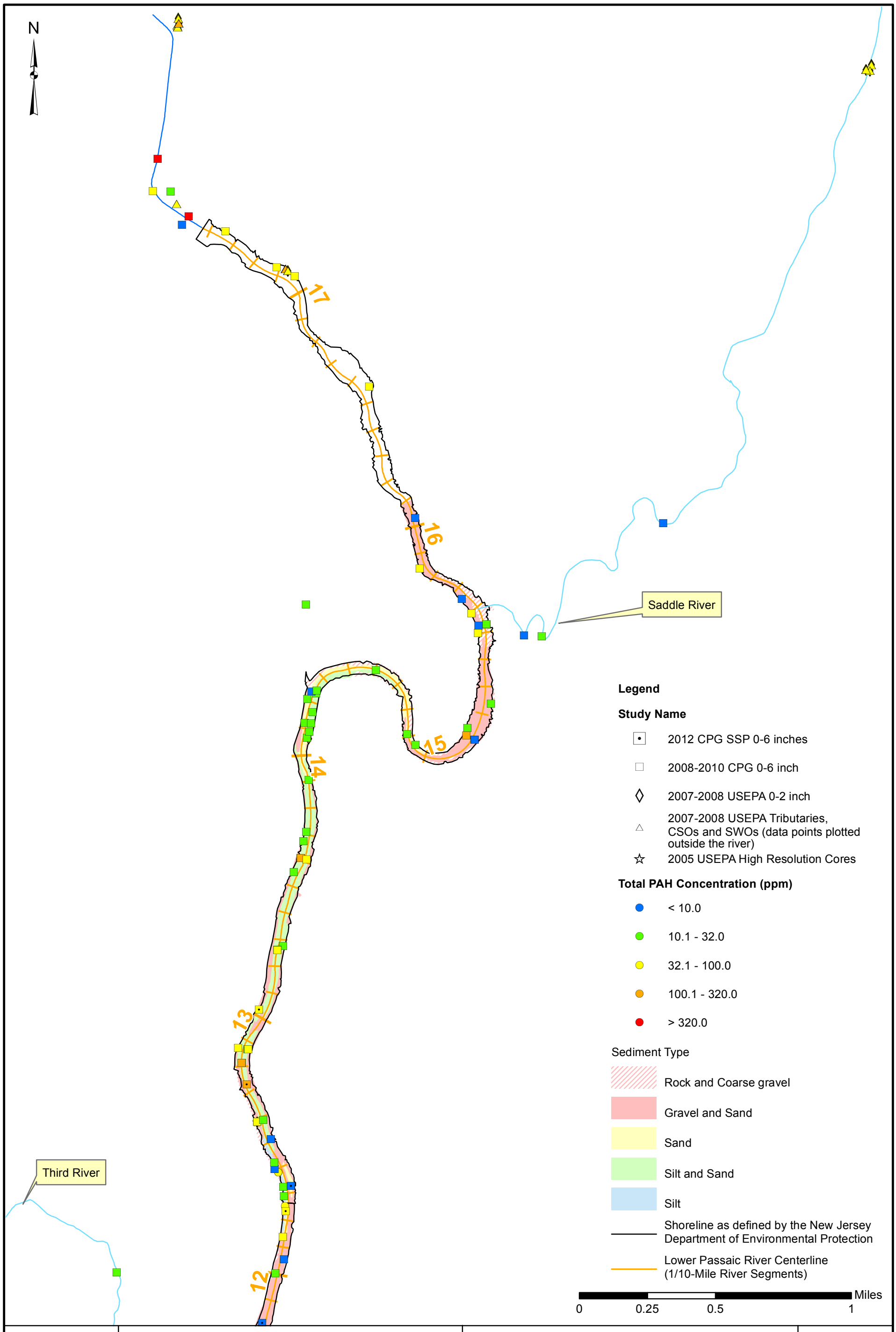
Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.3-5

2014

S:\Projects\passaic\MapDocuments\4553001-CERCLA\2012_Update\Total_PAH_Surficial_Sed_1991_2000



Total PAH Surface Sediment Samples from 2005 to 2012

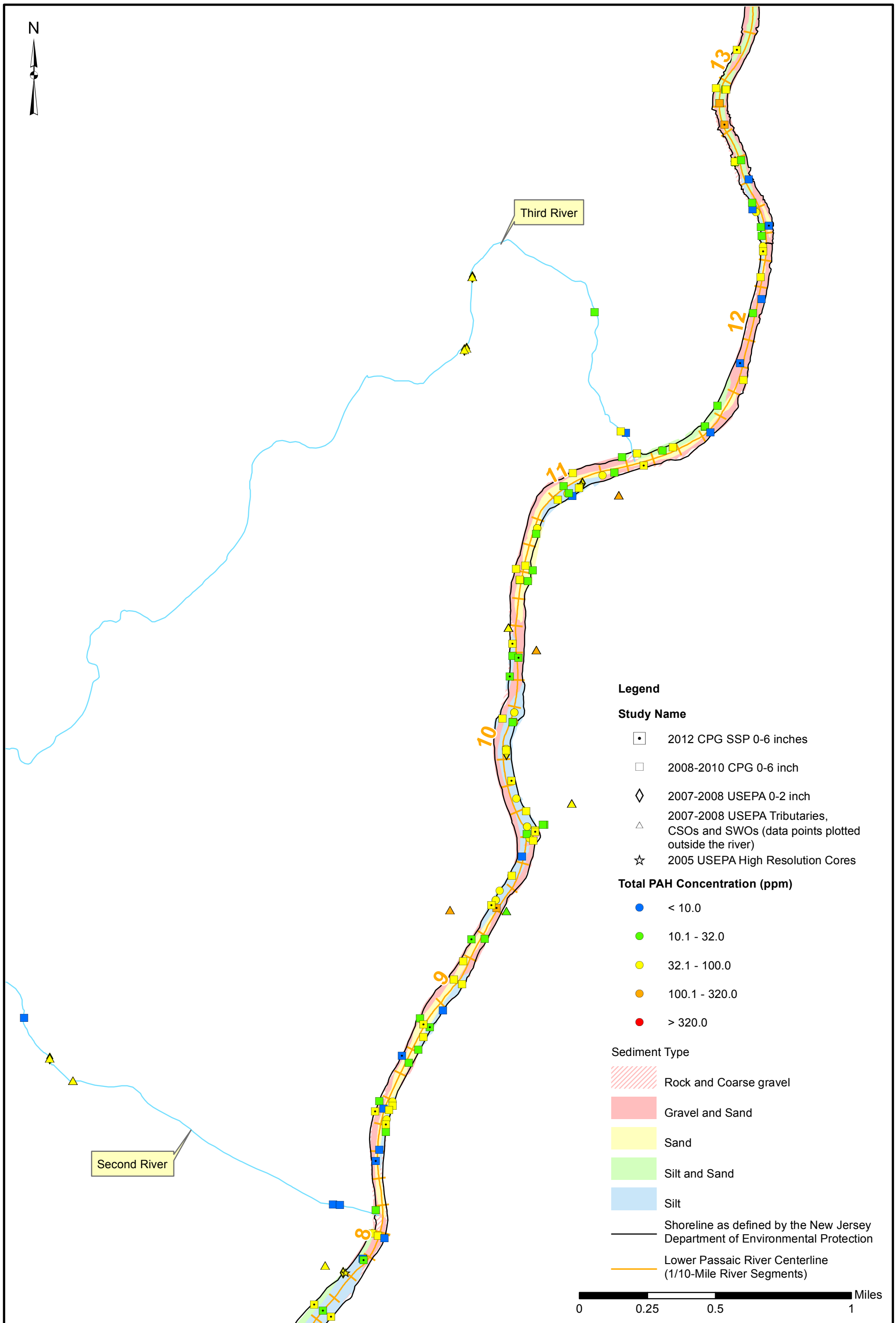
Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.3-6a

2014

Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\HS mxd\Total_PAH_Surficial_Sed_2005_2012.mxd



Total PAH Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.3-6b

2014

Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\HS mxd\Total_PAH_Surficial_Sed_2005_2012.mxd

Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\HS mxd\Total_PAH_Surficial_Sed_2005_2012.mxd

Total PAH Surface Sediment Samples from 2005 to 2012

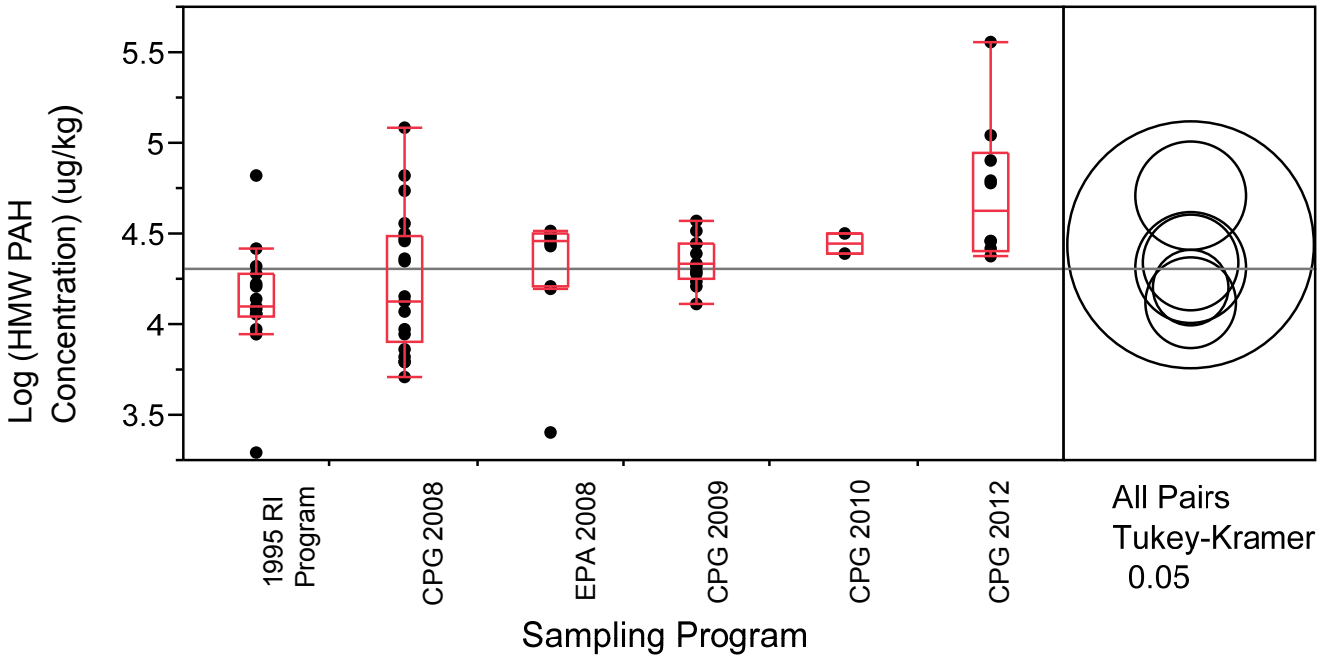
Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

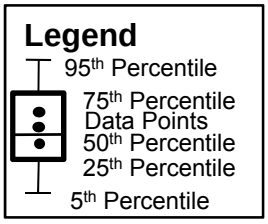
Figure 3.3-6c

2014

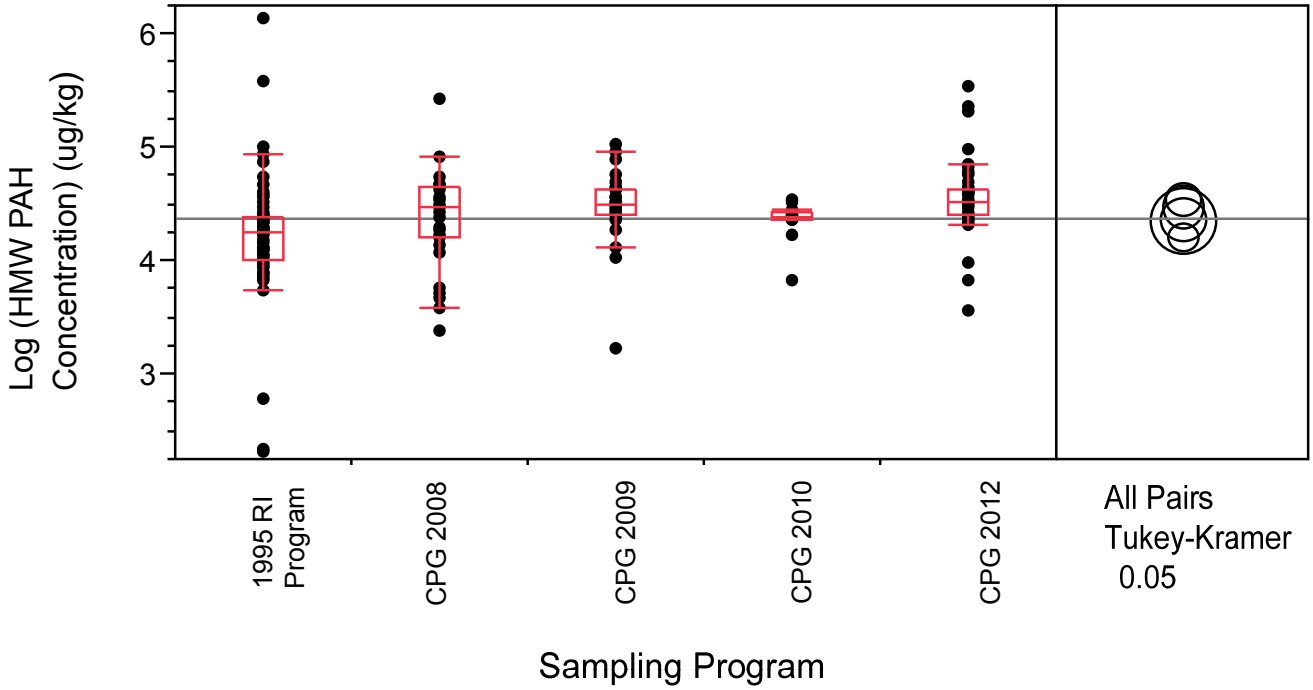
RM0 to RM2



Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.

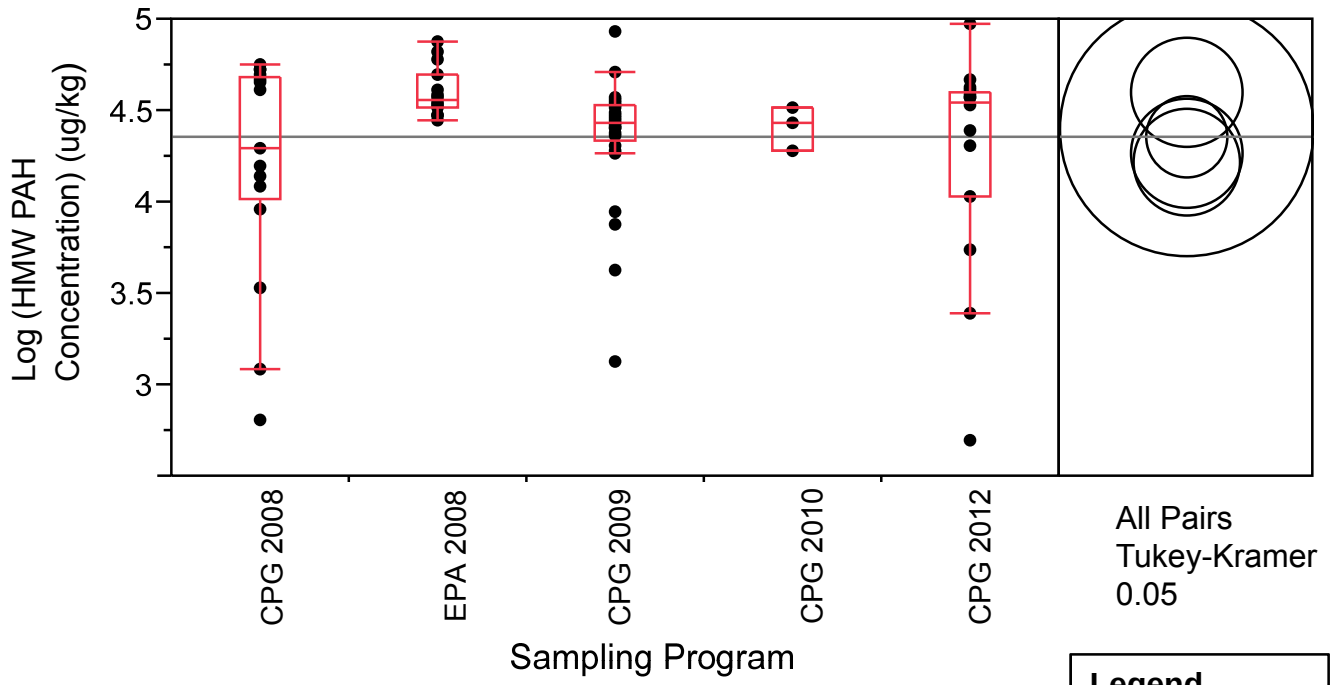


RM2 to RM8

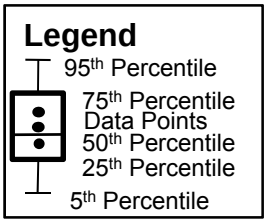


	HMW PAH (0-6 inch) by Sampling Program at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.3-7a** 2014

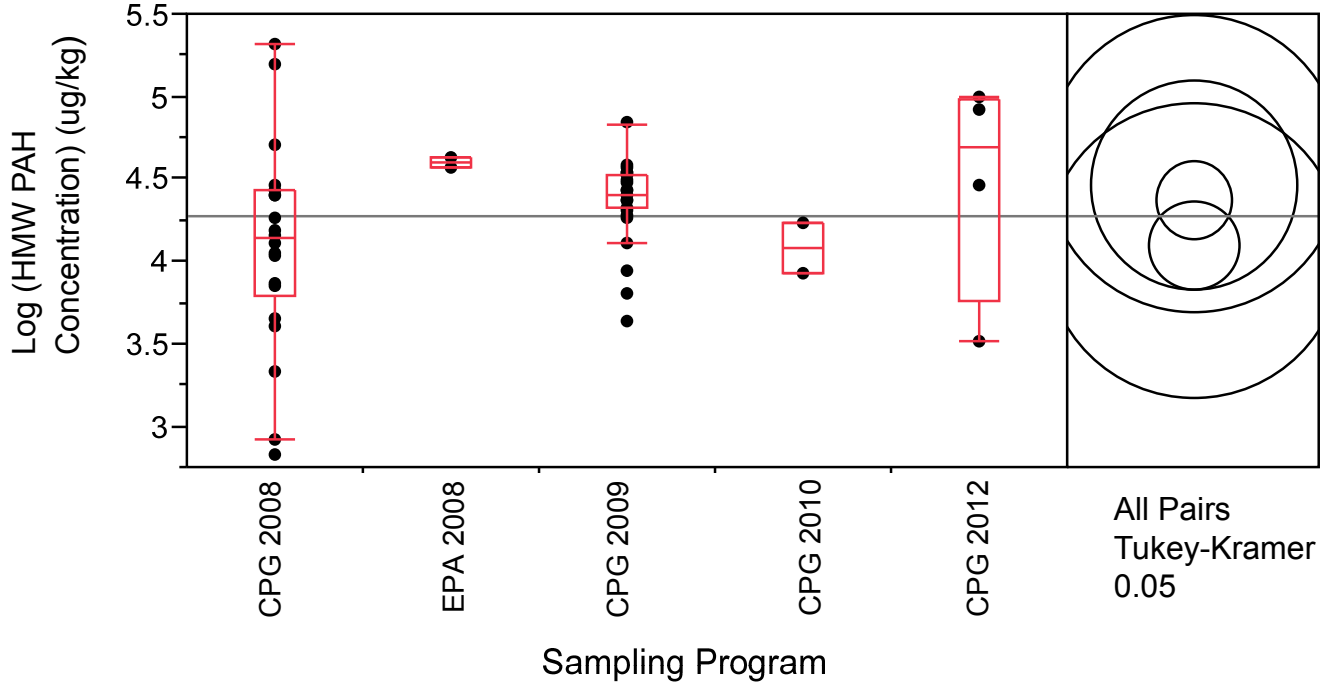
RM8 to RM12



Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.



RM12 to RM17.4



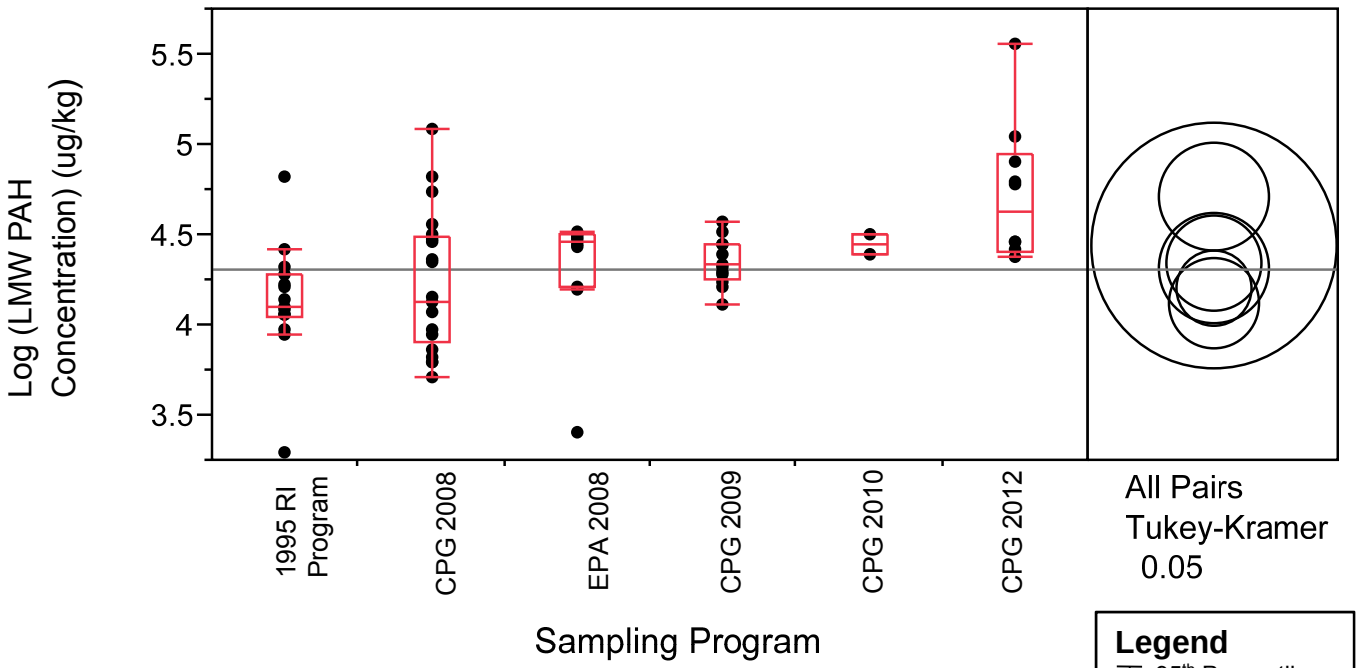
HMW PAH (0-6 inch) by Sampling Program at RM8 to RM12 and RM12 to RM17.4

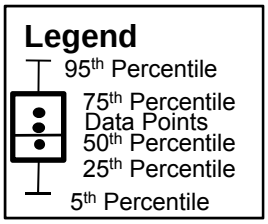
Lower Eight Miles of the Lower Passaic River

Figure 3.3-7b

2014

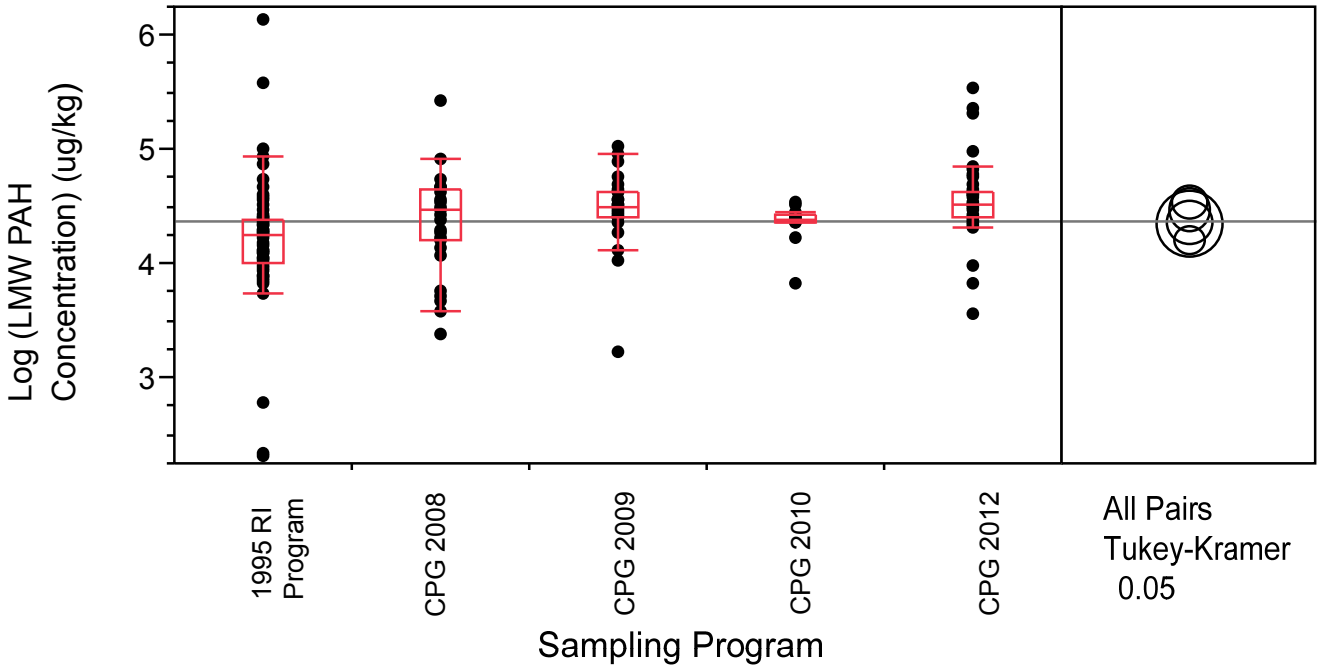
RM0 to RM2





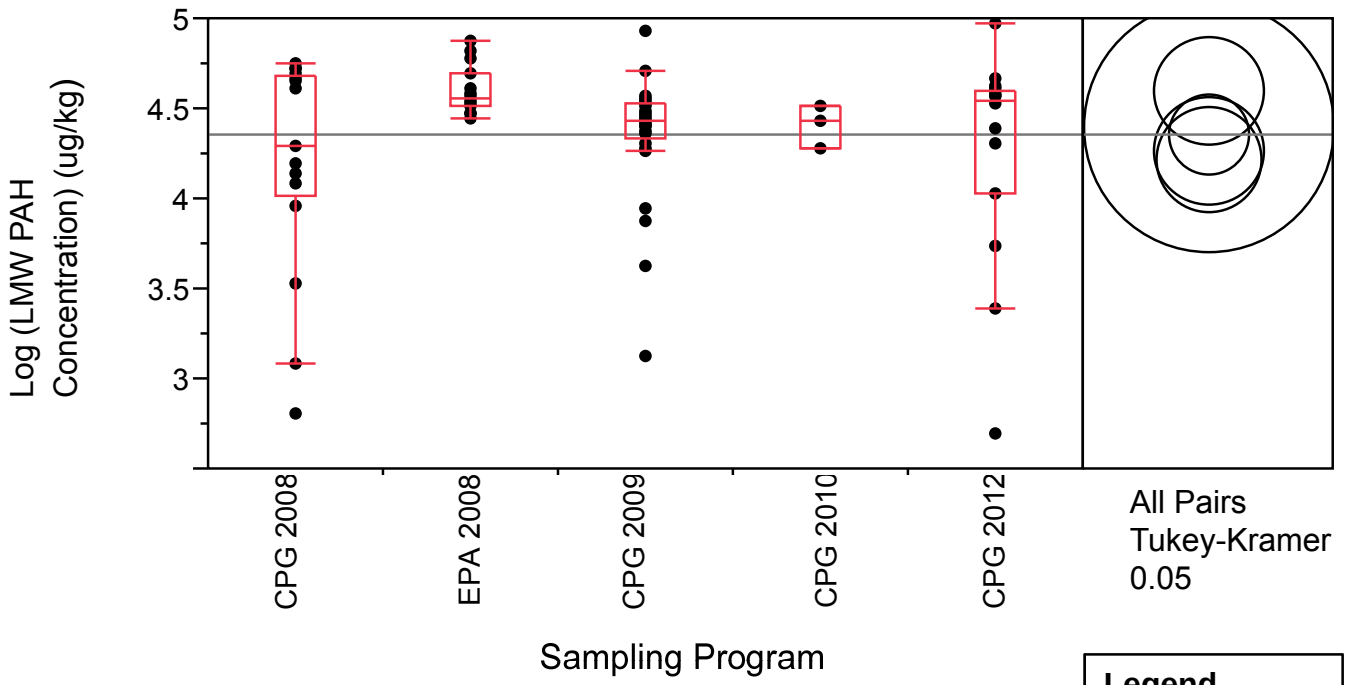
Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.

RM2 to RM8

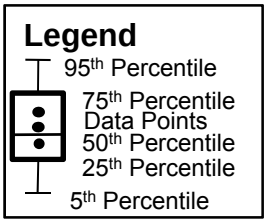


	LMW PAH (0-6 inch) by Sampling Program at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.3-8a** 2014

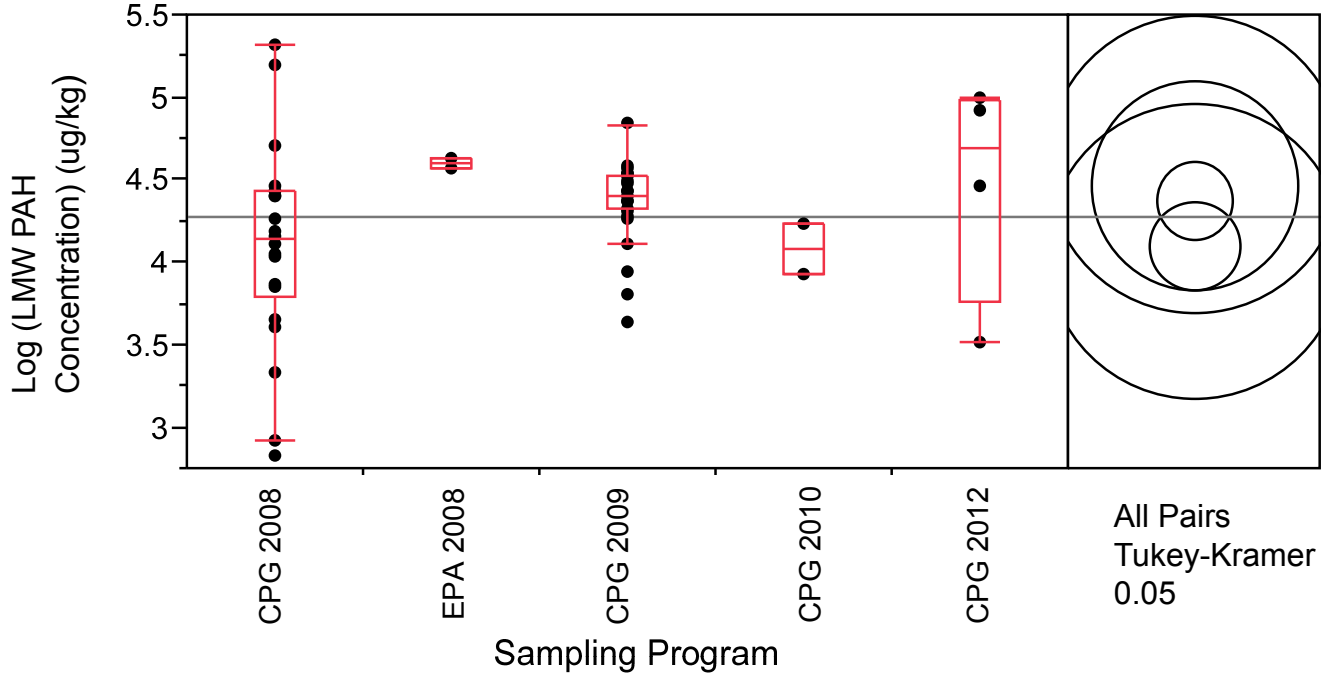
RM8 to RM12



Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.

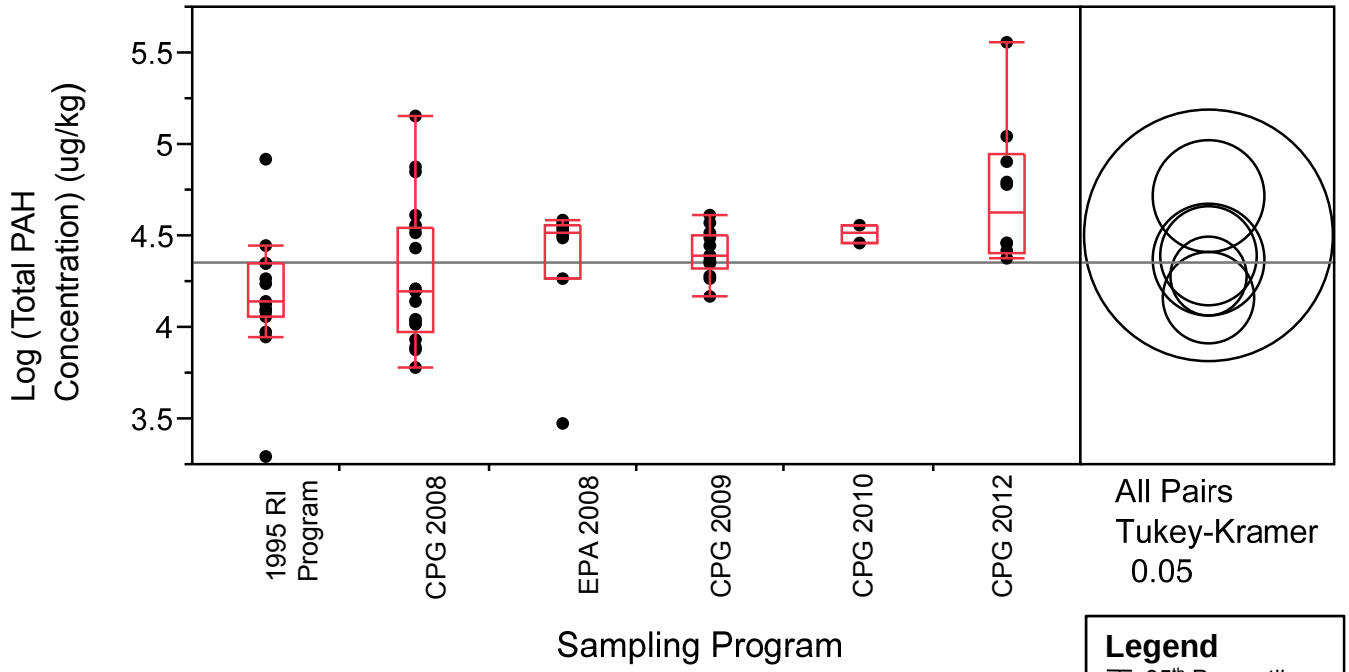


RM12 to RM17.4

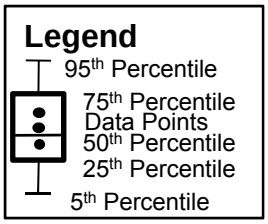


	LMW PAH (0-6 inch) by Sampling Program at RM8 to RM12 and RM12 to RM17.4 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.3-8b** 2014

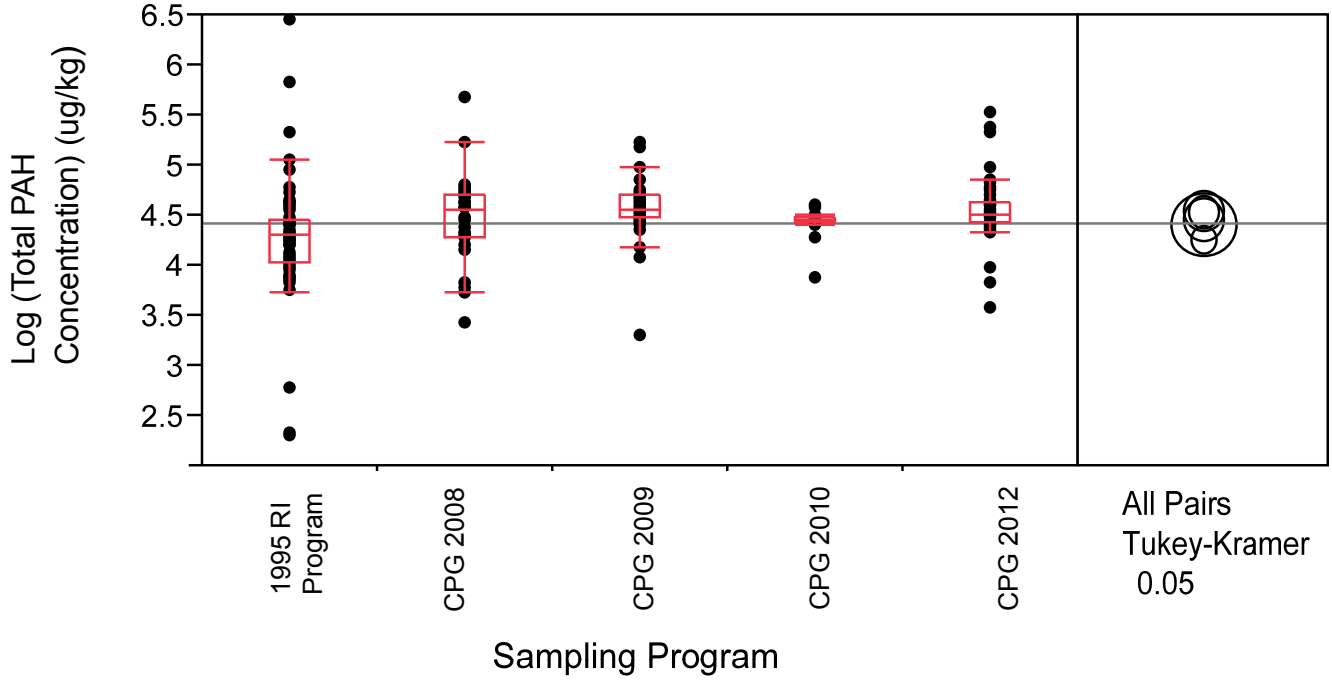
RM0 to RM2



Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.

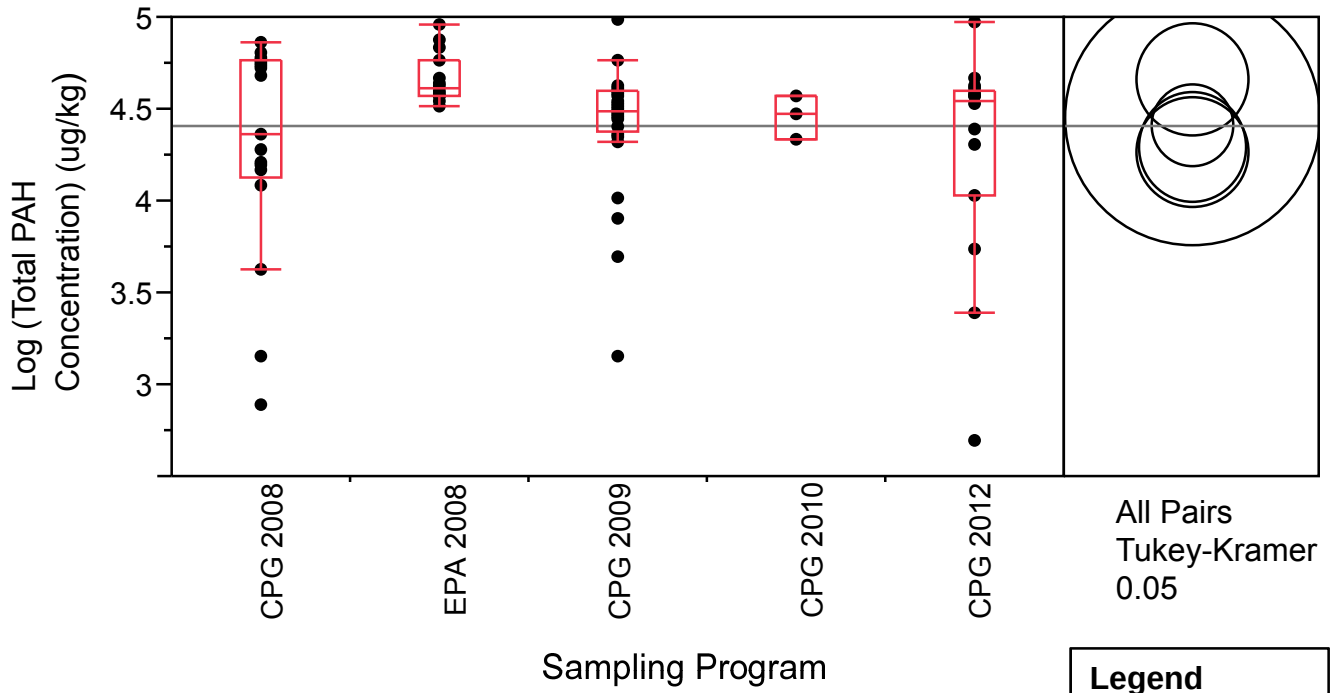


RM2 to RM8

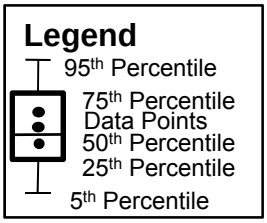


	Total PAH (0-6 inch) by Sampling Program at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.3-9a** 2014

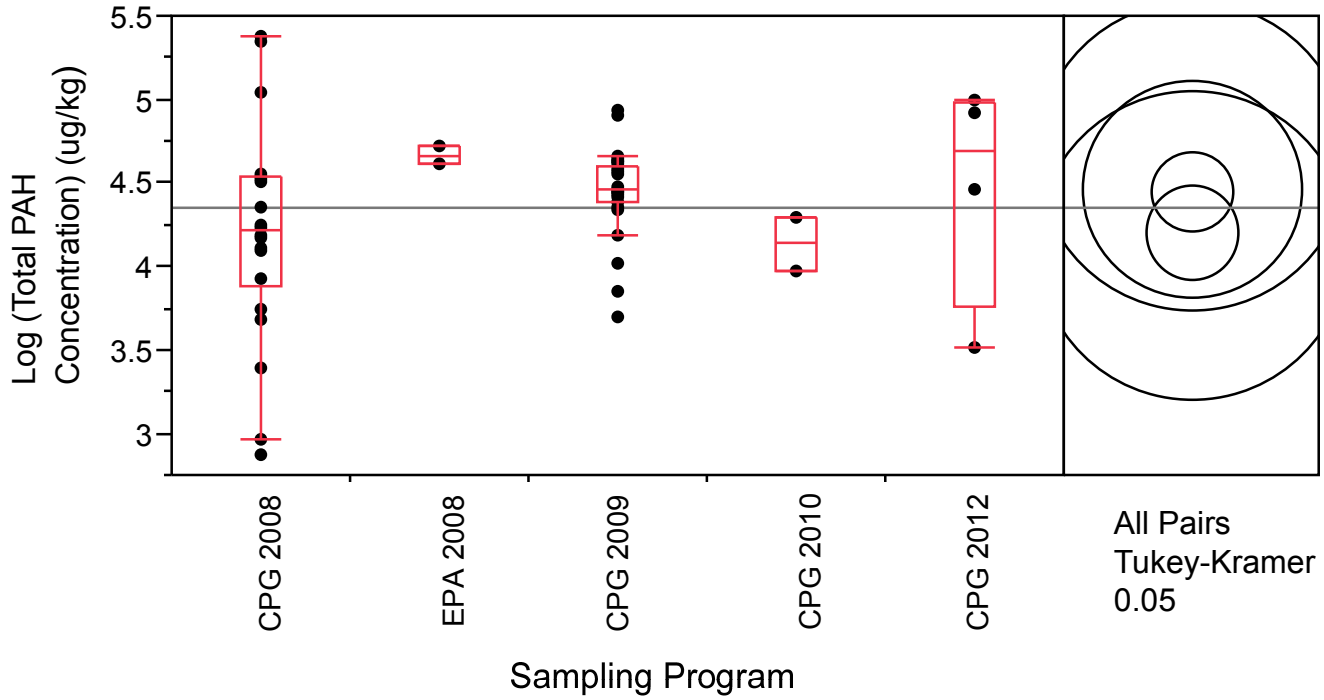
RM8 to RM12



Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.



RM12 to RM17.4

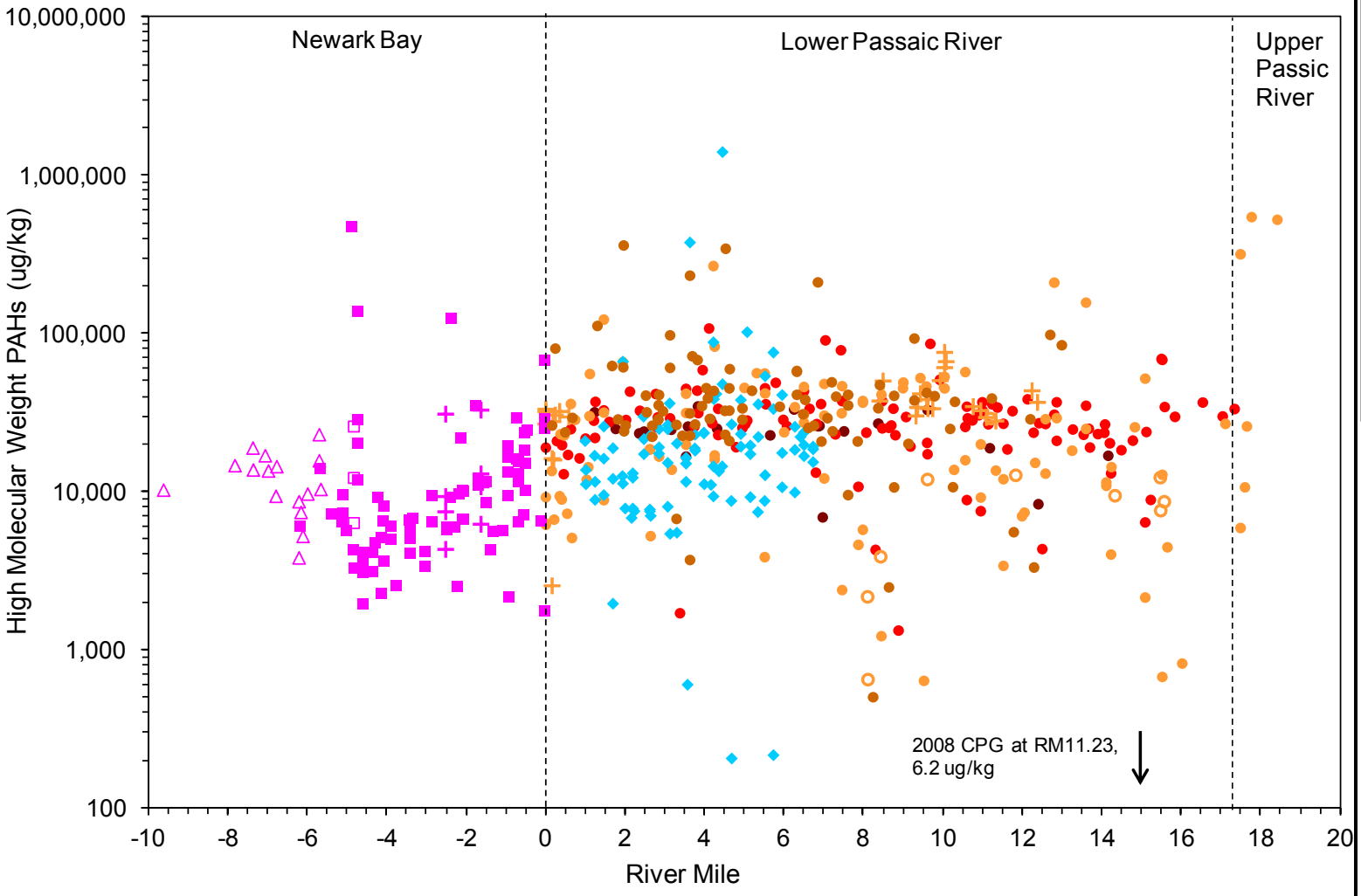


Total PAH (0-6 inch) by Sampling Program at RM8 to RM12 and RM12 to RM17.4

Lower Eight Miles of the Lower Passaic River

Figure 3.3-9b

2014



Legend

- 2012 CPG
- 2010 CPG
- 2009 CPG
- 2008 CPG
- 2008 CPG Tributary Below HoT
- 2008 EPA
- 2005&2007 Newark Bay
- 2005&2007 Shooters Island & Arthur Kill
- 2005&2007 Kill Van Kull
- 2005&2007 Port Elizabeth & Newark
- 1995 TSI

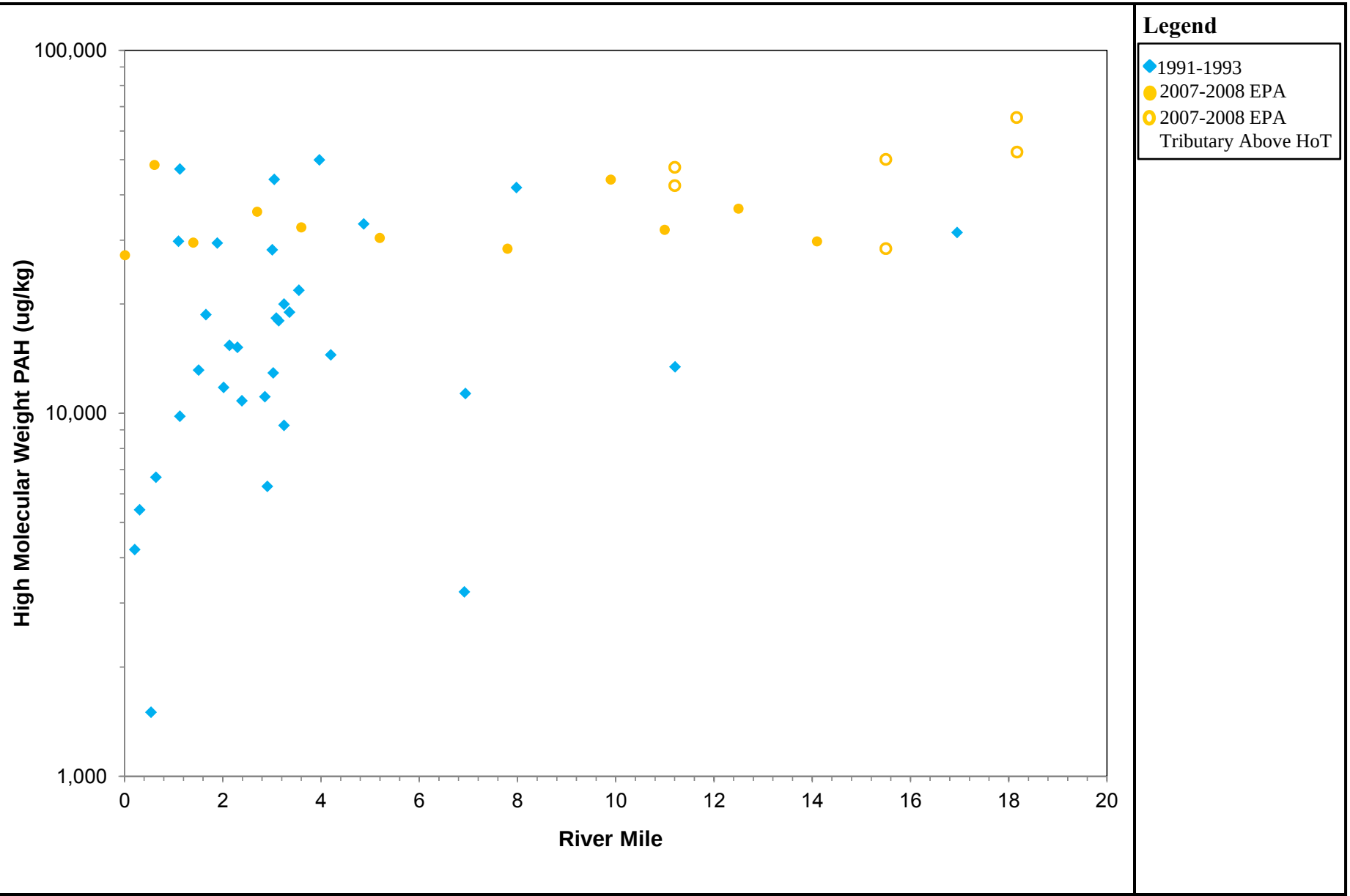
HMW PAH Concentration (0-6 inches) *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 3.3-10

2014

R2-0027189



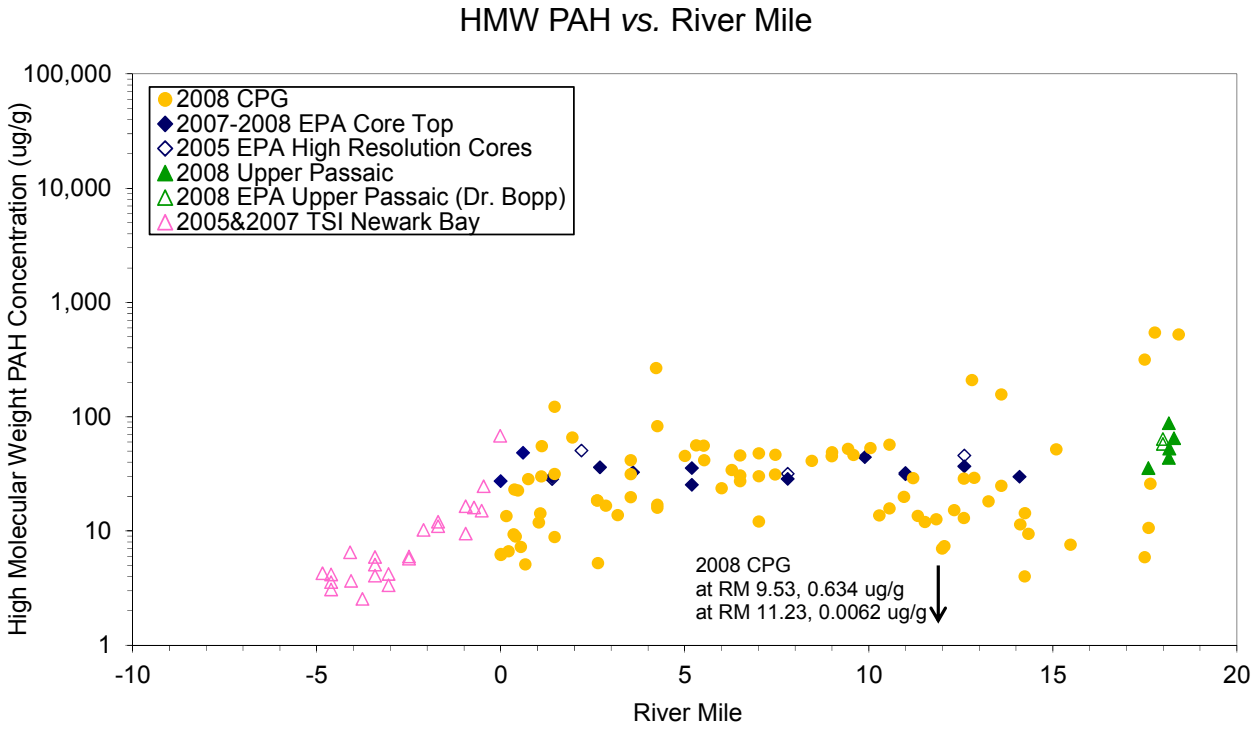
HMW PAH Concentration (0 - ≤2 inches) *vs.* River Mile

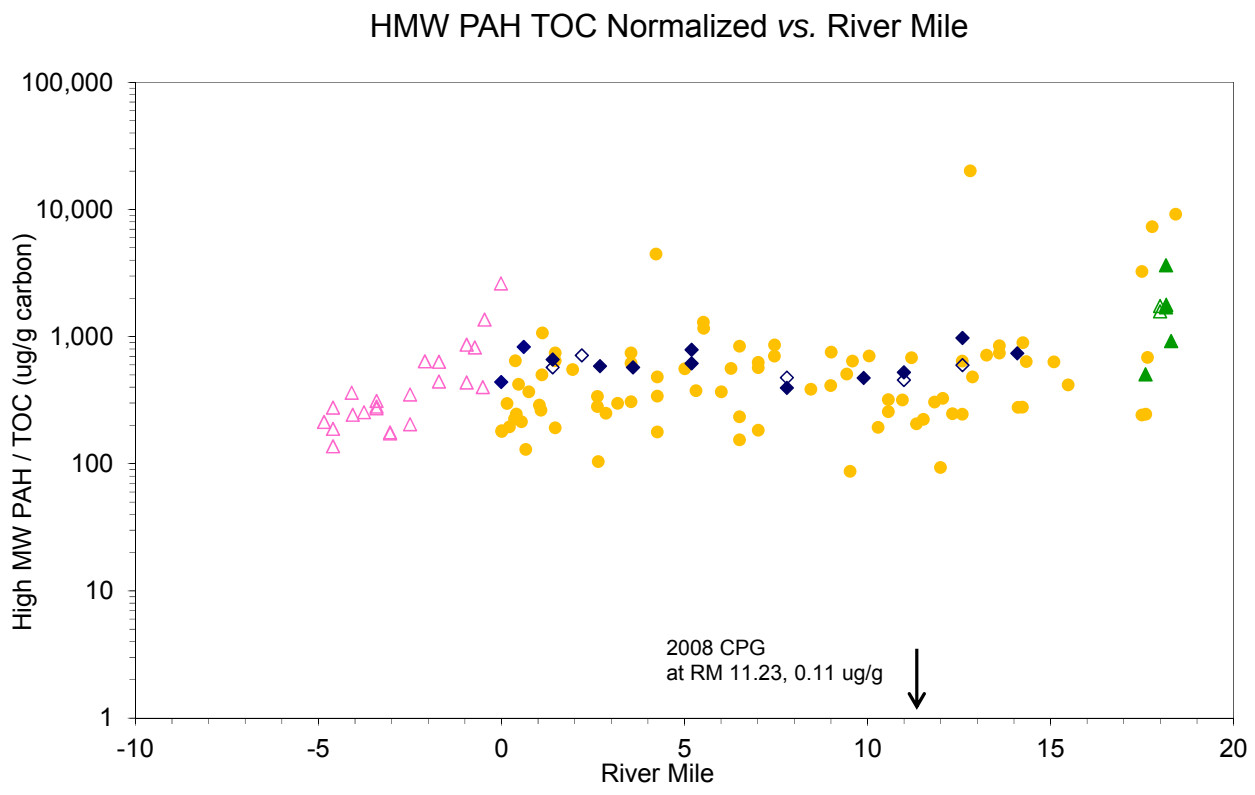
Lower Eight Miles of the Lower Passaic River

Figure 3.3-11

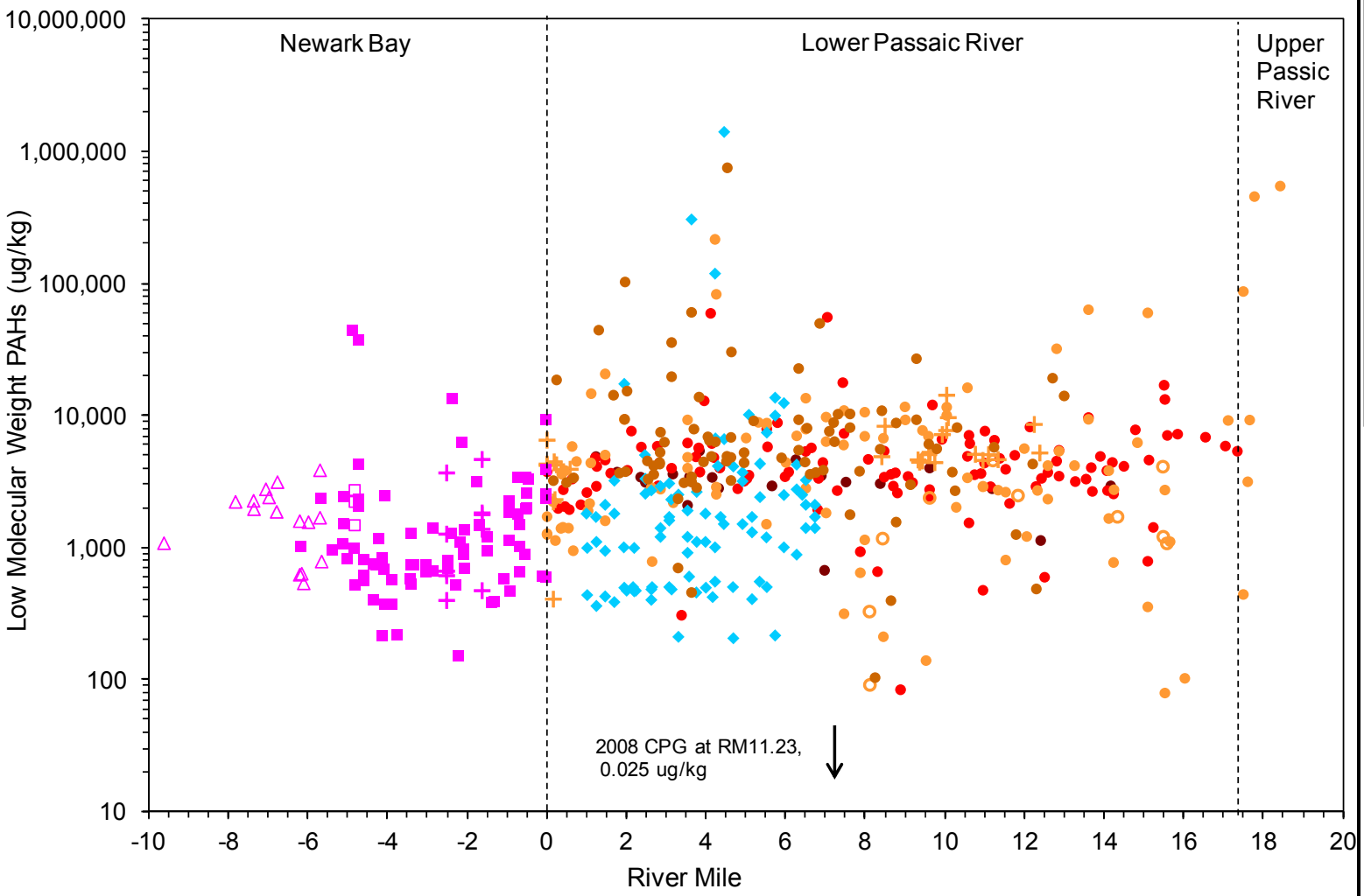
2014

R2-0027190





	HMW PAH in Recently-Deposited Sediments in the Lower Passaic River, Newark Bay and the Upper Passaic River *Lower Eight Miles of the Passaic River*	**Figure 3.3-12** 2014



Legend

- 2012 CPG
- 2010 CPG
- 2009 CPG
- 2008 CPG
- 2008 CPG Tributary Below HoT
- 2008 EPA
- 2005&2007 Newark Bay
- 2005&2007 Shooters Island & Arthur Kill
- 2005&2007 Kill Van Kull
- 2005&2007 Port Elizabeth & Newark
- 1995 TSI

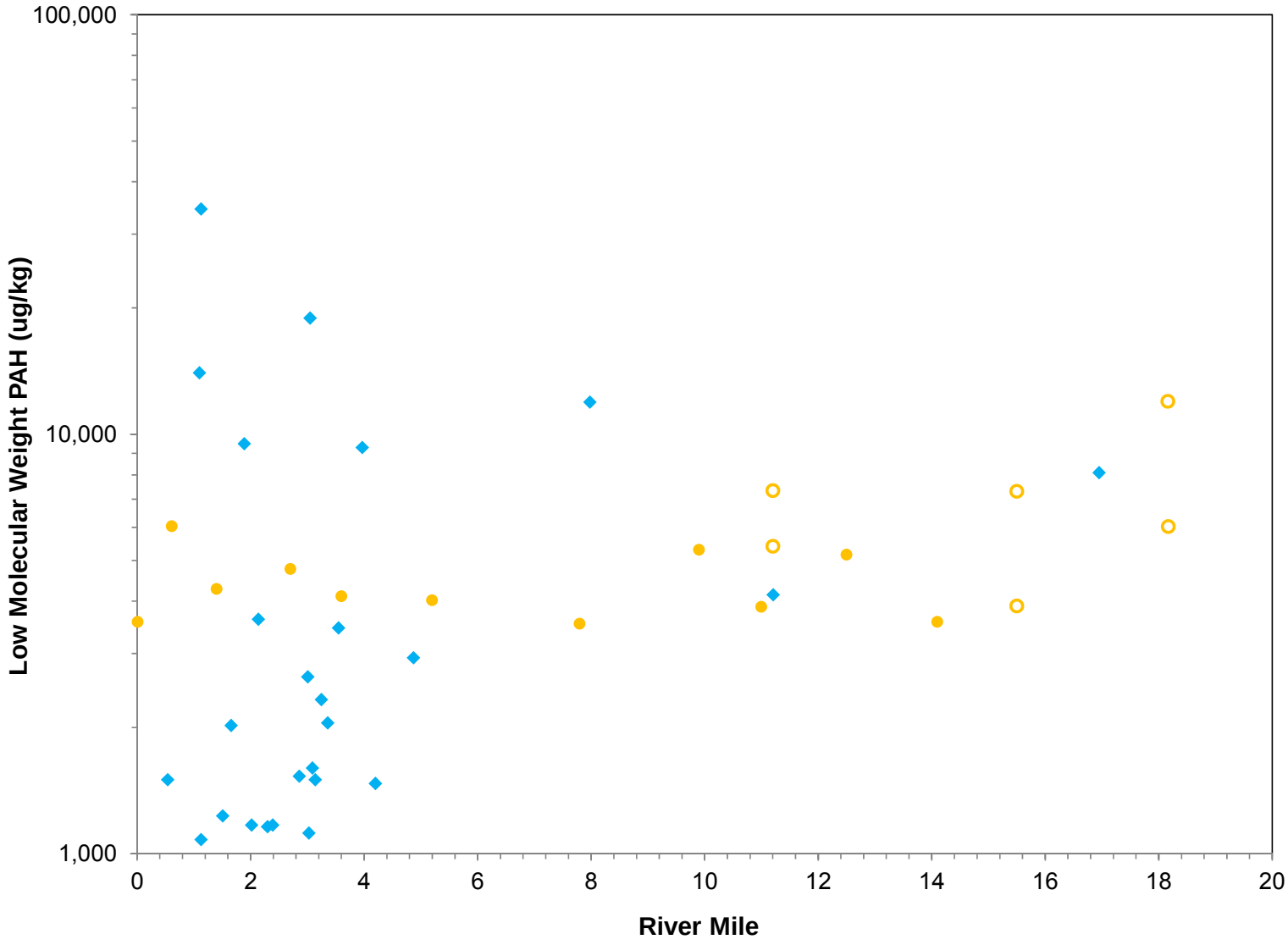
LMW PAH Concentration (0-6 inches) *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 3.3-13

2014

R2-0027192



Legend

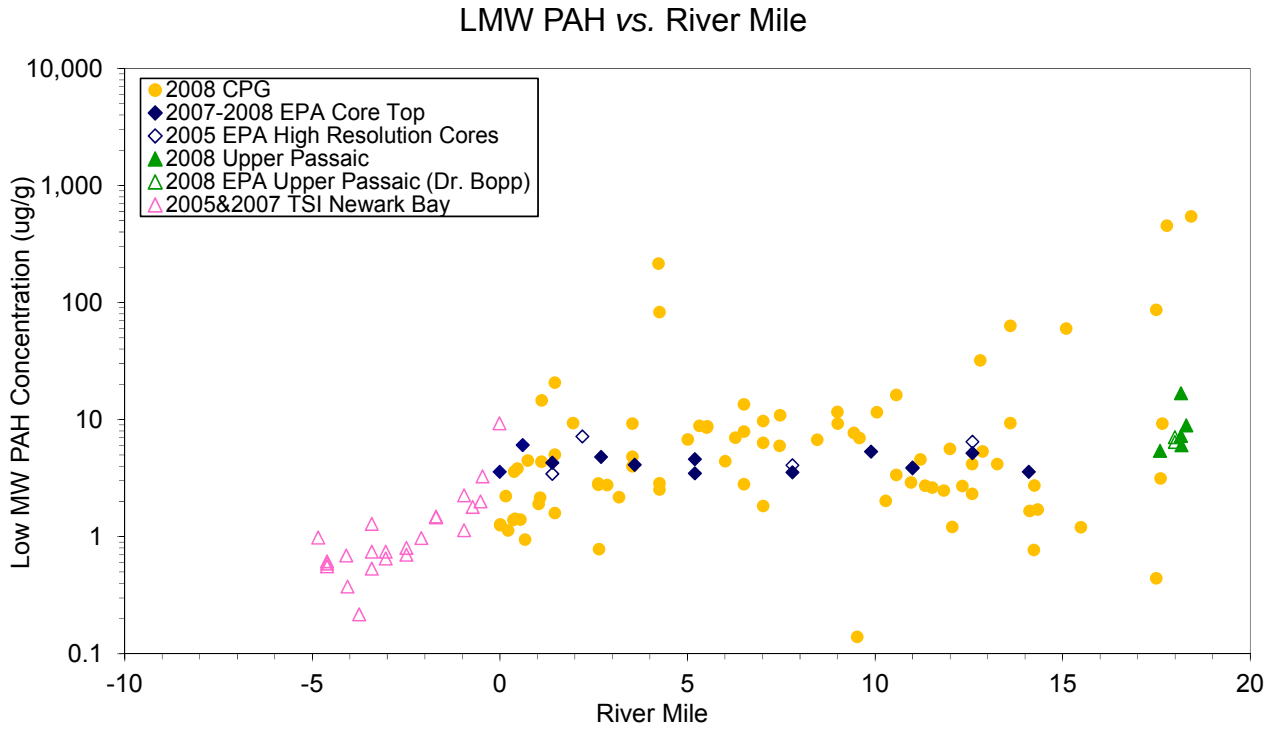
- 1991-1993
- 2007-2008 EPA
- 2007-2008 EPA Tributary Above HoT

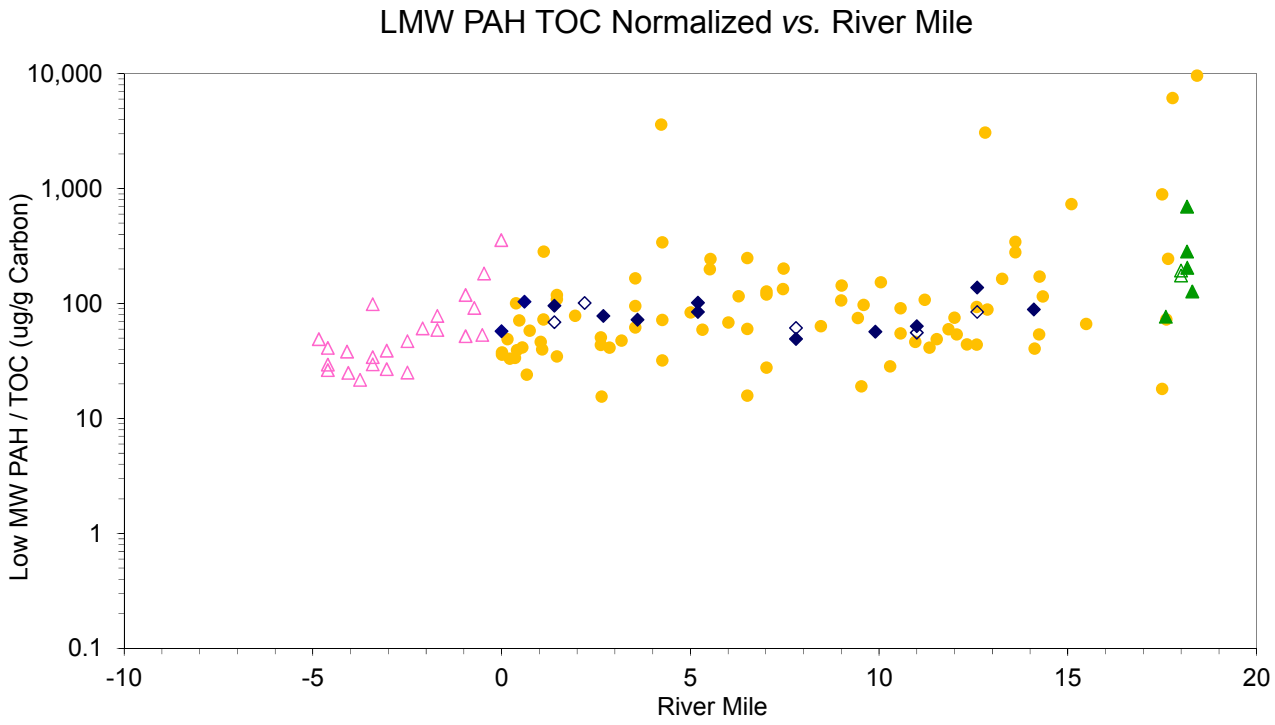
LMW PAH Concentration (0 - ≤2 inches) *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

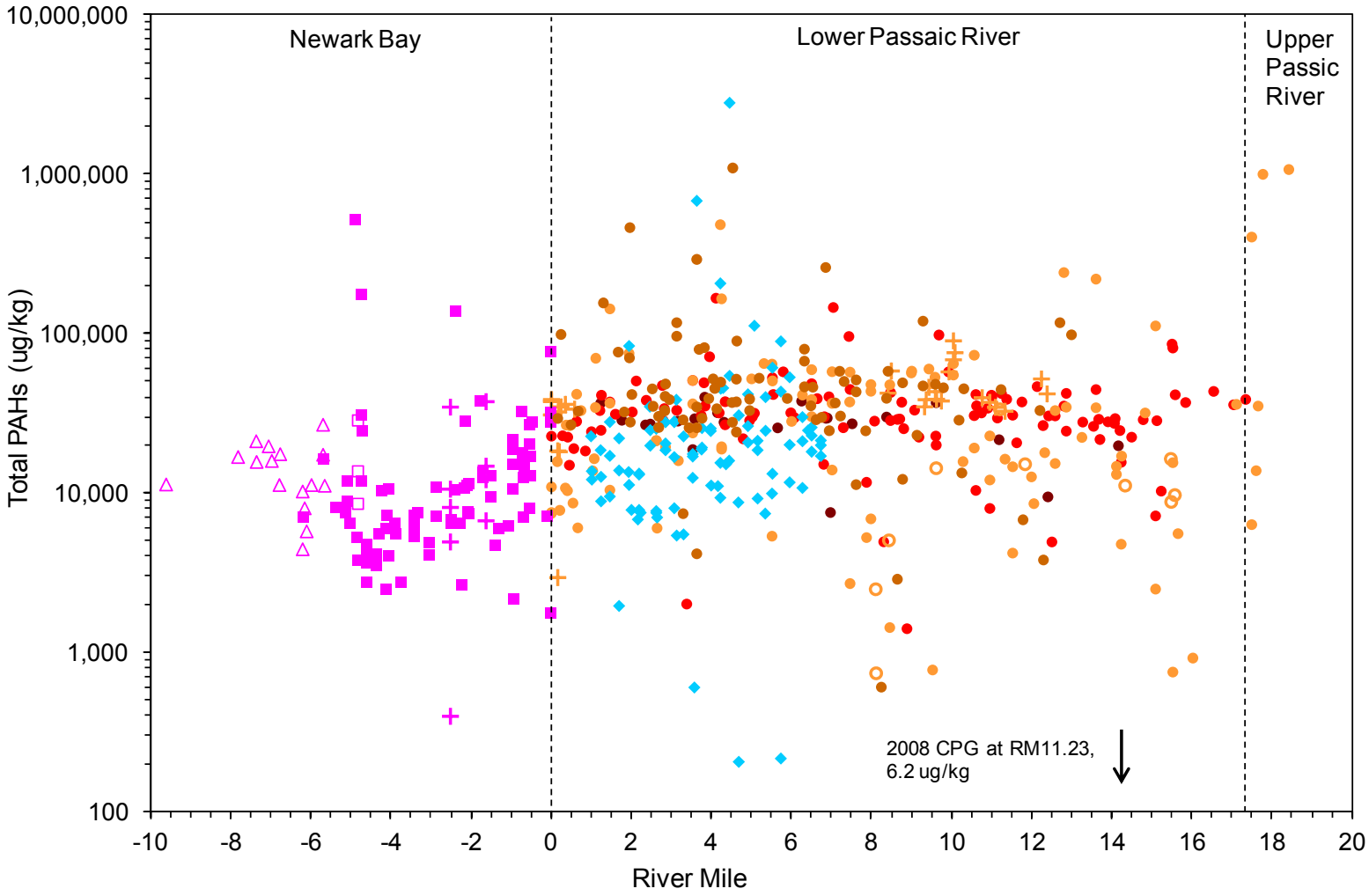
Figure 3.3-14

2014





	LMW PAH in Recently-Deposited Sediments in the Lower Passaic River, Newark Bay and the Upper Passaic River *Lower Eight Miles of the Passaic River*	**Figure 3.3-15** 2014



Legend

- 2012 CPG
- 2010 CPG
- 2009 CPG
- 2008 CPG
- 2008 CPG Tributary Below HoT
- 2008 EPA
- 2005&2007 Newark Bay
- 2005&2007 Shooters Island & Arthur Kill
- 2005&2007 Kill Van Kull
- 2005&2007 Port Elizabeth & Newark
- 1995 TSI

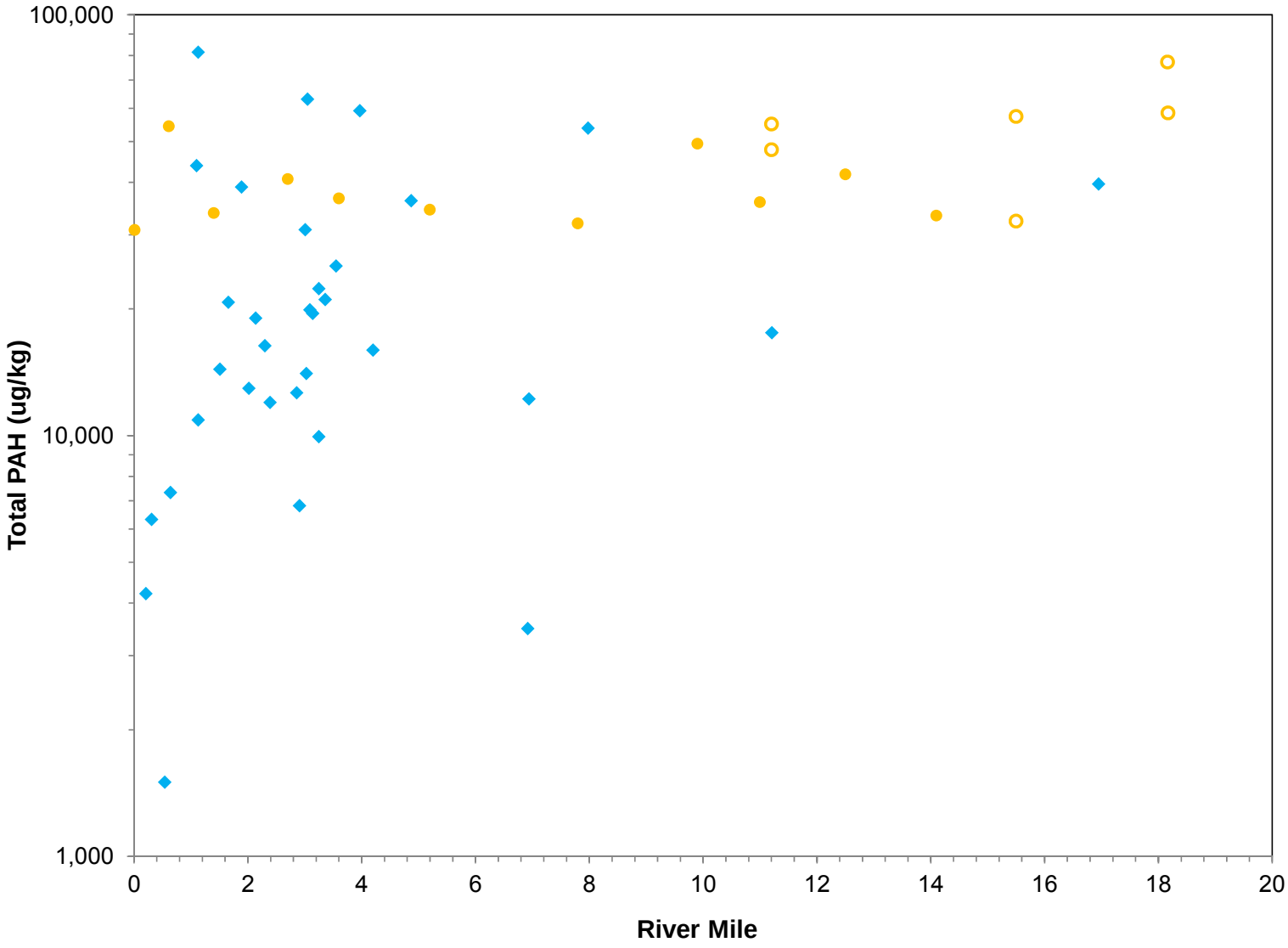
Total PAH Concentration (0-6 inches) *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 3.3-16

2014

R2-0027195



Legend

- 1991-1993
- 2007-2008 EPA
- 2007-2008 EPA Tributary Above HoT

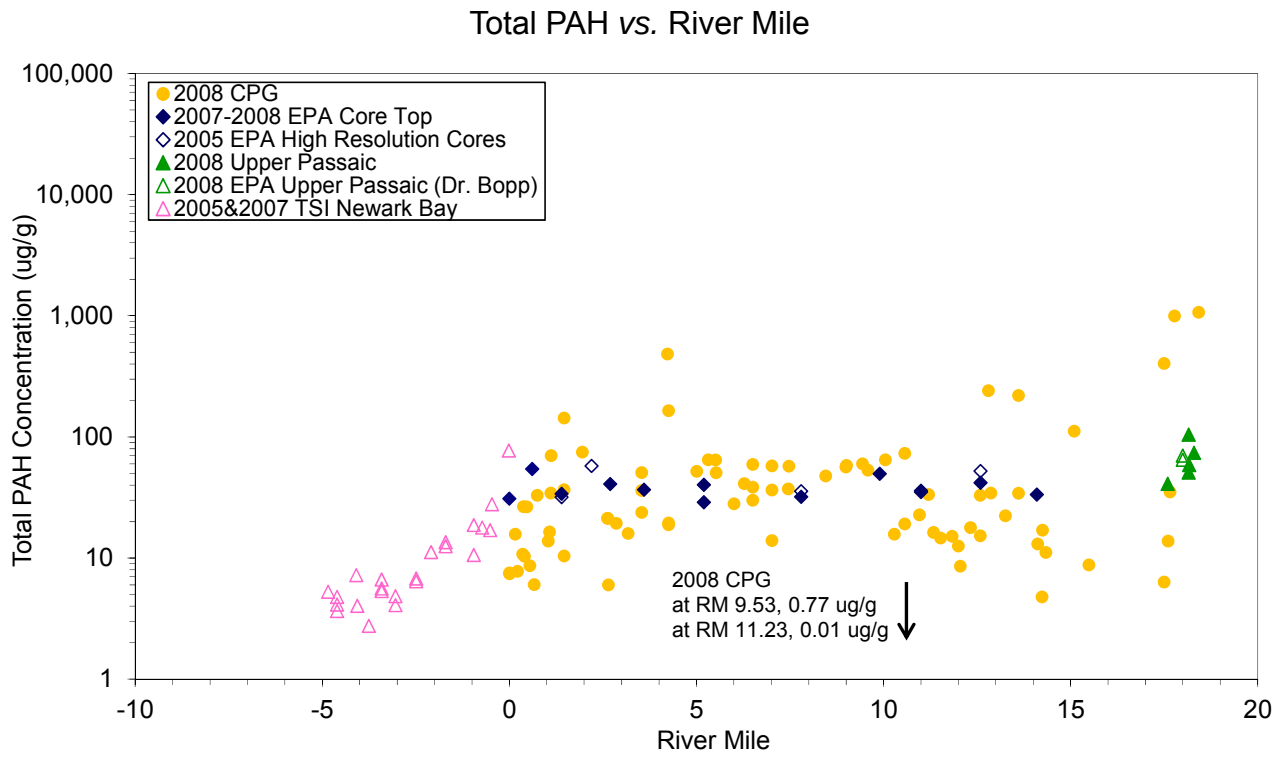
Total PAH Concentration (0 - ≤2 inches) *vs.* River Mile

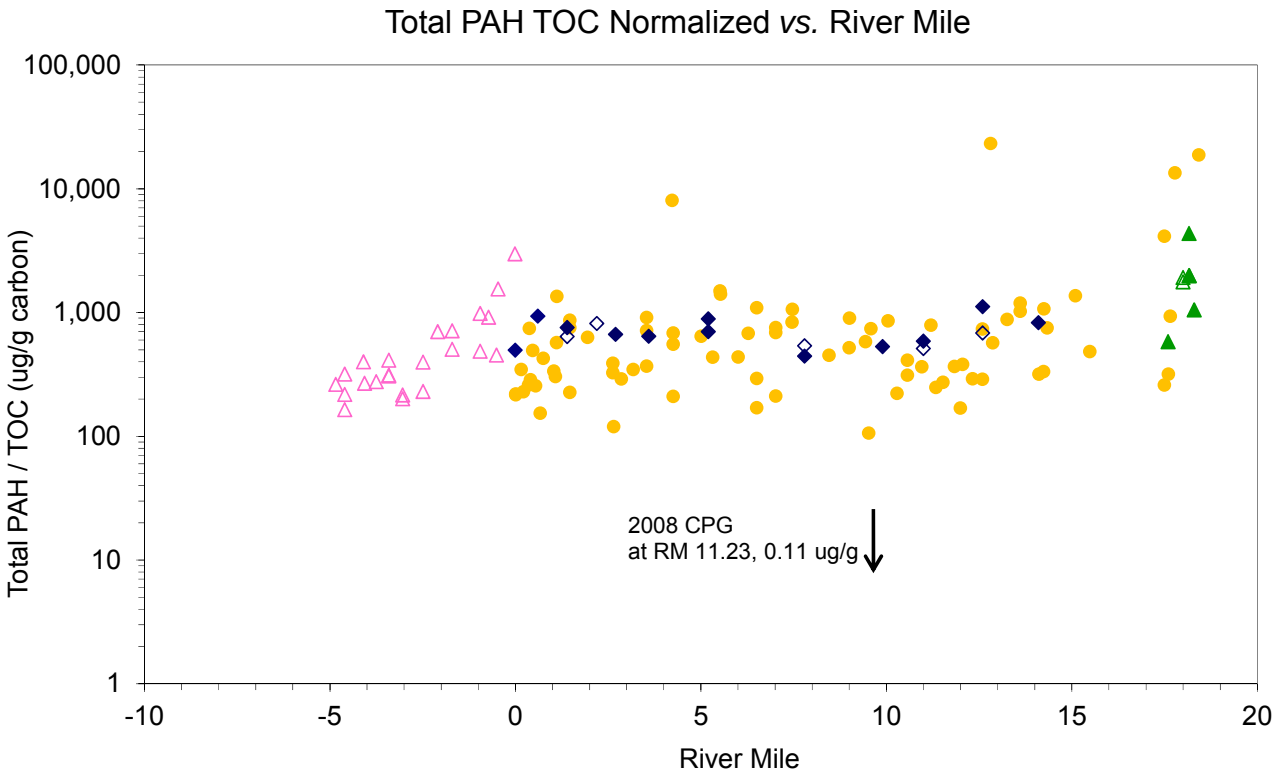
Lower Eight Miles of the Lower Passaic River

Figure 3.3-17

2014

R2-0027196





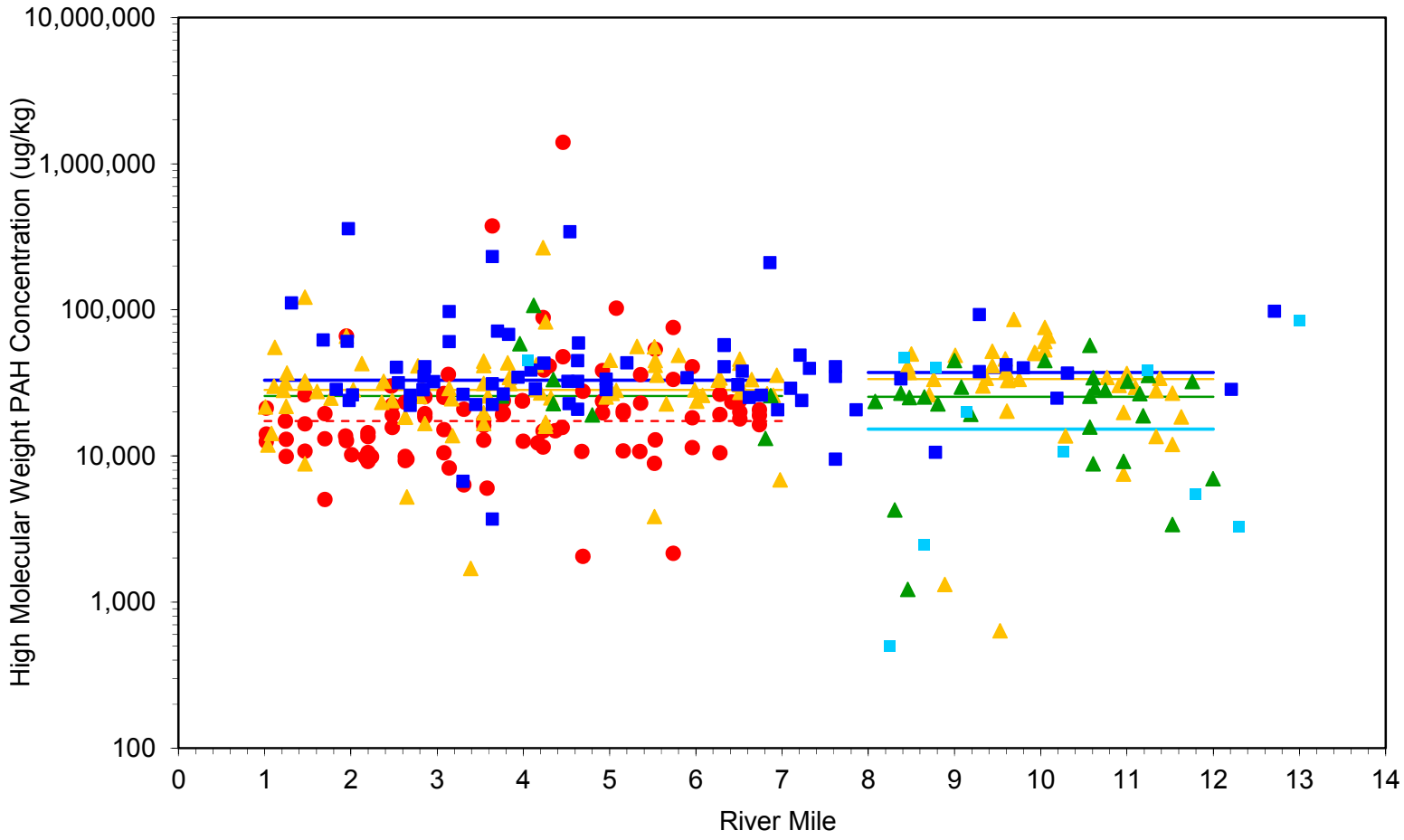
Total PAH in Recently-Deposited Sediments in the Lower Passaic River, Newark Bay and the Upper Passaic River

Lower Eight Miles of the Passaic River

Figure 3.3-18

2014

R2-0027197



Legend

- 2012 Fine-Grained
- 2012 Fine-Grained Median
- 2012 Coarse-Grained
- 2012 Coarse-Grained Median
- 2008-2010 Fine-Grained
- 2008-2010 Fine-Grained Median
- 2008-2010 Coarse-Grained
- 2008-2010 Coarse-Grained Median
- 1995
- 1995 Median

Comparison of HMW PAH Surface Concentration (0-6 inches)
RM1 to RM7 *vs.* RM8 to RM12

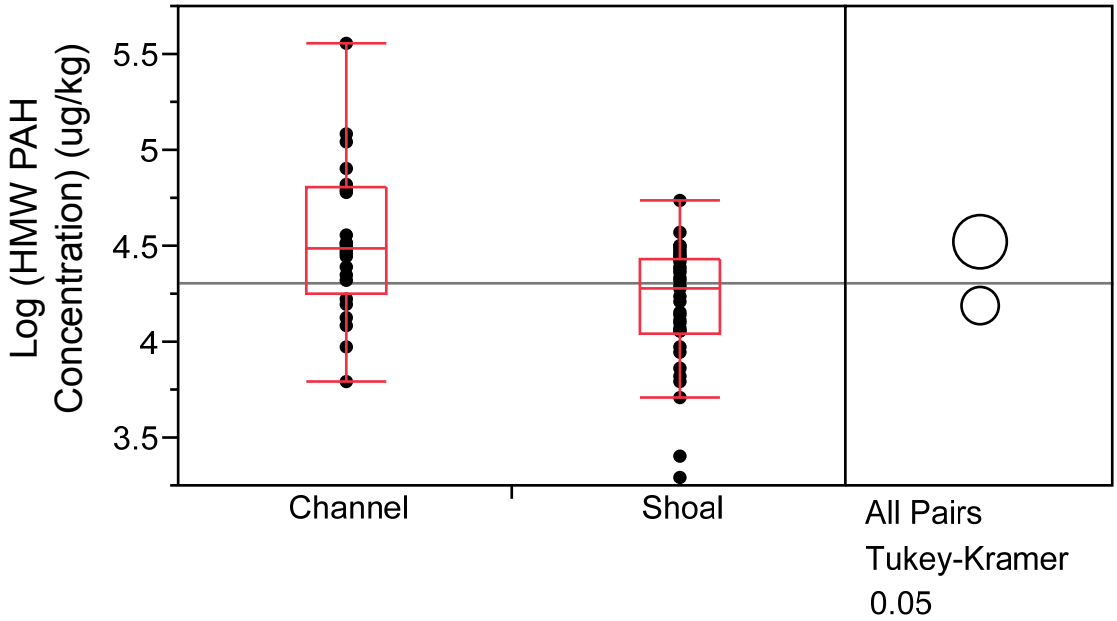
Lower Eight Miles of the Lower Passaic River

Figure 3.3-19

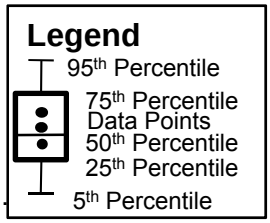
2014

R2-0027198

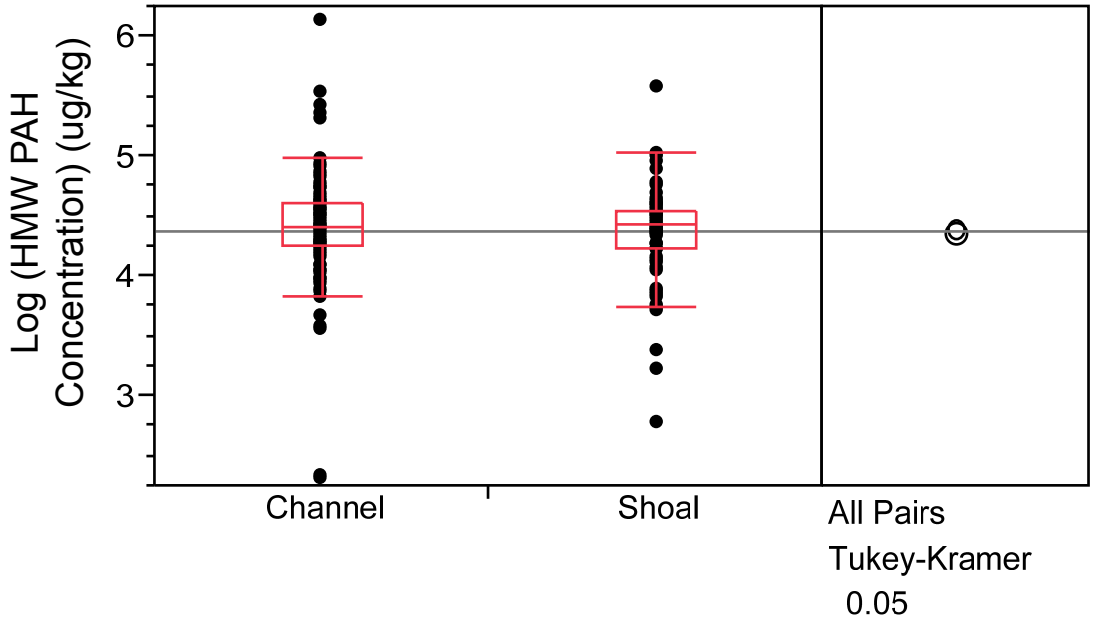
RM0 to RM2



Notes:
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 1995, 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.

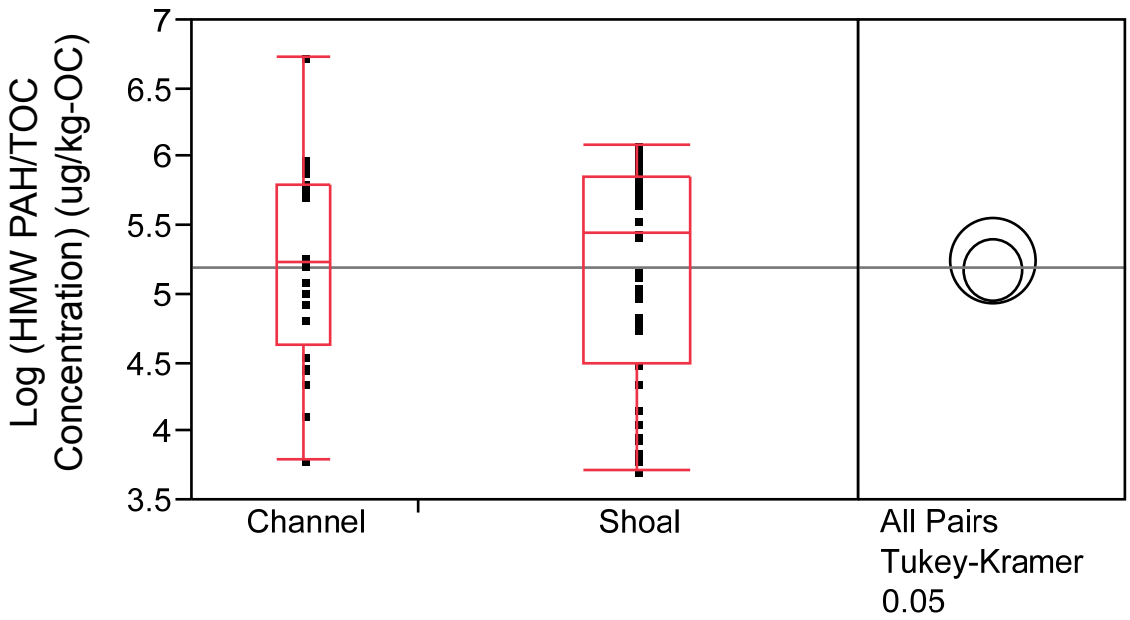


RM2 to RM8



	HMW PAH (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.3-20a** 2014

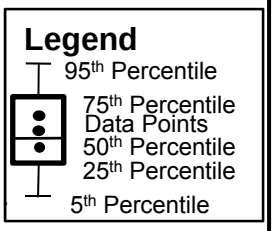
RM0 to RM2



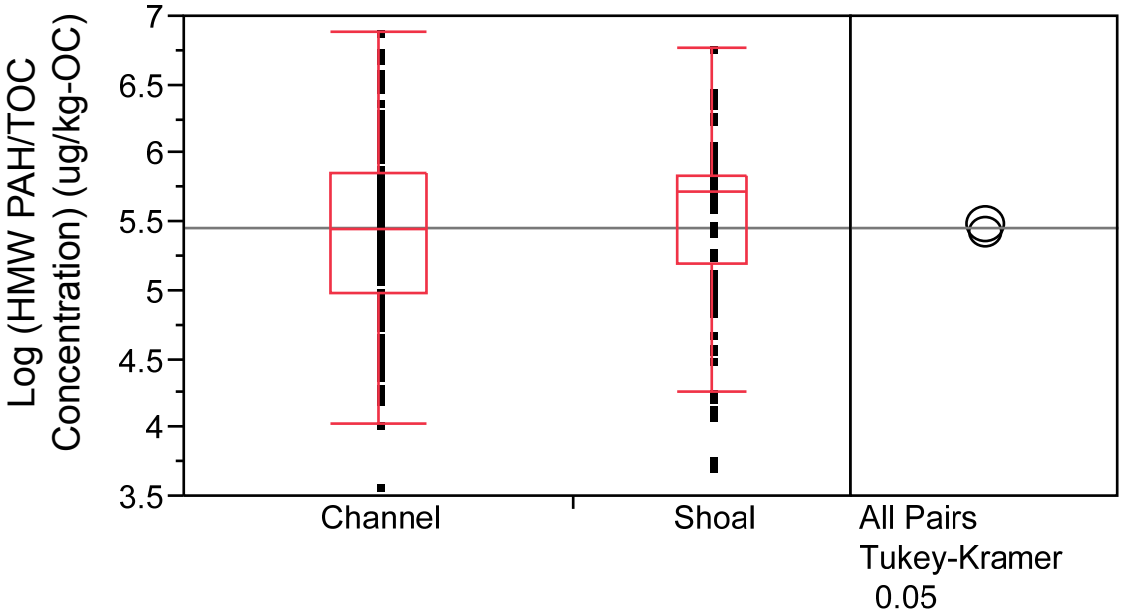
Notes:

1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.

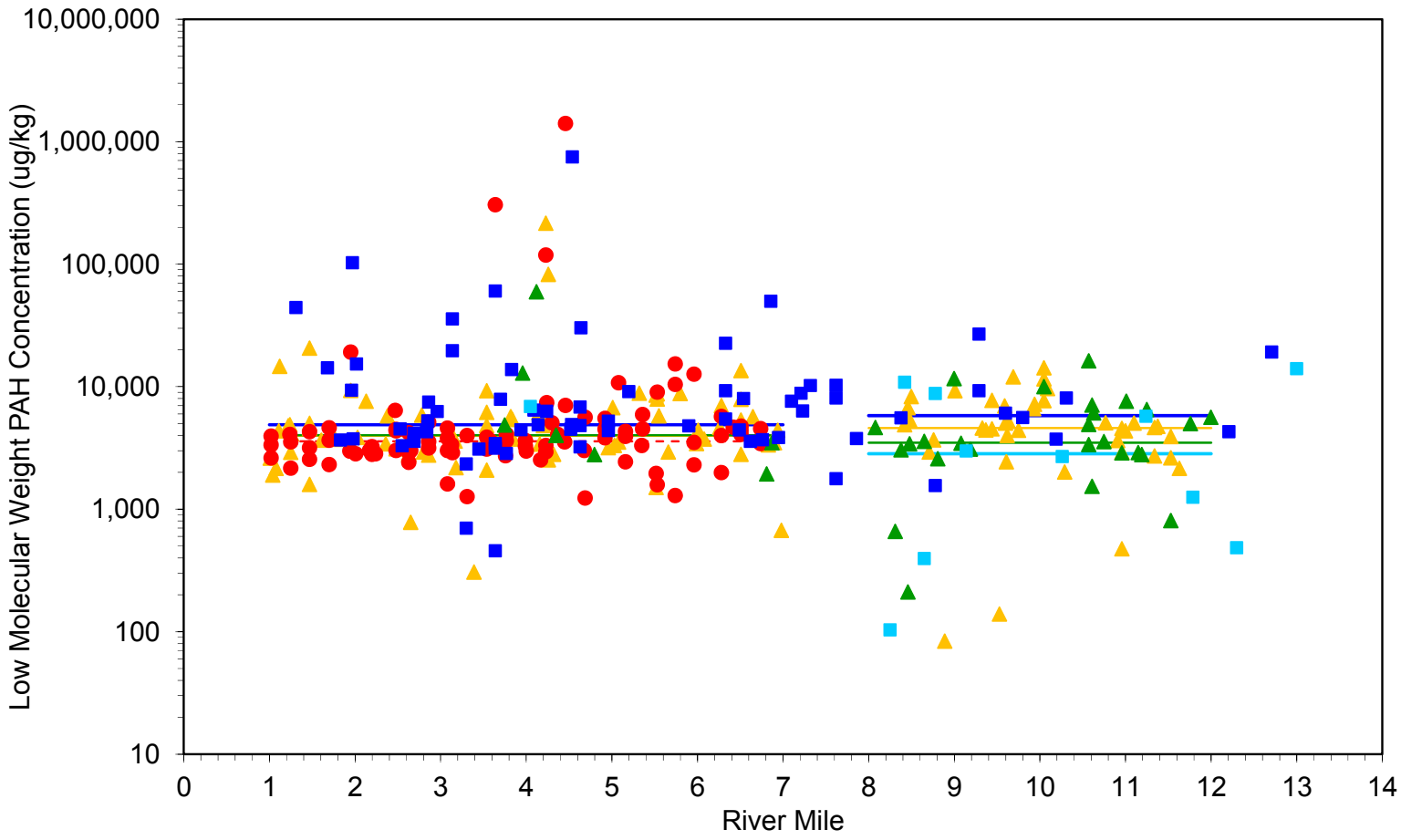
2) Data included 1995, 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG



RM2 to RM8



	TOC Normalized HMW PAH (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.3-20b** 2014



Legend

- 2012 Fine-Grained
- 2012 Fine-Grained Median
- 2012 Coarse-Grained
- 2012 Coarse-Grained Median
- 2008-2010 Fine-Grained
- 2008-2010 Fine-Grained Median
- 2008-2010 Coarse-Grained
- 2008-2010 Coarse-Grained Median
- 1995
- 1995 Median

Comparison of LMW PAH Surface Concentration (0-6 inches)
RM1 to RM7 *vs.* RM8 to RM12

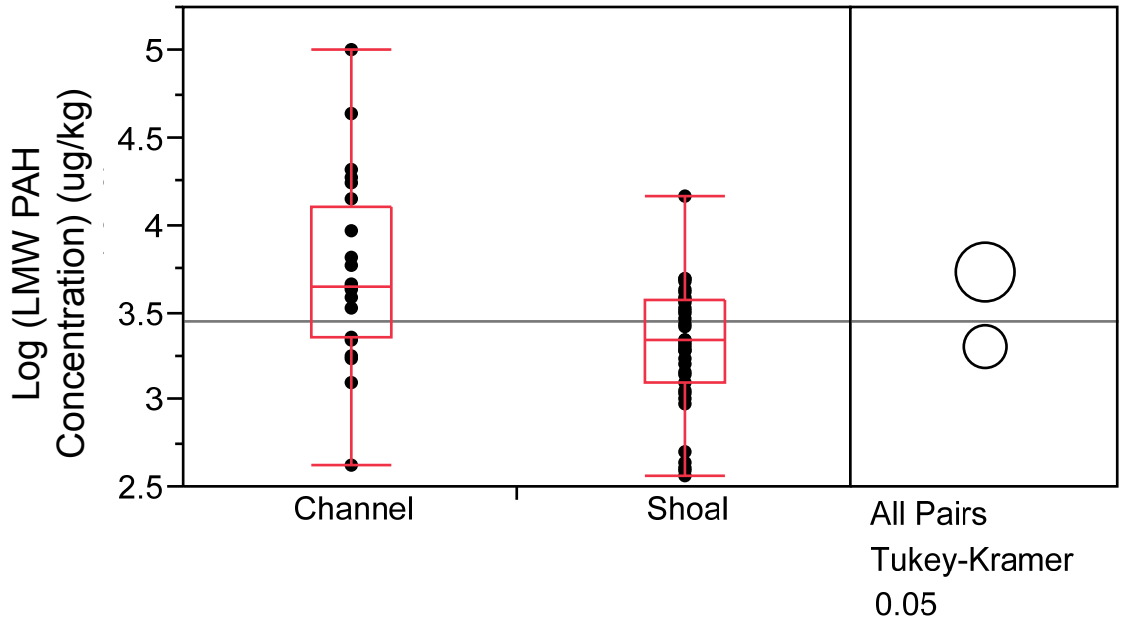
Lower Eight Miles of the Lower Passaic River

Figure 3.3-21

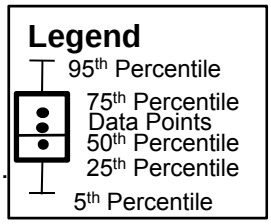
2014

R2-0027201

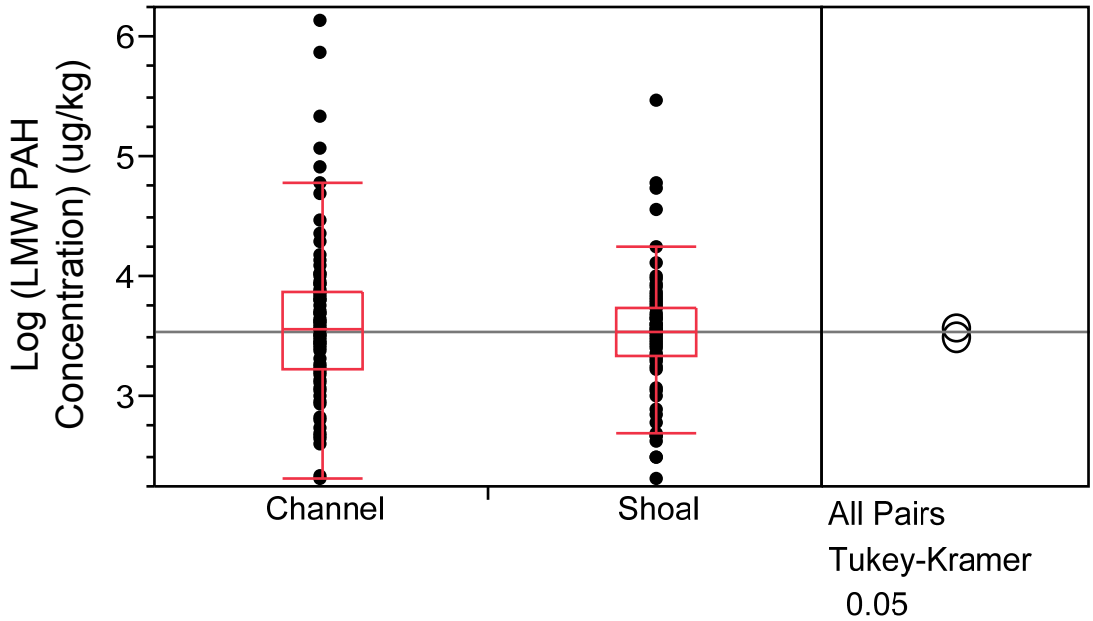
RM0 to RM2



Notes:
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 1995, 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.

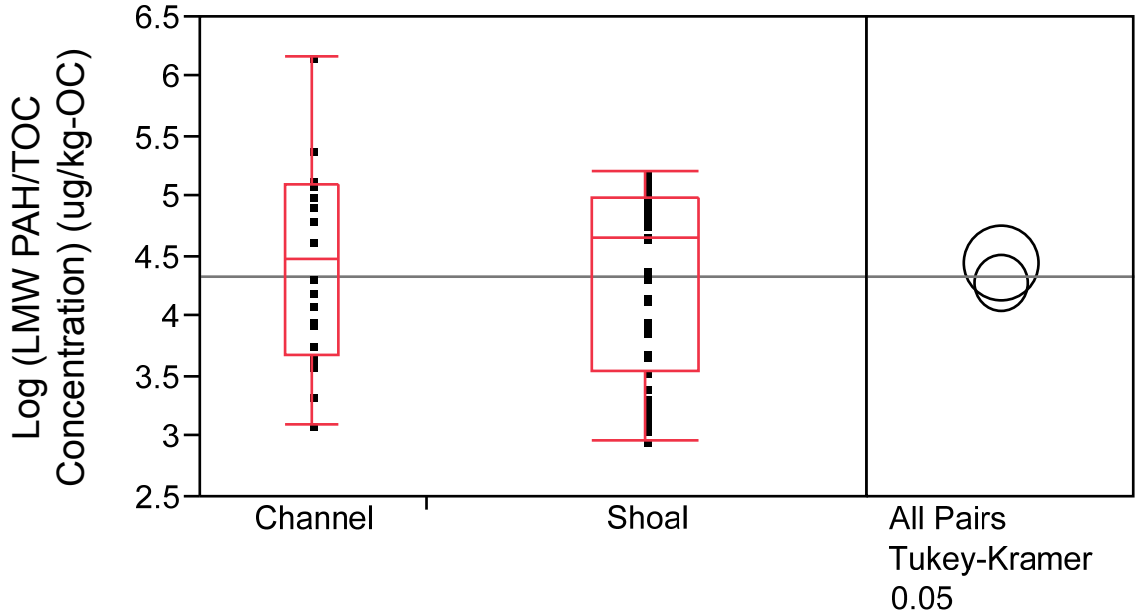


RM2 to RM8



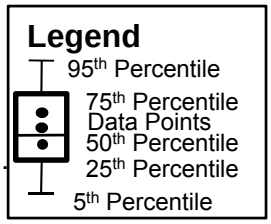
	LMW PAH (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.3-22a** 2014

RM0 to RM2

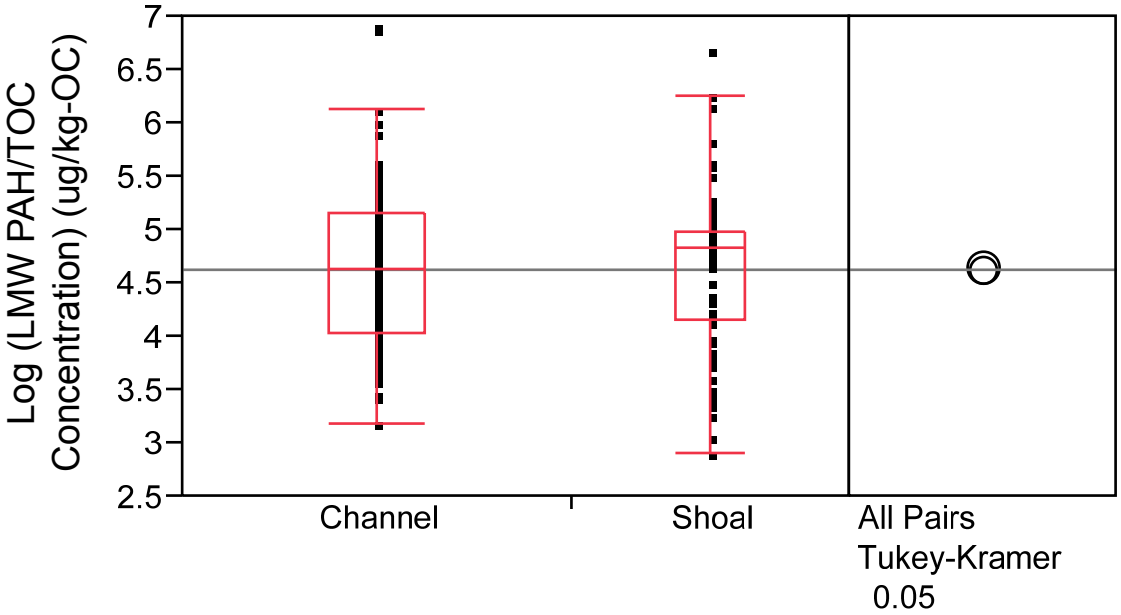


Notes:

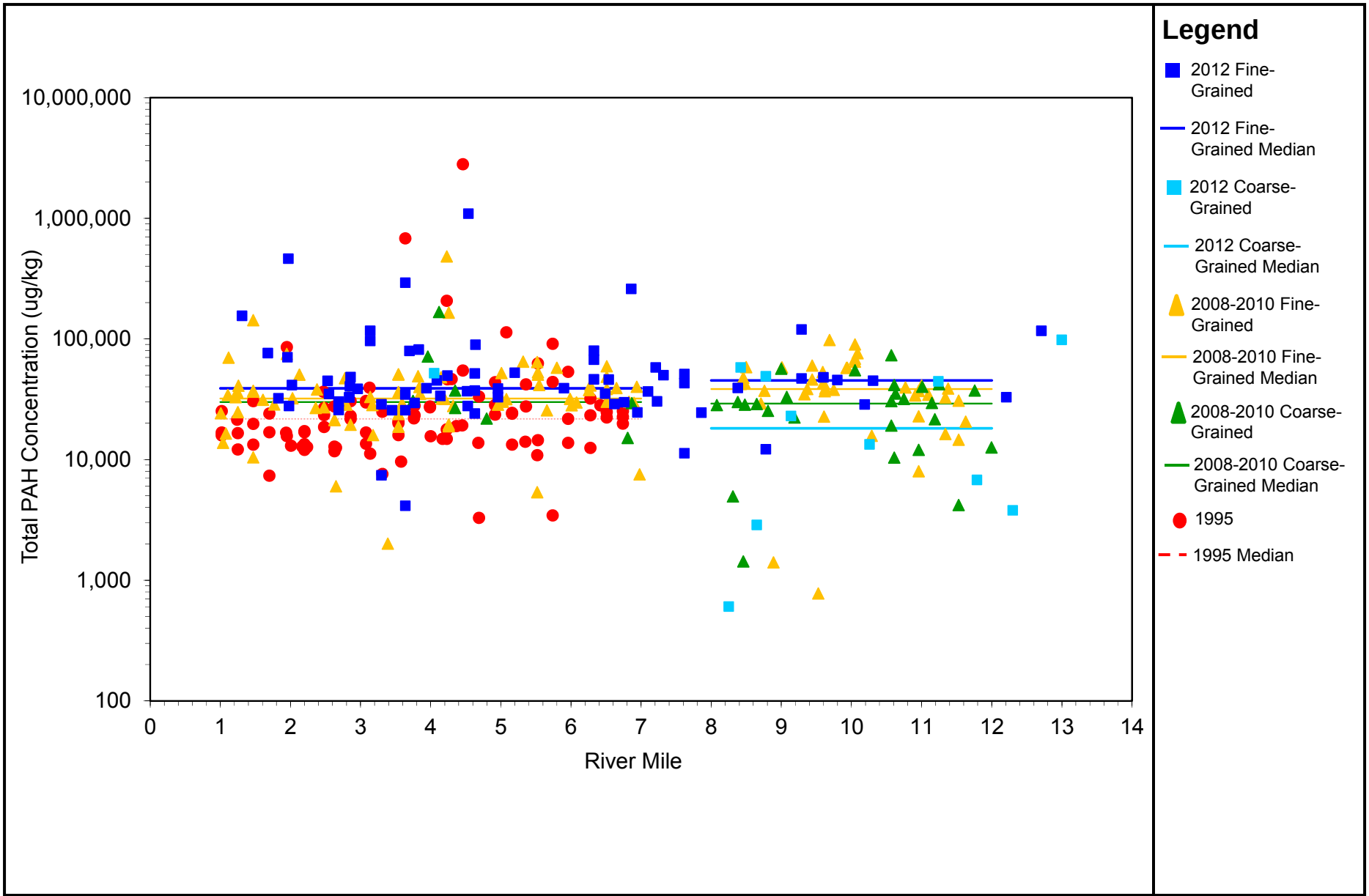
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 1995, 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.



RM2 to RM8



	TOC Normalized LMW PAH (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.3-22b** 2014



Comparison of Total PAH Surface Concentration (0-6 inches)
RM1 to RM7 *vs.* RM8 to RM12

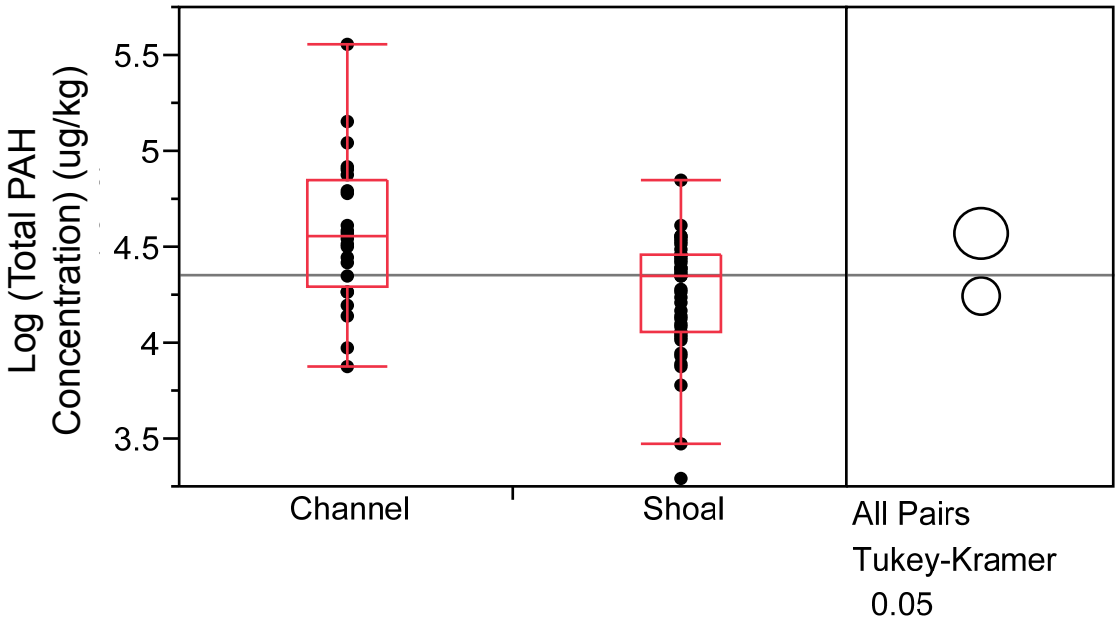
Lower Eight Miles of the Lower Passaic River

Figure 3.3-23

2014

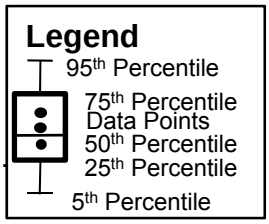
R2-0027204

RM0 to RM2

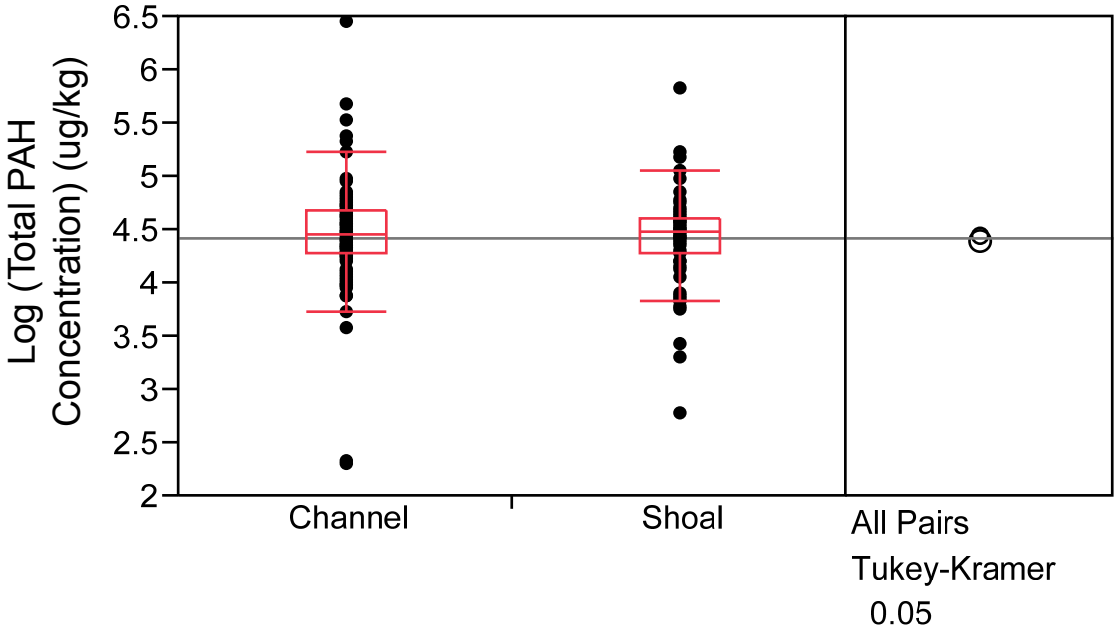


Notes:

1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 1995, 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.

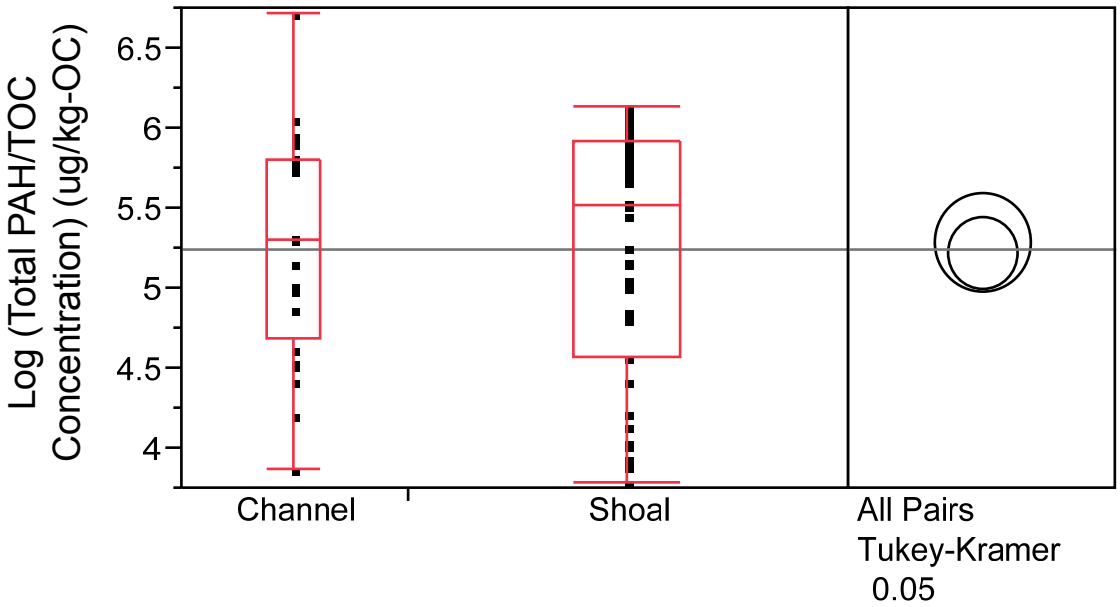


RM2 to RM8



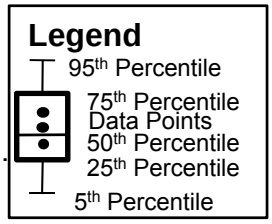
	Total PAHs (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.3-24a** 2014

RM0 to RM2

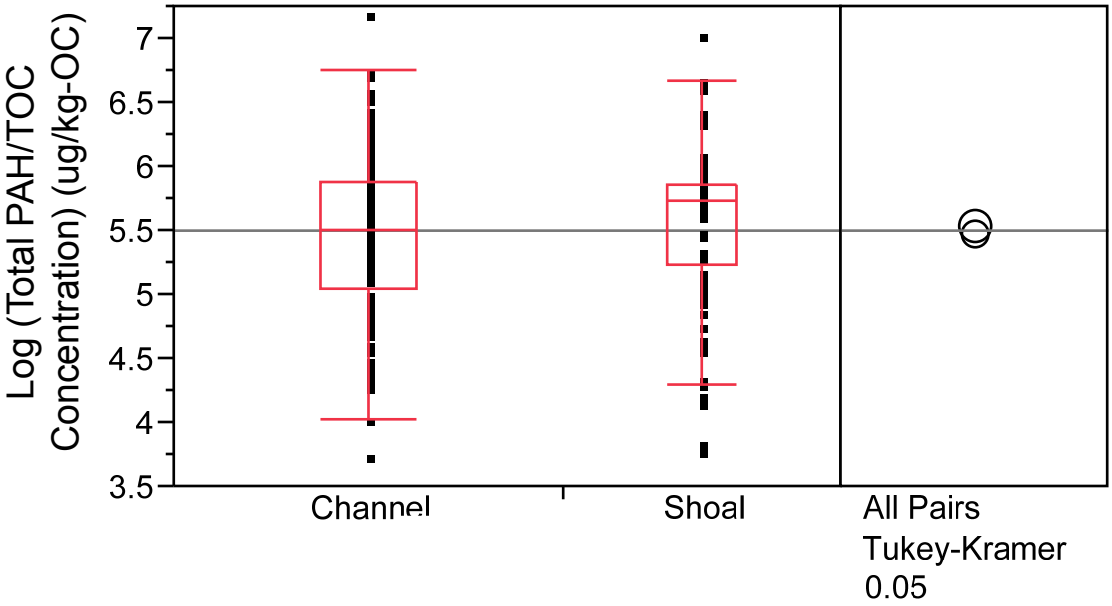


Notes:

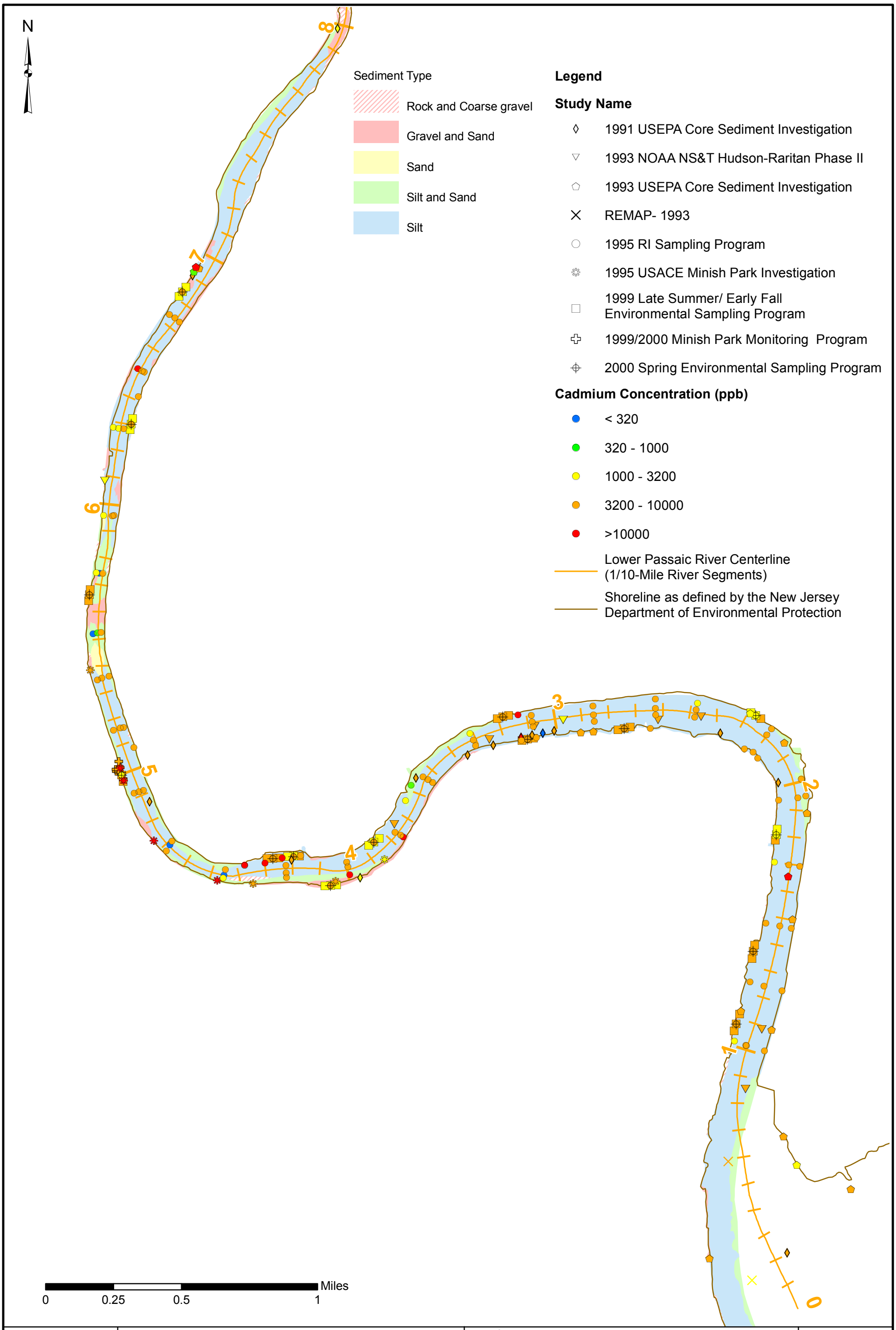
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 1995, 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.



RM2 to RM8



	TOC Normalized Total PAHs (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.3-24b** 2014



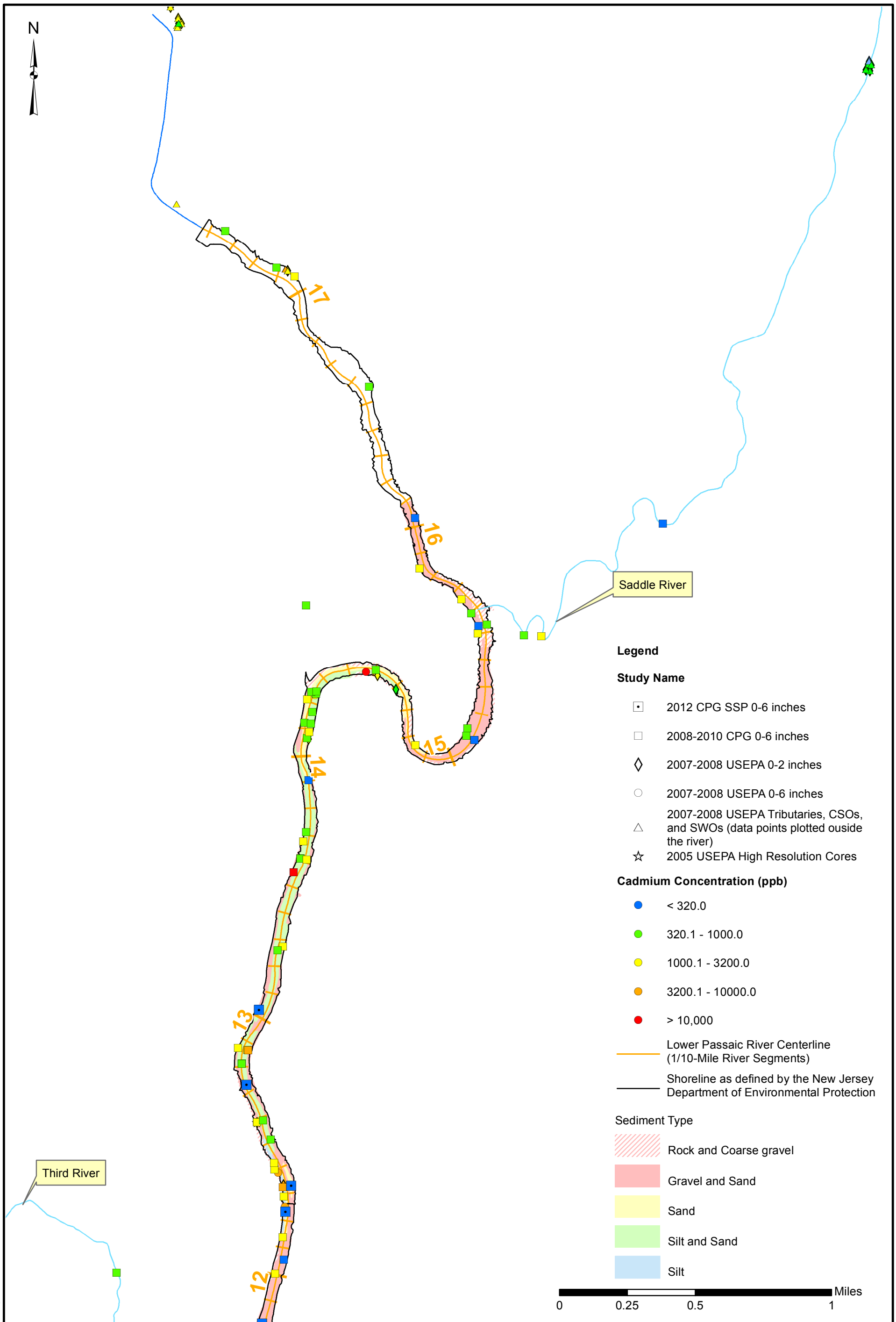
Cadmium Surface Sediment Samples from 1991 to 2000

Lower Eight Miles of the Lower Passaic Rivert

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting. No nondetect values were reported.

Figure 3.4-1

2014



Cadmium Surface Sediment Samples from 2005 to 2012

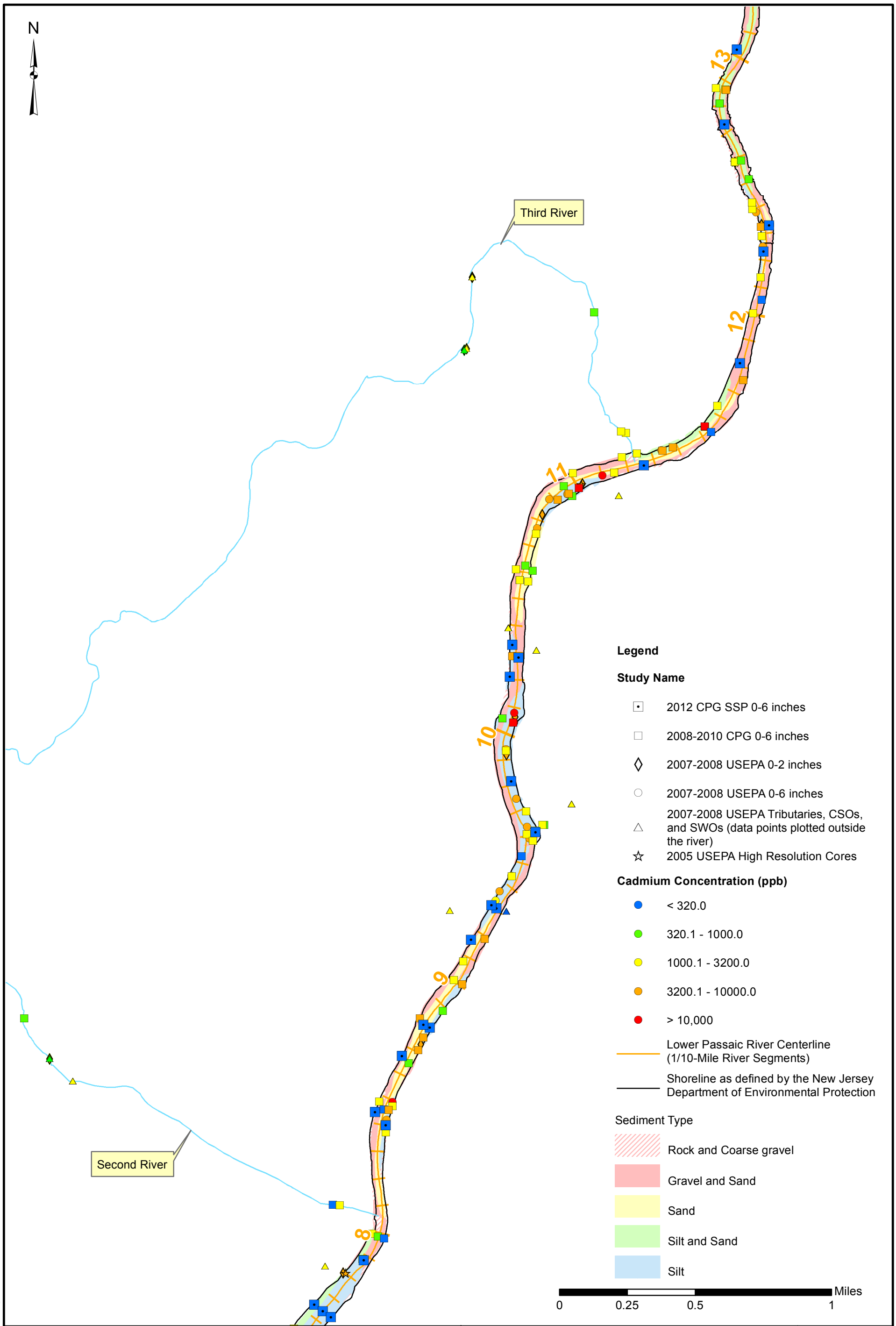
Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.4-2a

2014

Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\HS mxd\Cd_Surficial_Sed_2007_2010_SamplesRM12-DD_Fig14-3h1.mxd



Cadmium Surface Sediment Samples from 2005 to 2012

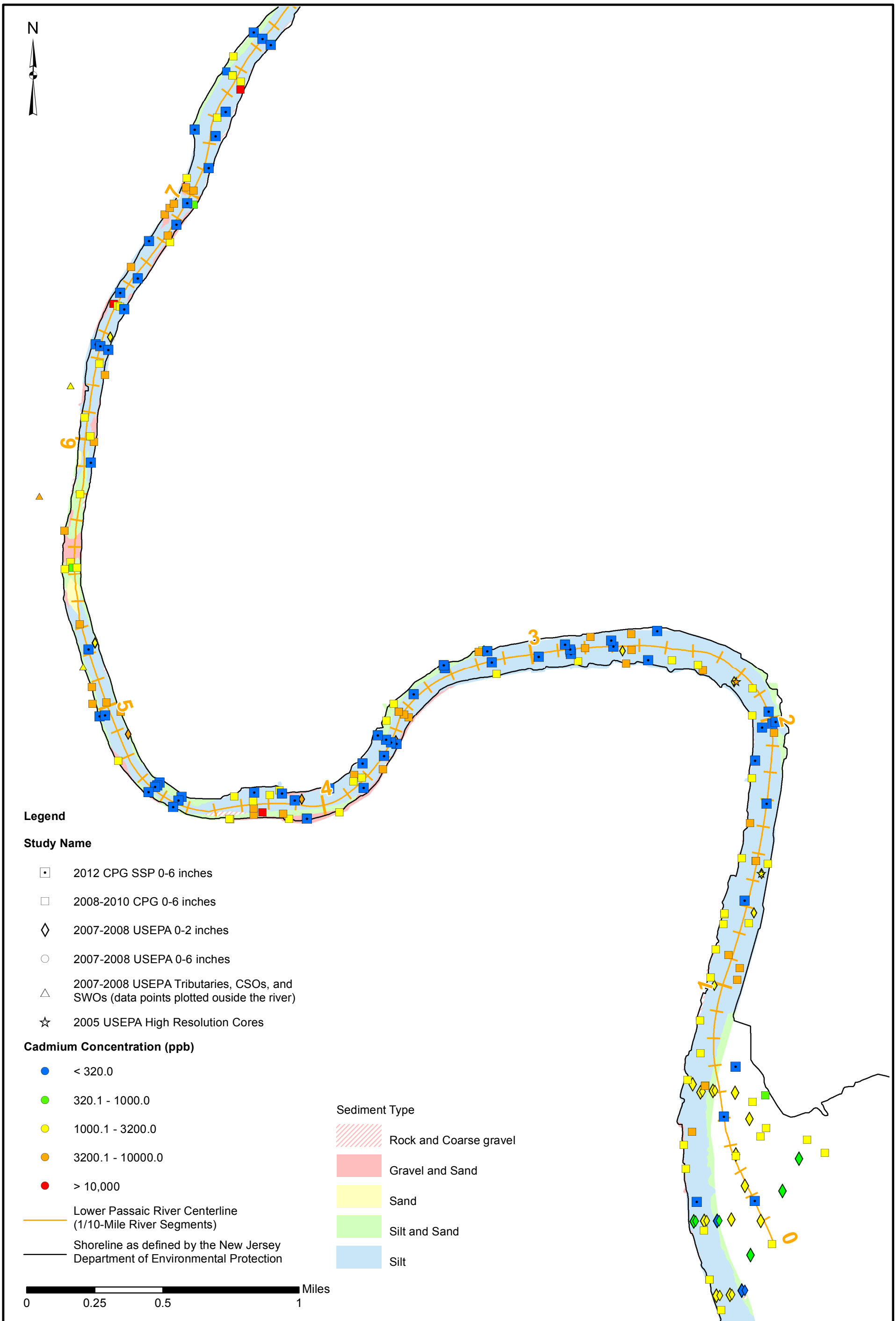
Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.4-2b

2014

Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\HS mxd\Cd_Surficial_Sed_2007_2010_SamplesRM12-DD_Fig14-3h1.mxd



Cadmium Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.4-2c

2014

Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\HS mxd\Cd_Surficial_Sed_2007_2010_SamplesRM12-DD_Fig14-3h1.mxd

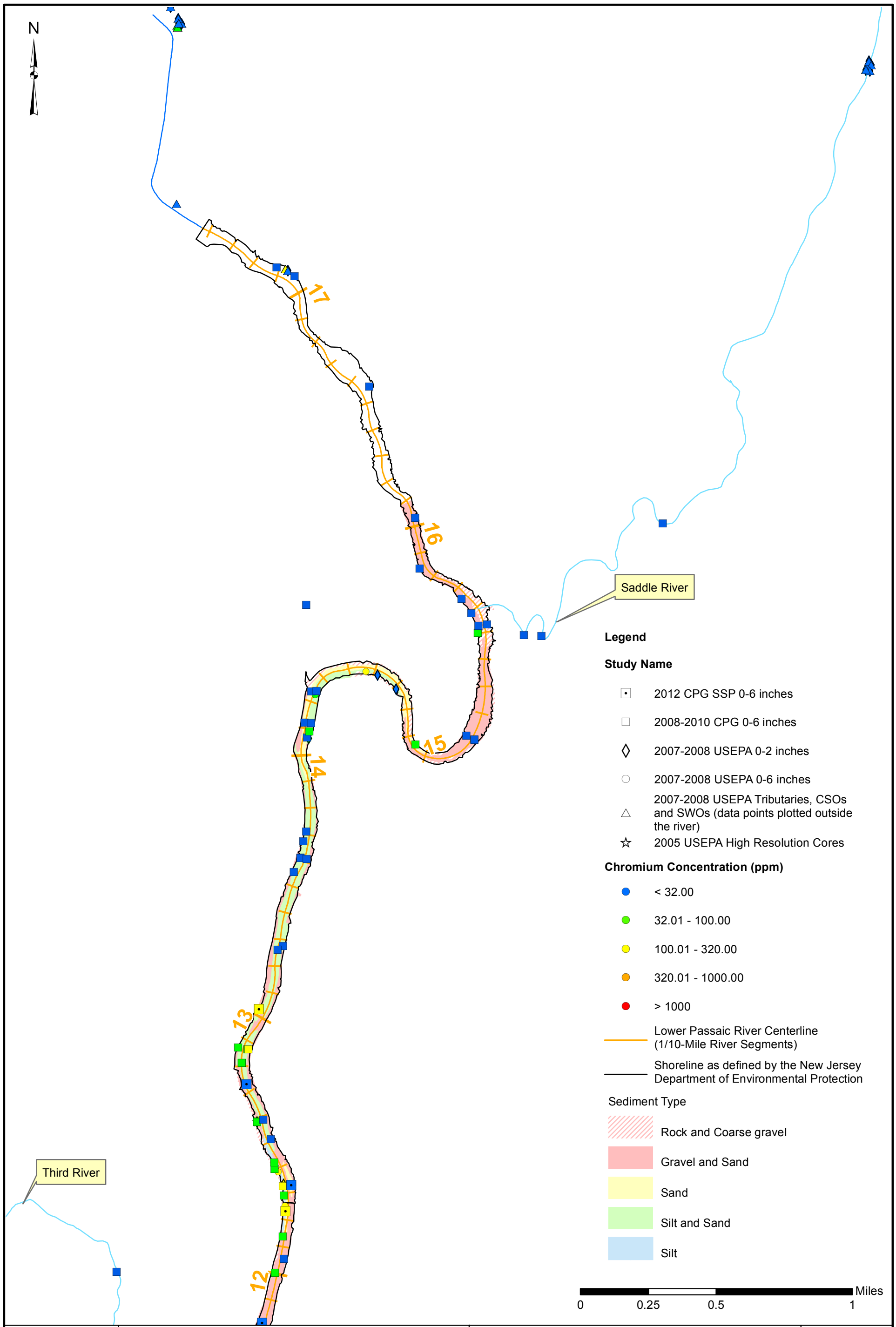
Chromium Surface Sediment Samples from 1991 to 2000

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting. No nondetect values were reported.

Figure 3.4-3

2014



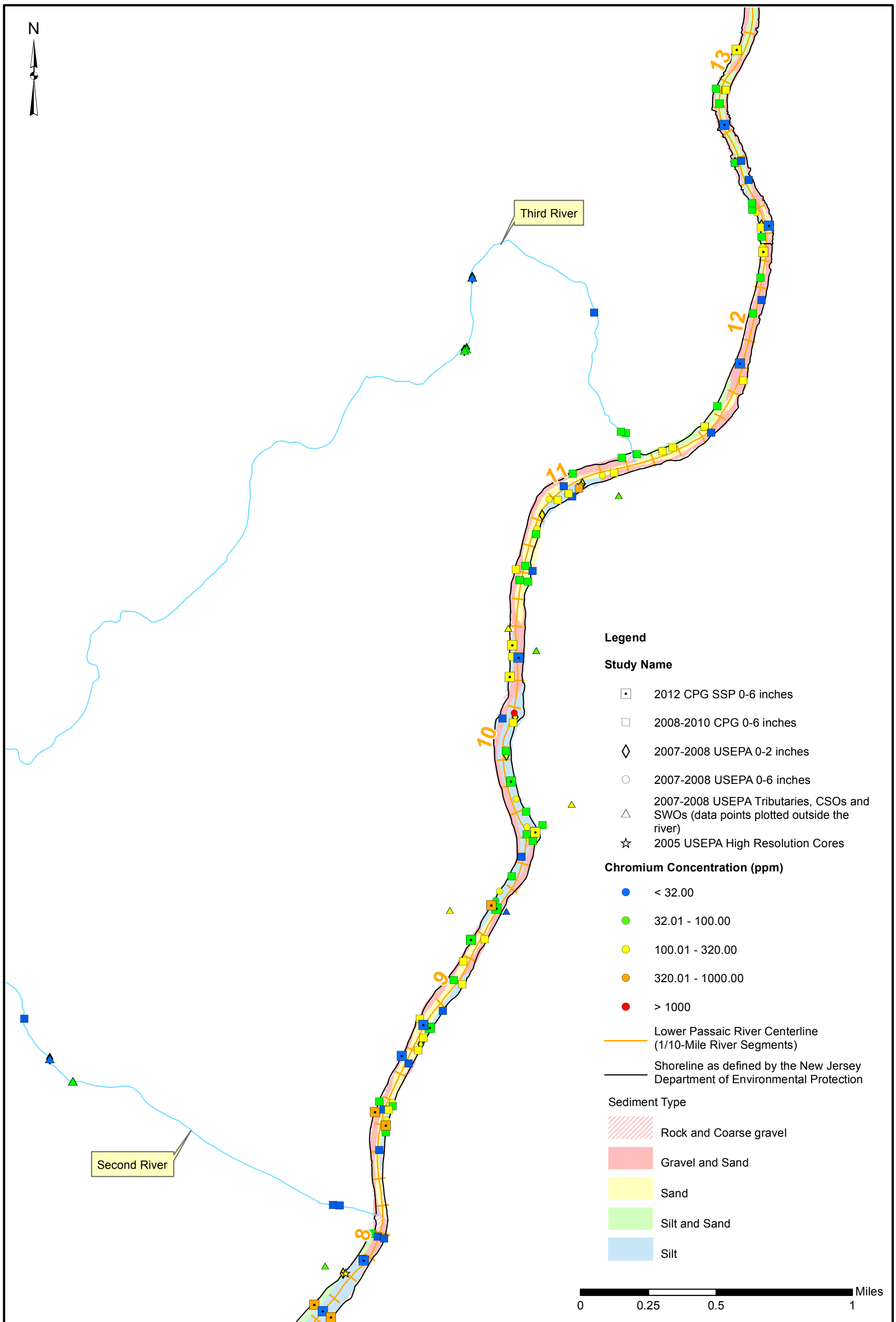
Chromium Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.4-4a

2014



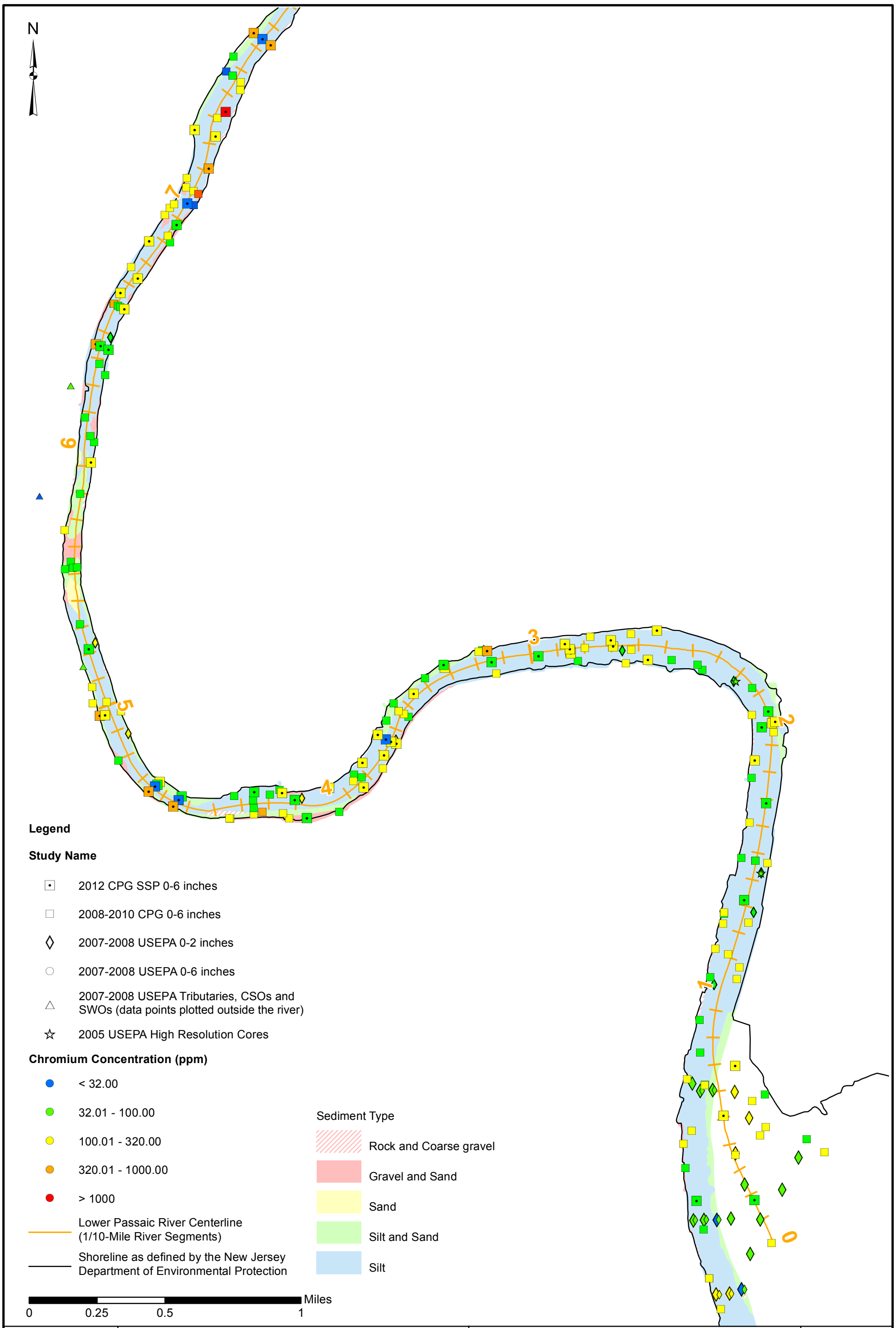
Chromium Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.4-4b

2014



Chromium Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.4-4c

2014

Copper Surface Sediment Samples from 1991 to 2000

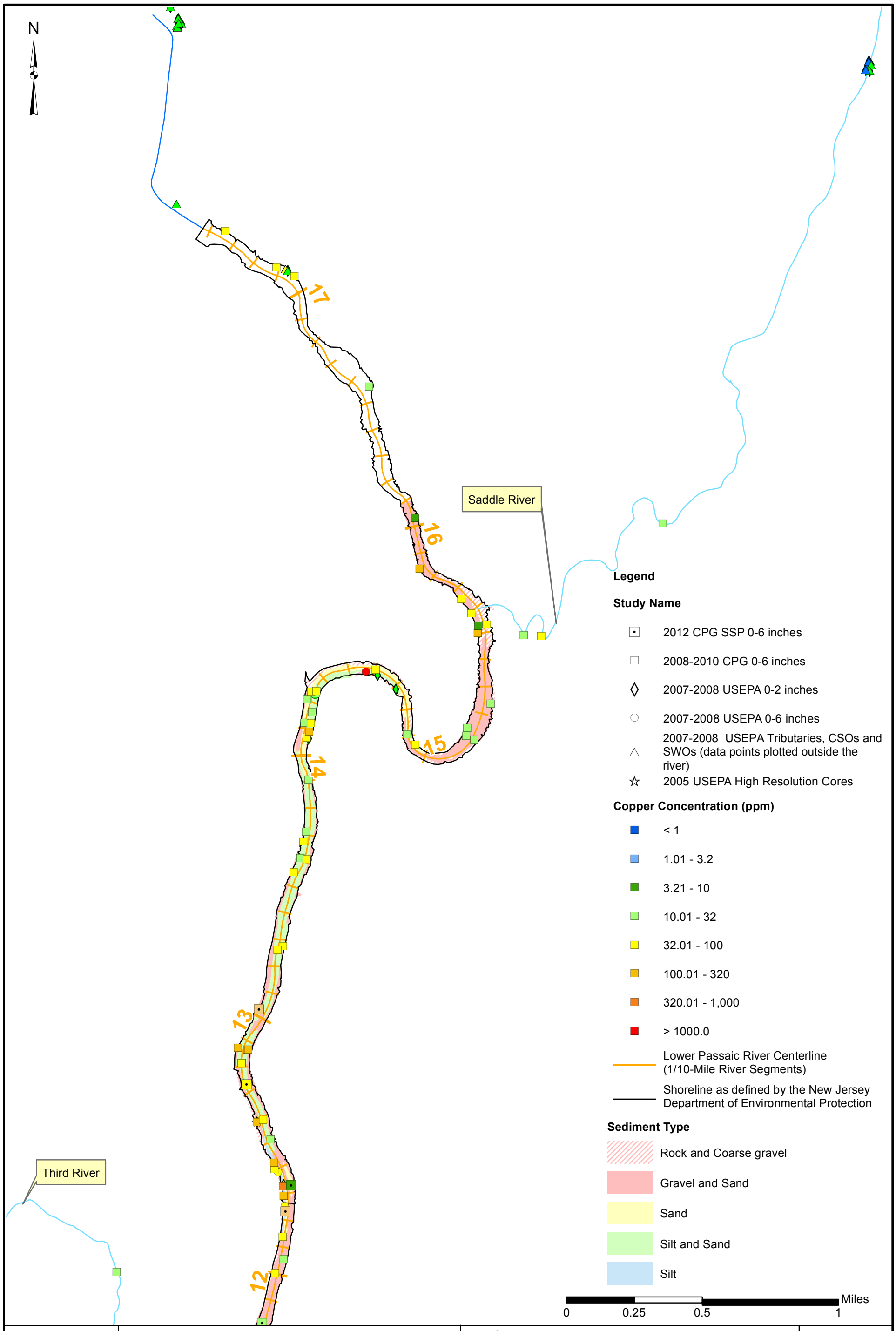
Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting. No nondetect values were reported.

Figure 3.4-5

2014

S:\Projects\passaic\MapDocuments\4553001-CERCLA\Cu_Surficial_Sed_1999_20001_Arc83.mxd



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Copper Surface Sediment Samples from 2005 to 2012

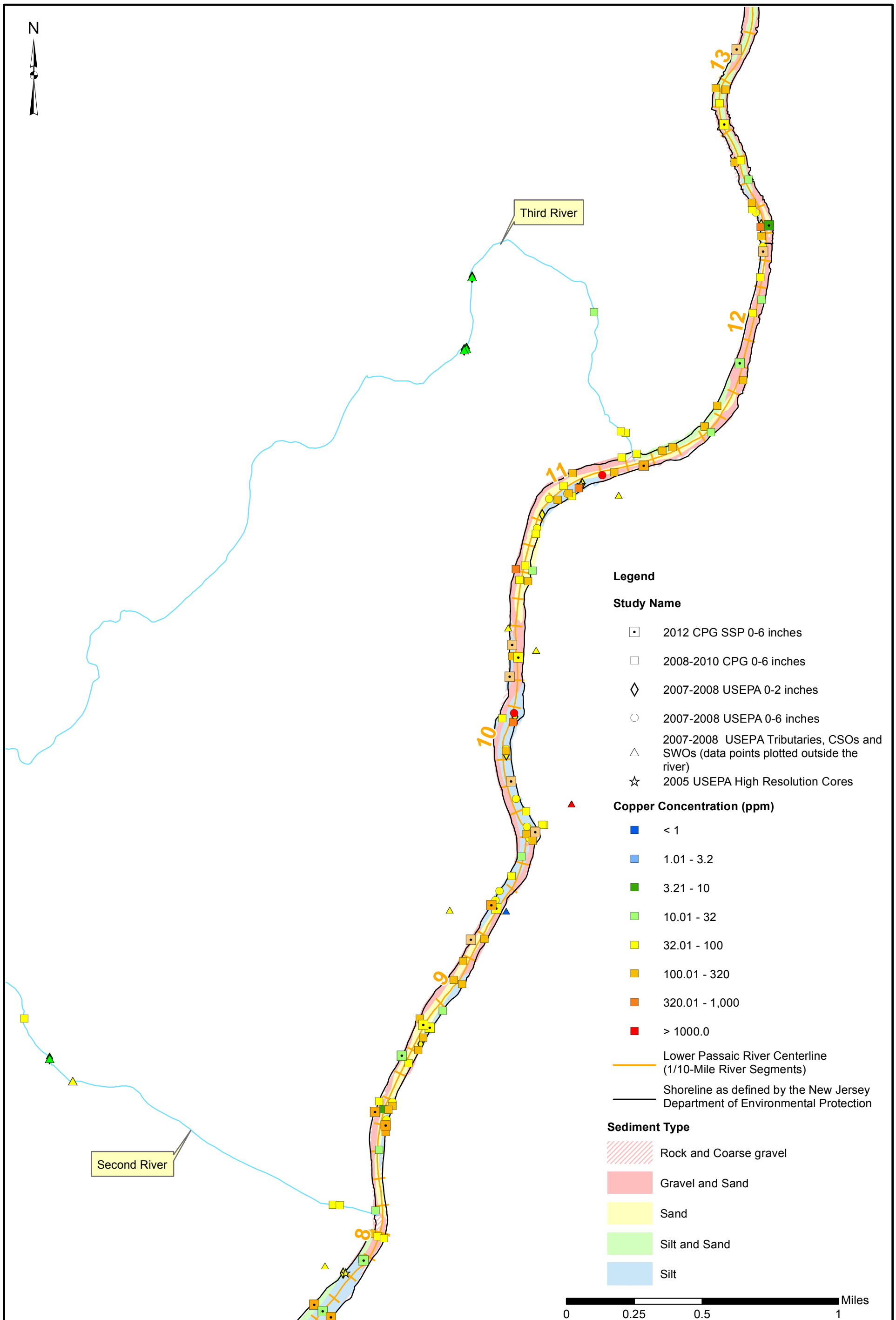
Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.4-6a

2014

R2-0027216



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Copper Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.4-6b

2014

S:\Projects\passaic\MapDocuments\4553001-CERCLA\Cu_Surficial_Sed_2007_2010_Samples_RM12-DD_Fig14-3j1.mxd

Copper Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.4-6c

2014

Lead Surface Sediment Samples from 1991 to 2000

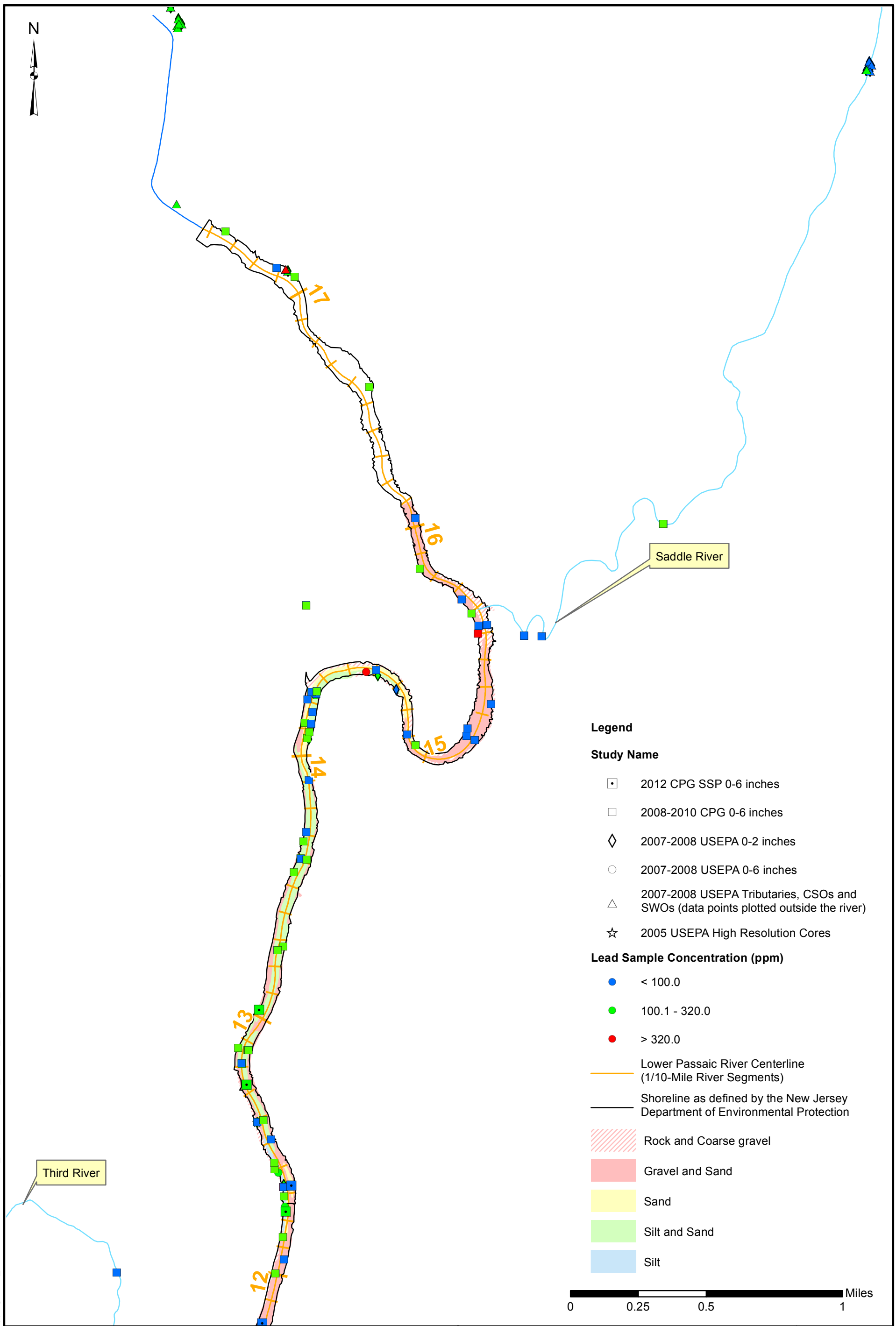
Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.4-7

2014

S:\Projects\passaic\MapDocuments\4553001-CERCLA\Pb_Surficial_Sed_1999_2000.mxd



Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\HS mxd\Pb_Surficial_Sed_2007_2010_SamplesRM12-DD_fig14-3k1.mxd

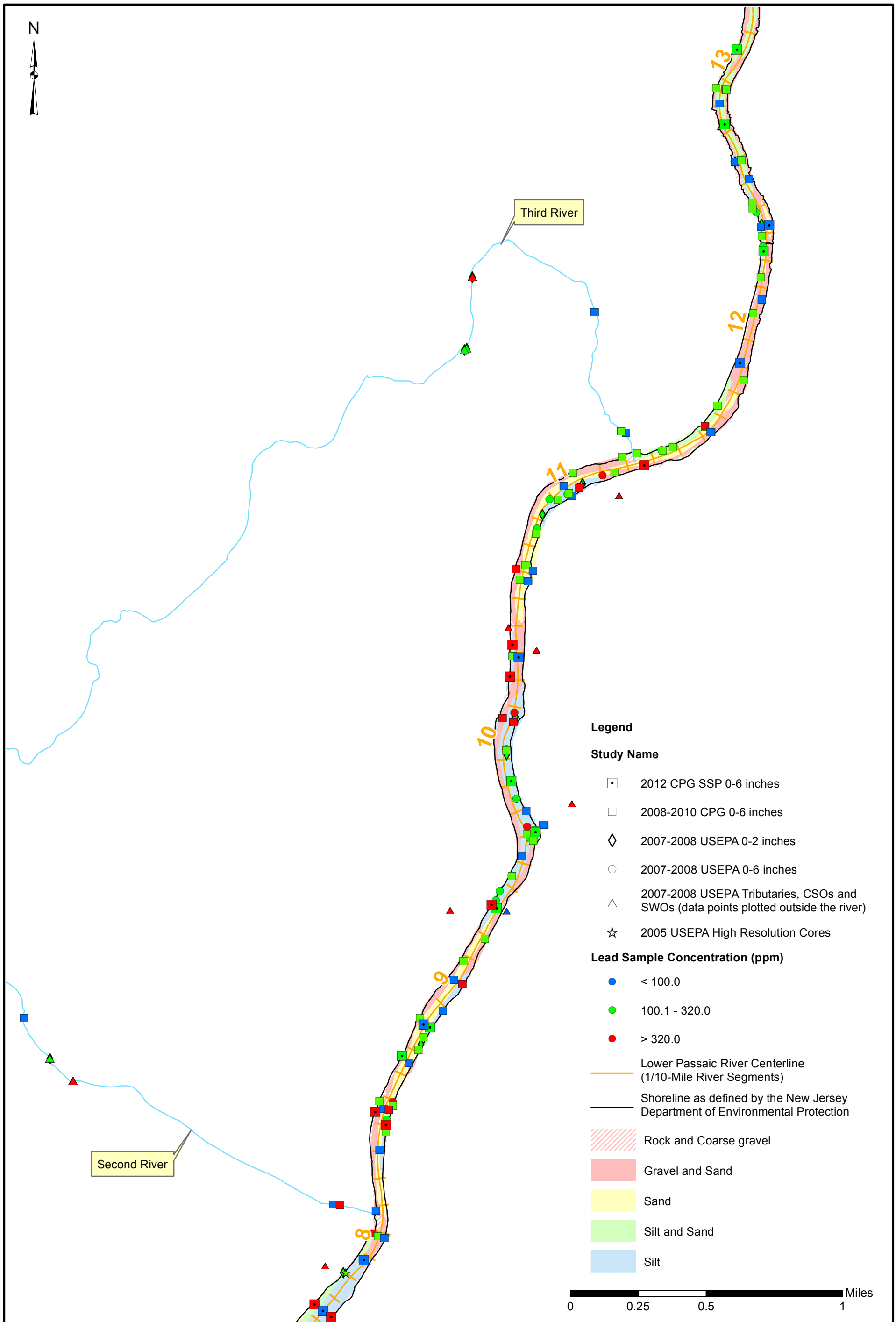
Lead Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.4-8a

2014



Lead Surface Sediment Samples from 2005 to 2012

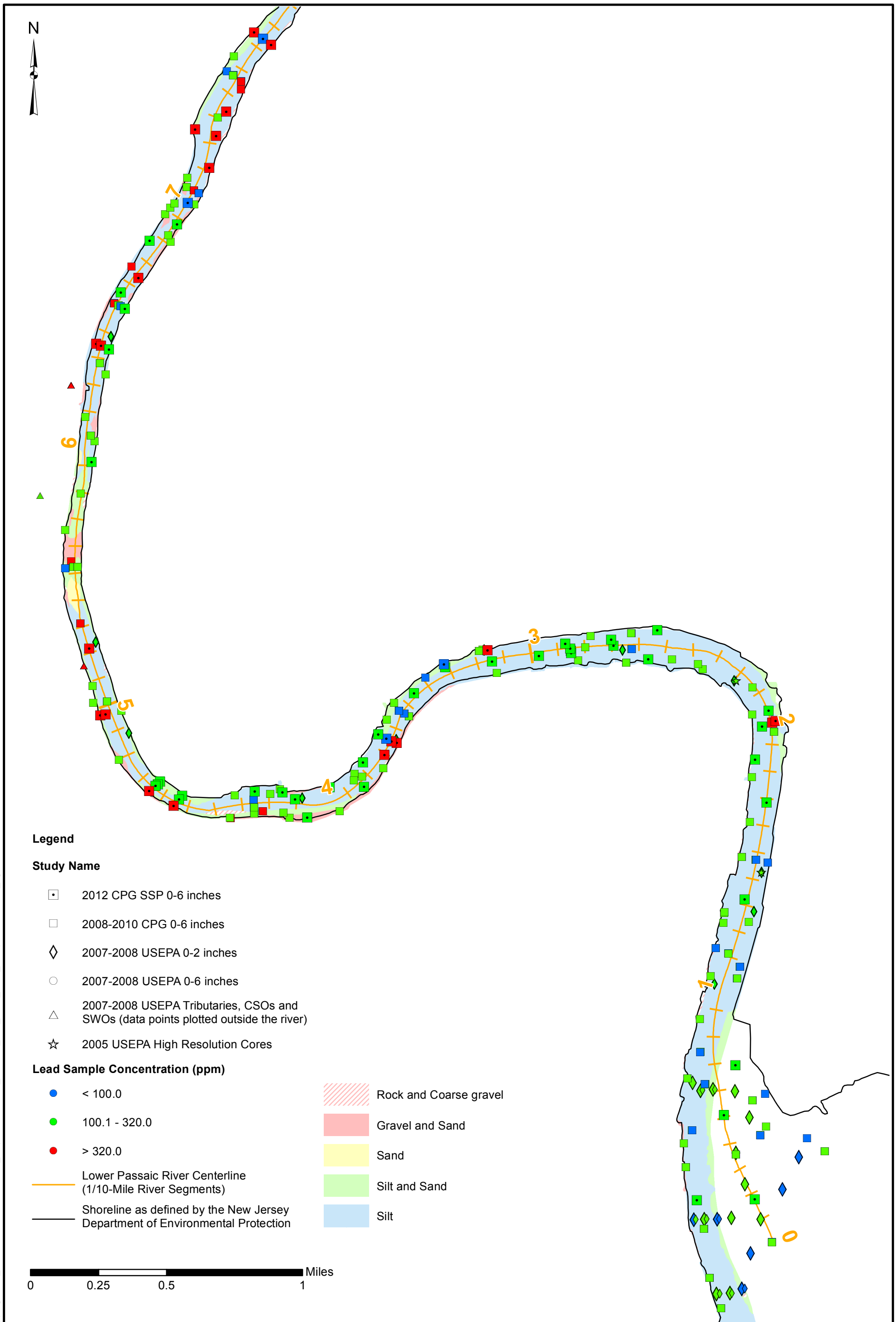
Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.4-8b

2014

Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\HS mxd\Pb_Surficial_Sed_2007_2010_SamplesRM12-DD_fig14-3k1.mxd



Lead Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.4-8c

2014

Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\HS mxd\Pb_Surficial_Sed_2007_2010_SamplesRM12-DD_fig14-3k1.mxd

Mercury Surface Sediment Samples from 1991 to 2000

Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.4-9

2014

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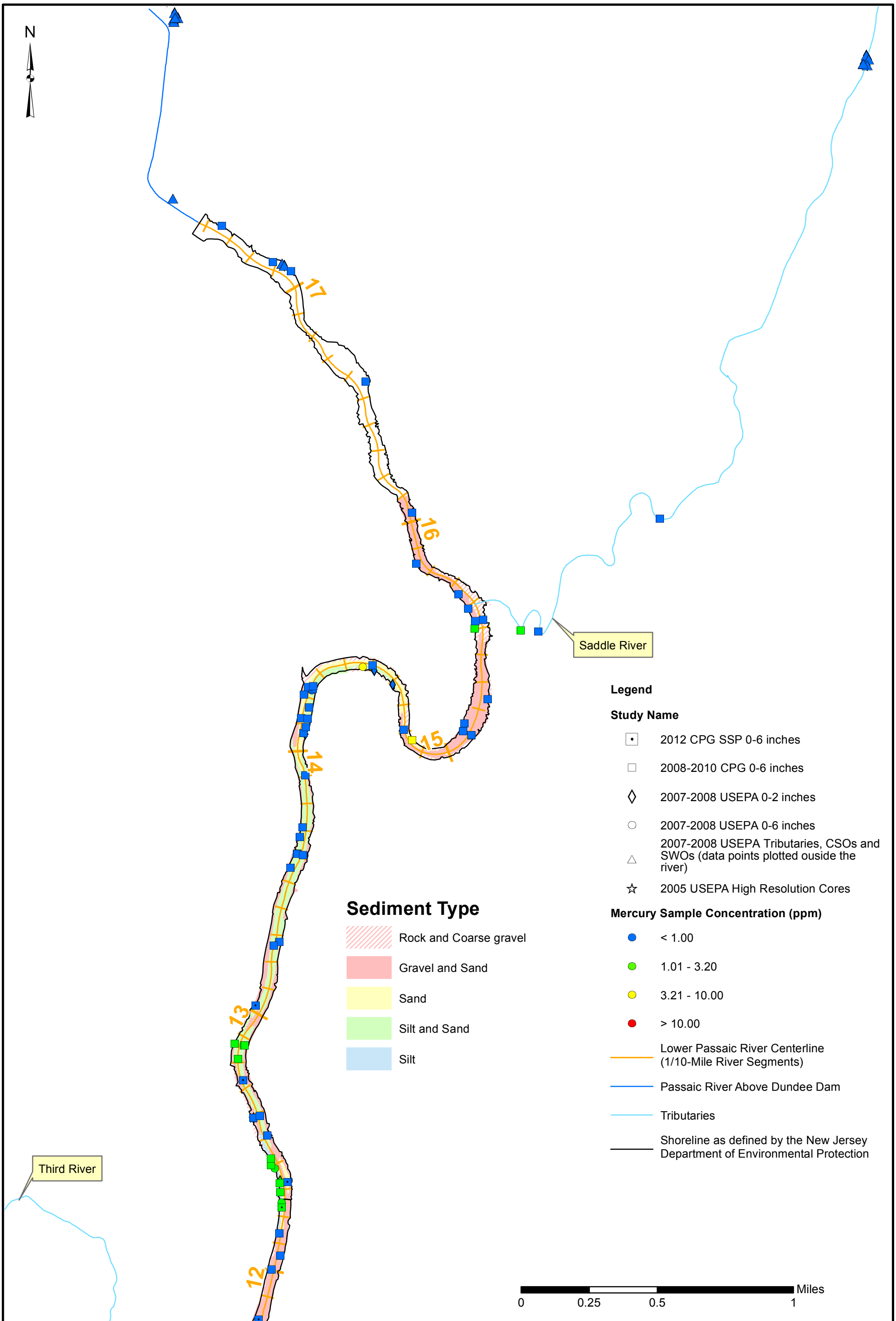


Mercury Surface Sediment Samples from 2005 to 2012

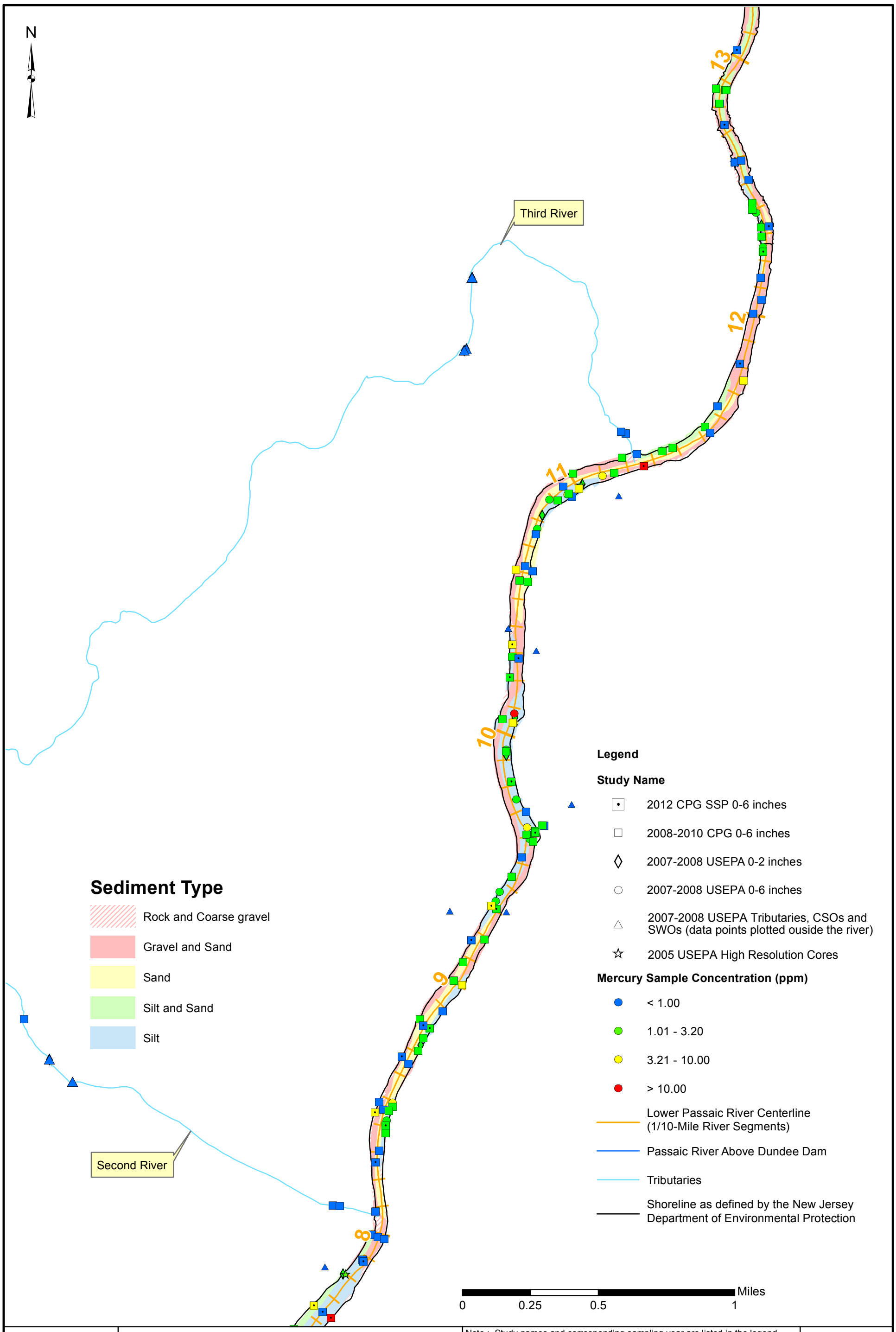
Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.4-10a

2014

Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\Hg_Surficial_Sed_2005_2012.mxd



Mercury Surface Sediment Samples from 2005 to 2012

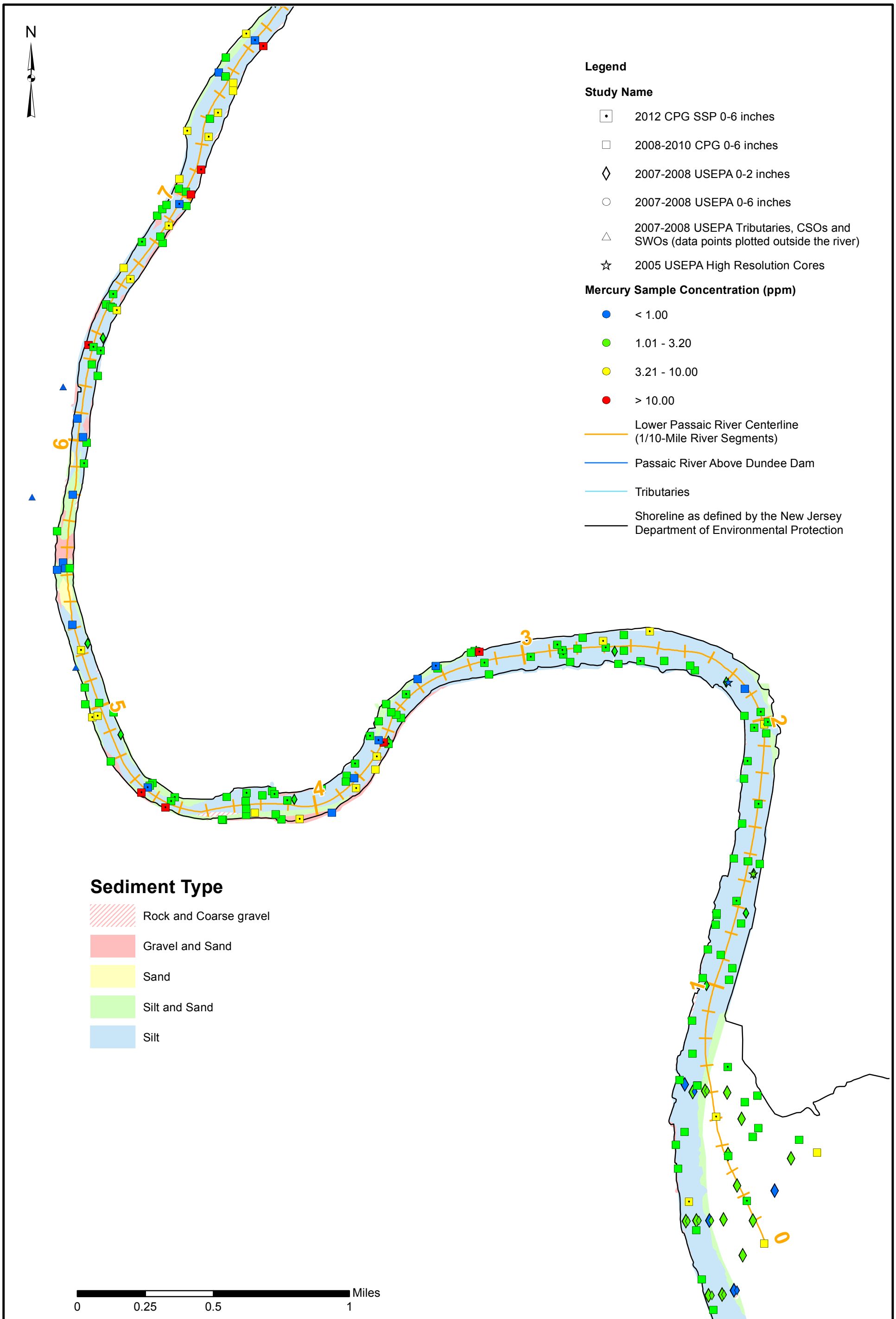
Lower Eight Miles of the Lower Passaic River

Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.4-10b

2014

Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\Hg_Surficial_Sed_2005_2012.mxd



Mercury Surface Sediment Samples from 2005 to 2012

Lower Eight Miles of the Lower Passaic River

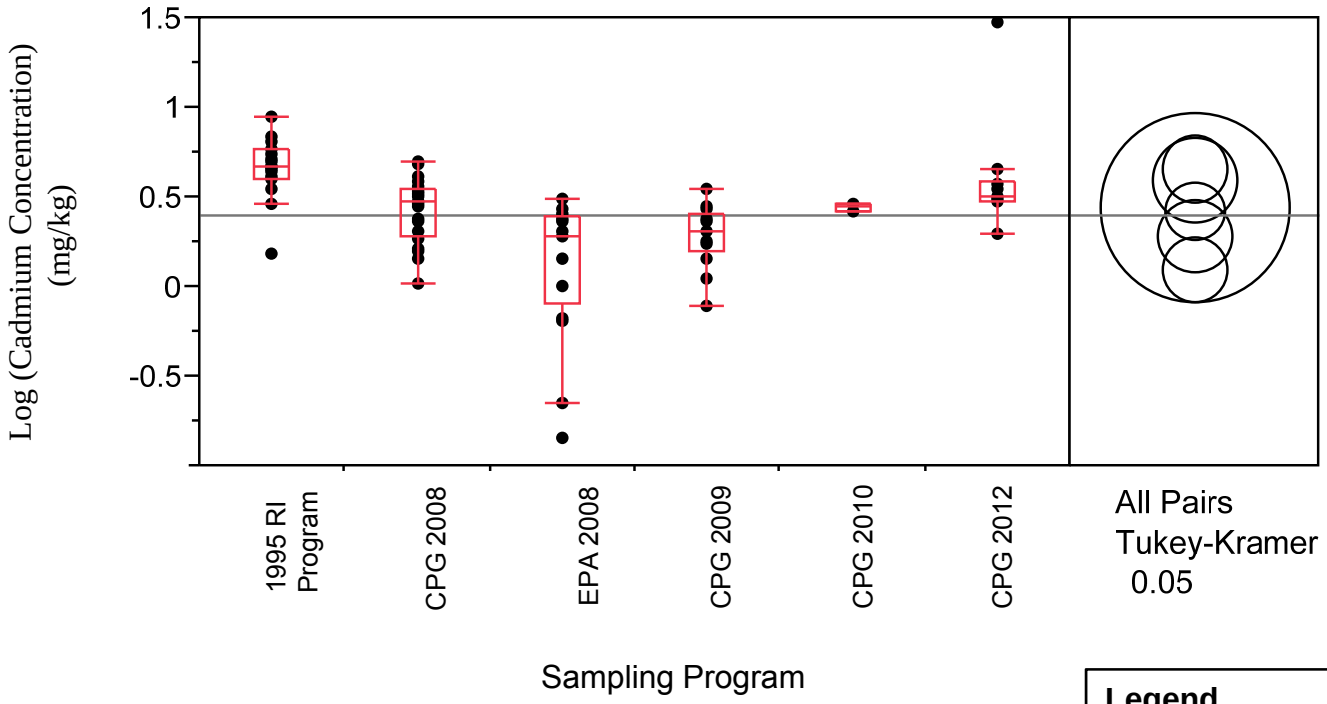
Note : Study names and corresponding sampling year are listed in the legend. Samples represent either sediment grab samples or the top segment of a sediment core. Because each study provided a different definition for "surface sediments," the samples plotted on this figure generally represent sediments from a depth of 0 foot to less than 1 foot. If samples are plotted at the same location, samples from the latest sampling event were plotted on top. Duplicate samples were averaged before plotting.

Figure 3.4-10c

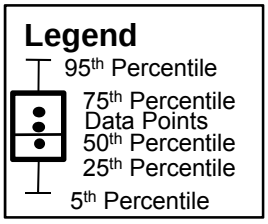
2014

Path: P:\0285924\Mapping\CSM_MassBalance\SurfaceSed_Maps\Hg_Surficial_Sed_2005_2012.mxd

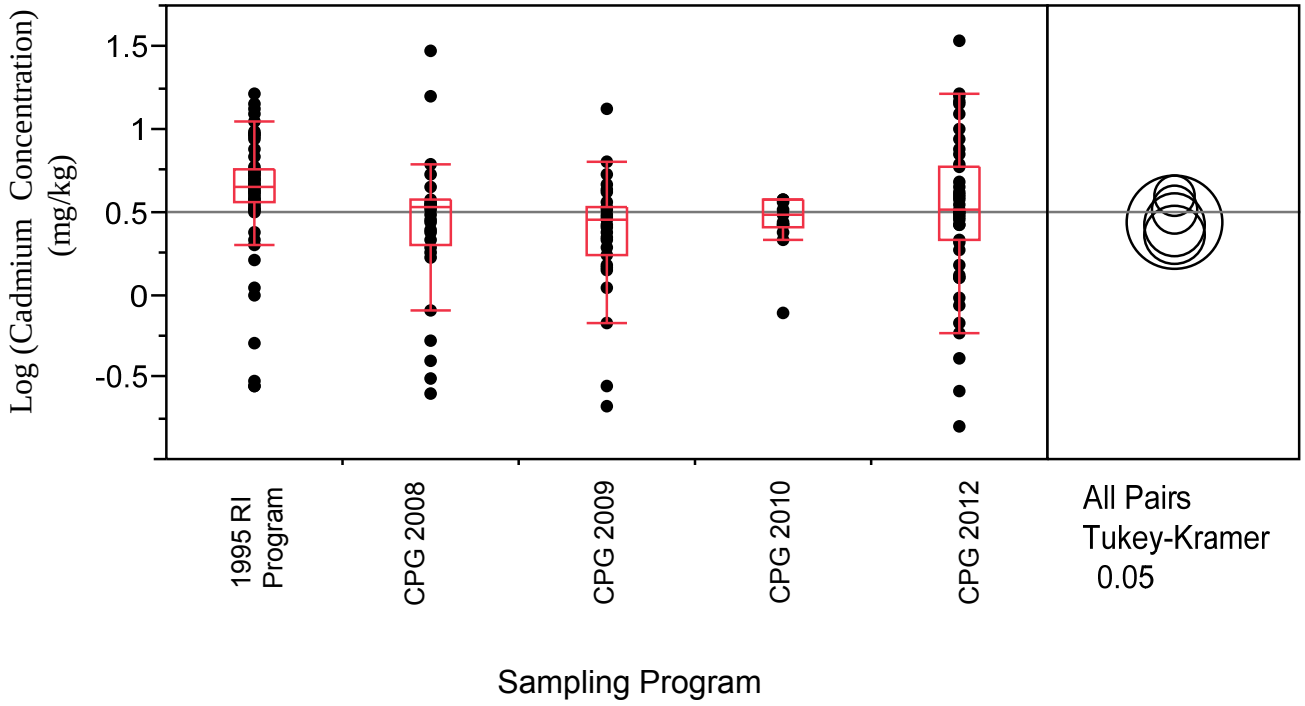
RM0 to RM2



Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles..

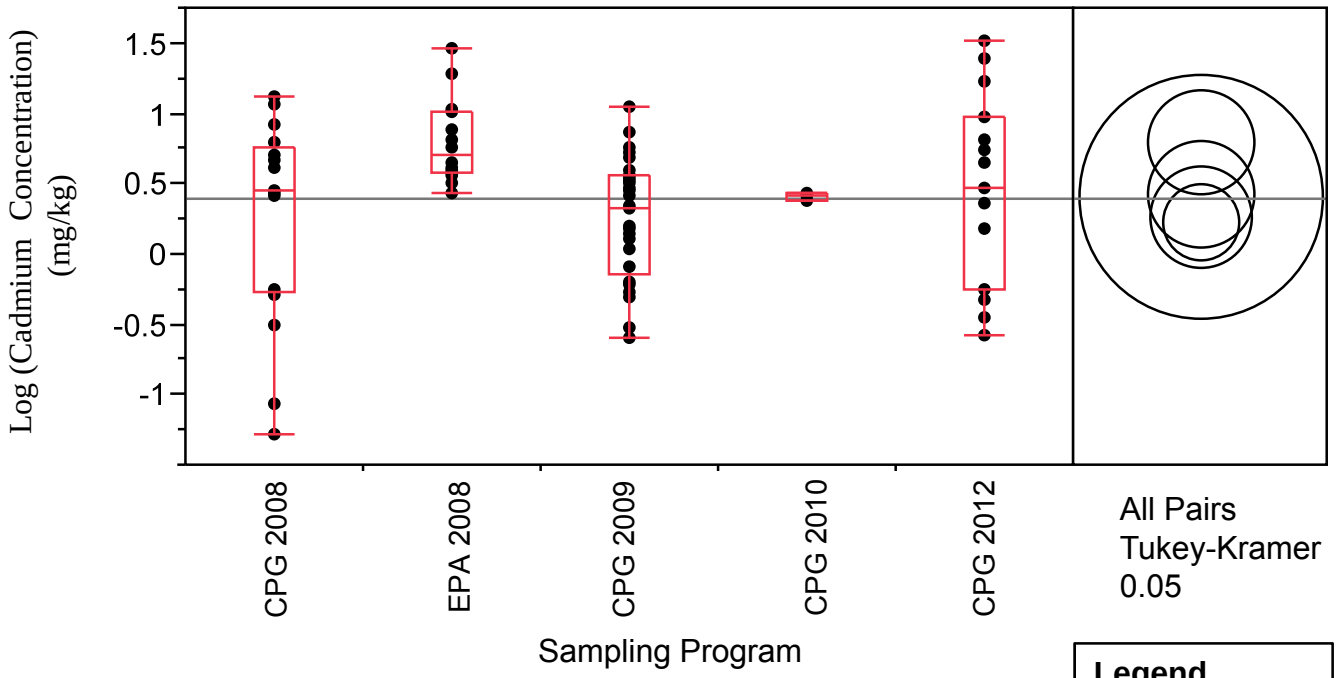


RM2 to RM8

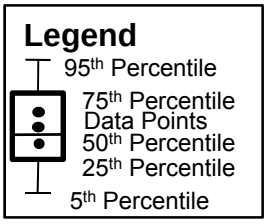


	Cadmium (0-6 inch) by Sampling Program at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-11a** 2014

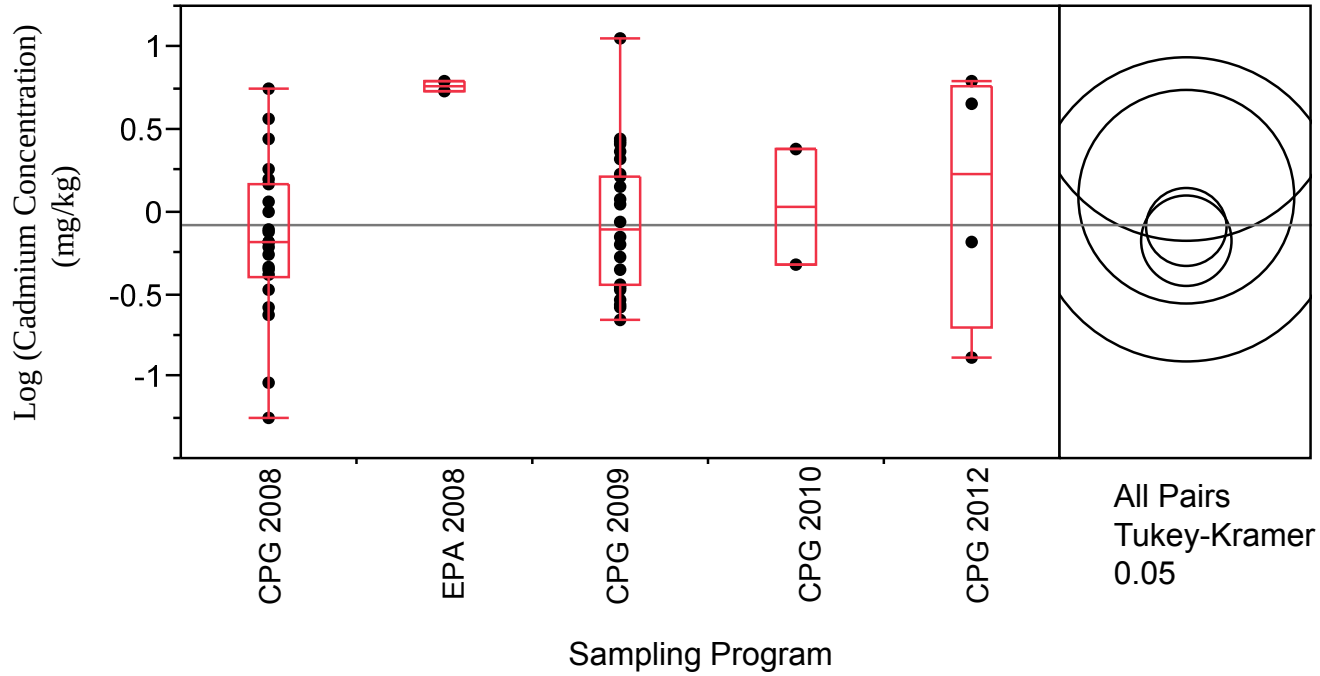
RM8 to RM12



Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles..

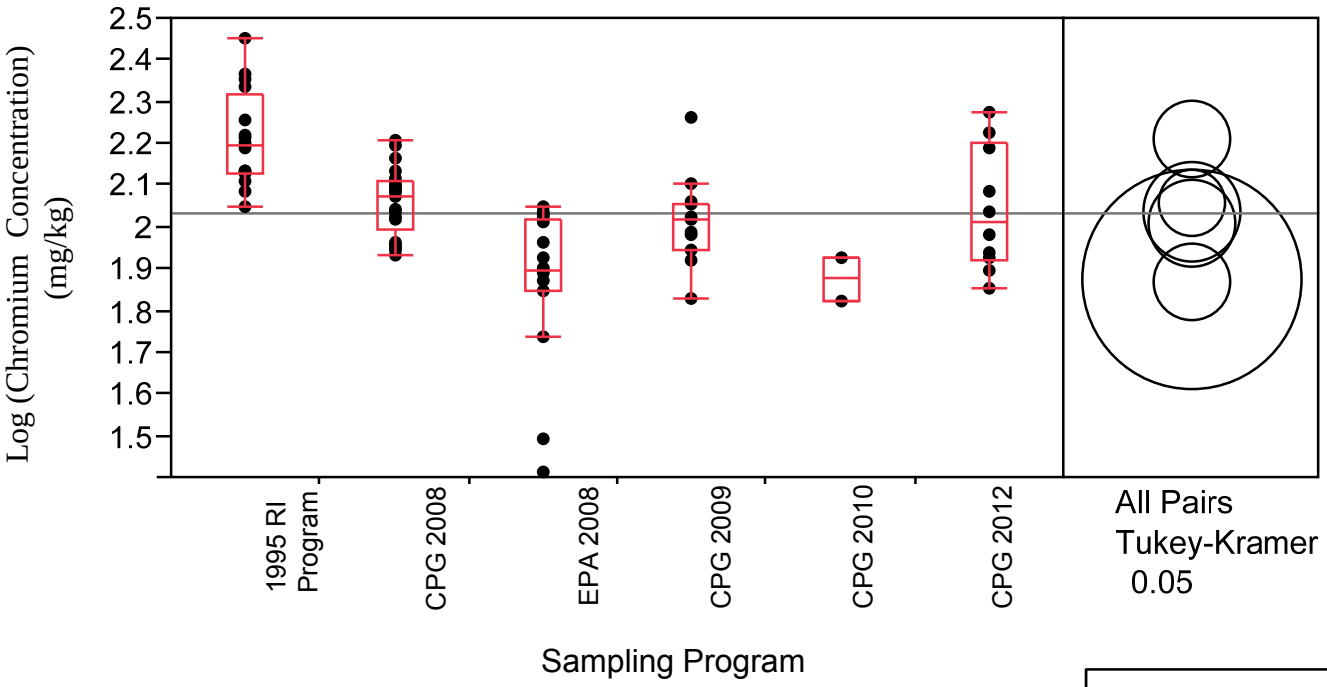


RM12 to RM17.4

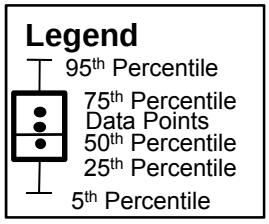


	Cadmium (0-6 inch) by Sampling Program at RM8 to RM12 and RM12 to RM17.4 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-11b** 2014

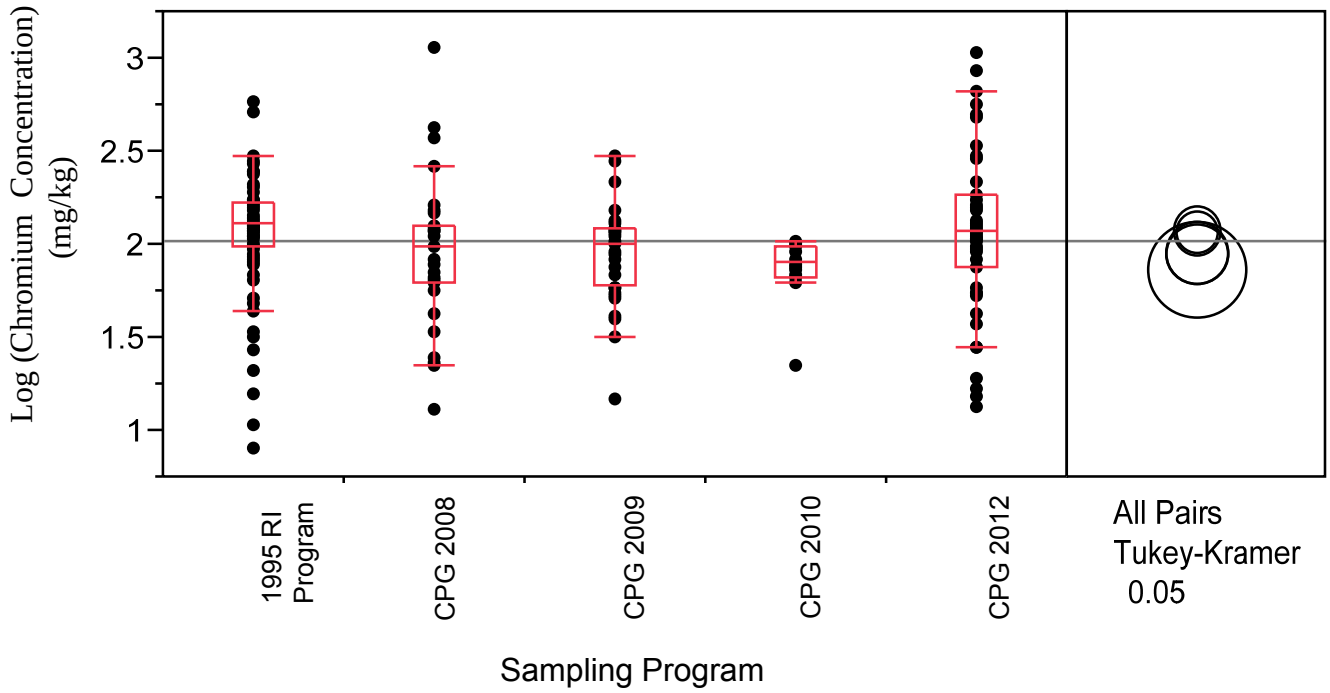
RM0 to RM2



Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles..

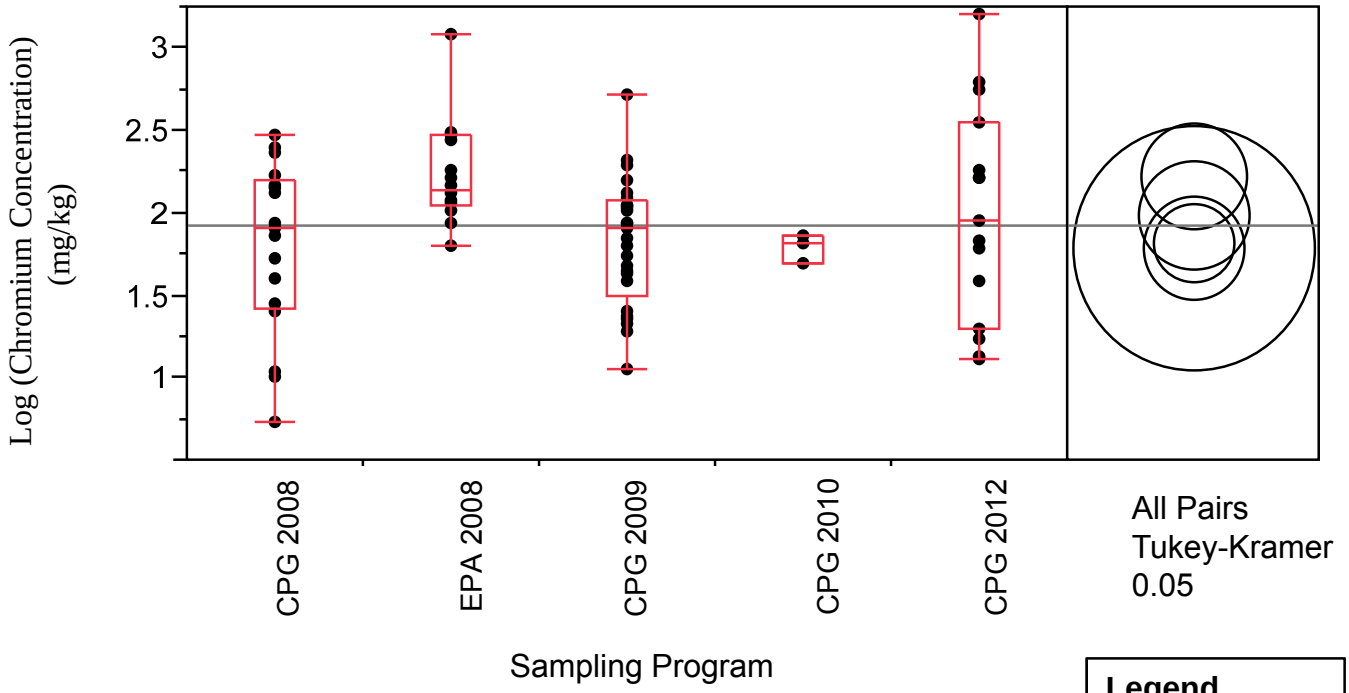


RM2 to RM8

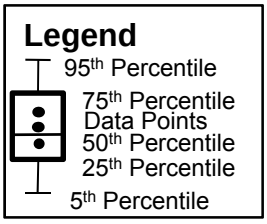


	Chromium (0-6 inch) by Sampling Program at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-12a** 2014

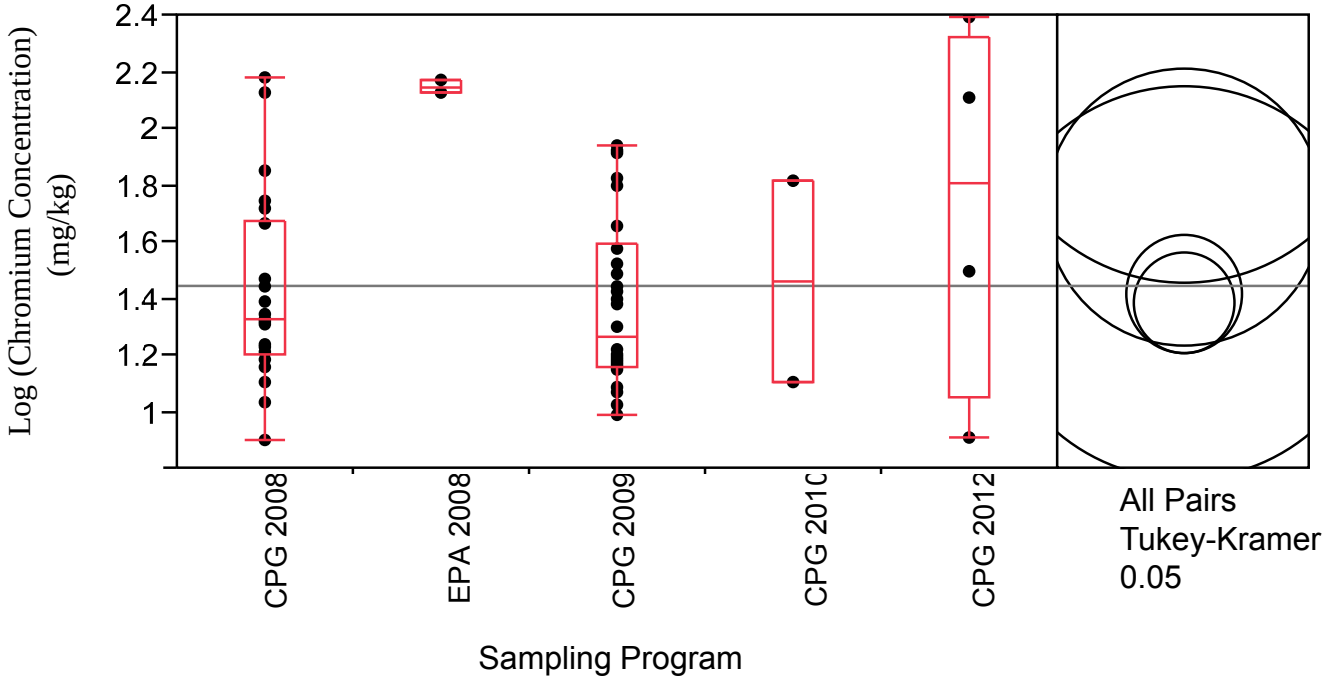
RM8 to RM12



Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles..

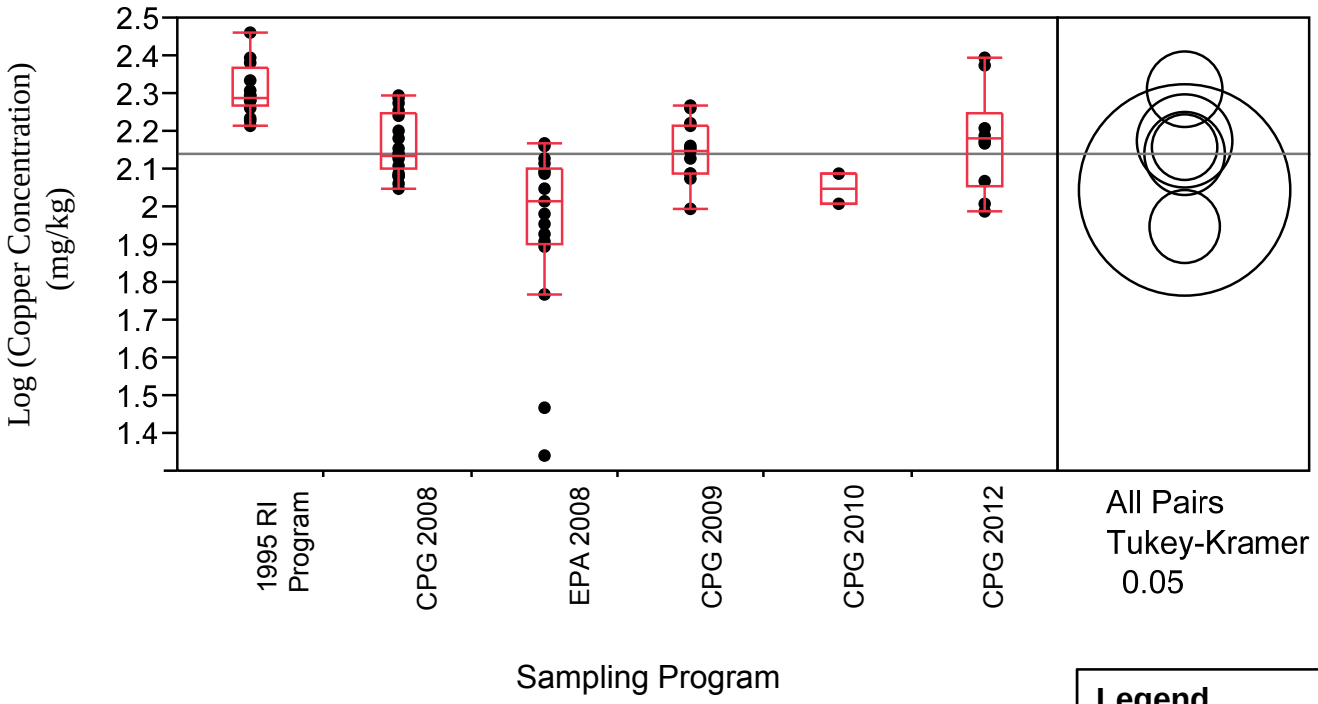


RM12 to RM17.4

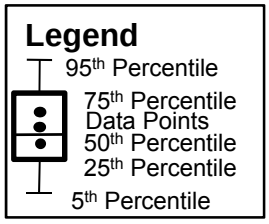


	Chromium (0-6 inch) by Sampling Program at RM8 to RM12 and RM12 to RM17.4 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-12b** 2014

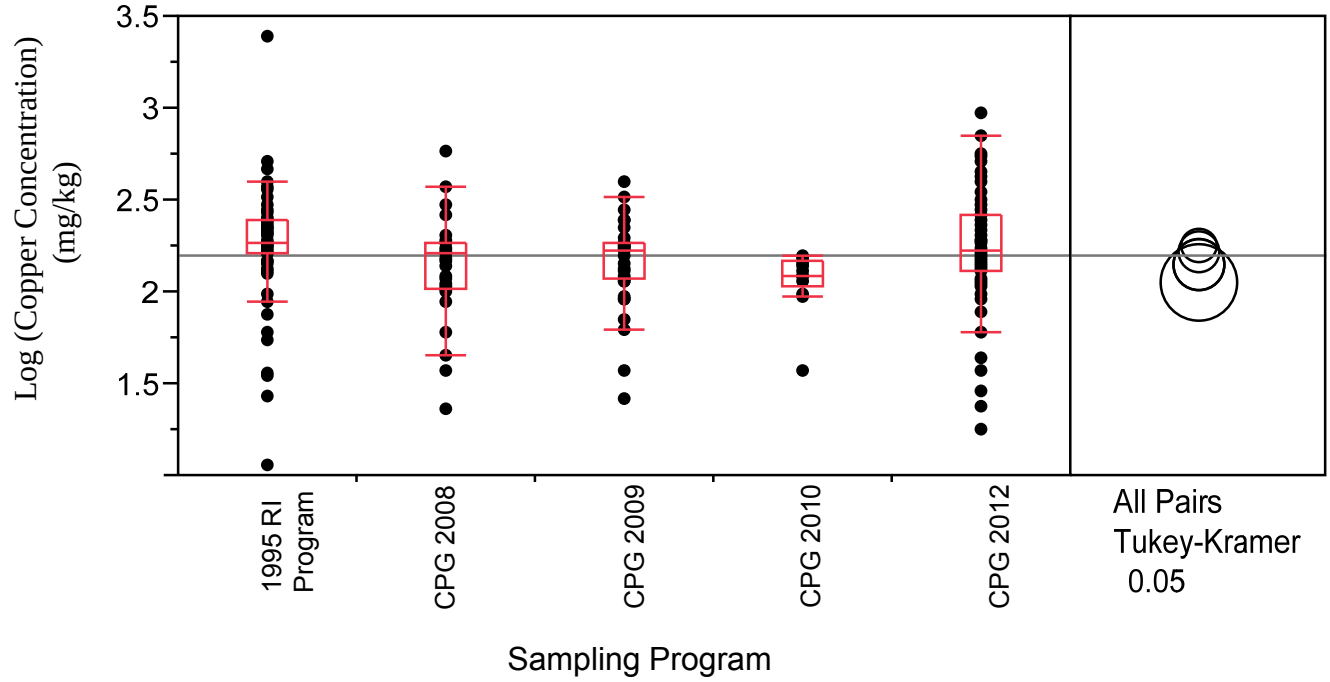
RM0 to RM2



Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles..

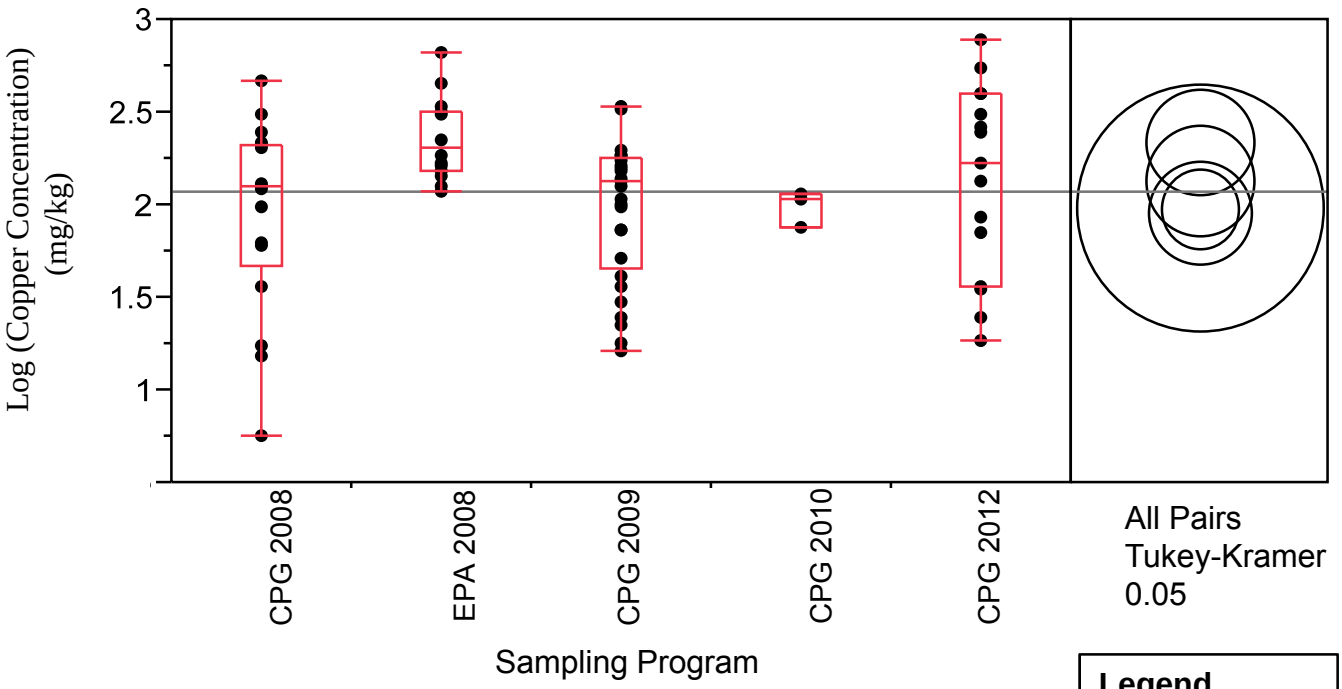


RM2 to RM8

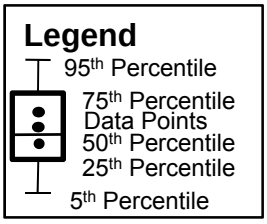


	Copper (0-6 inch) by Sampling Program at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-13a** 2014

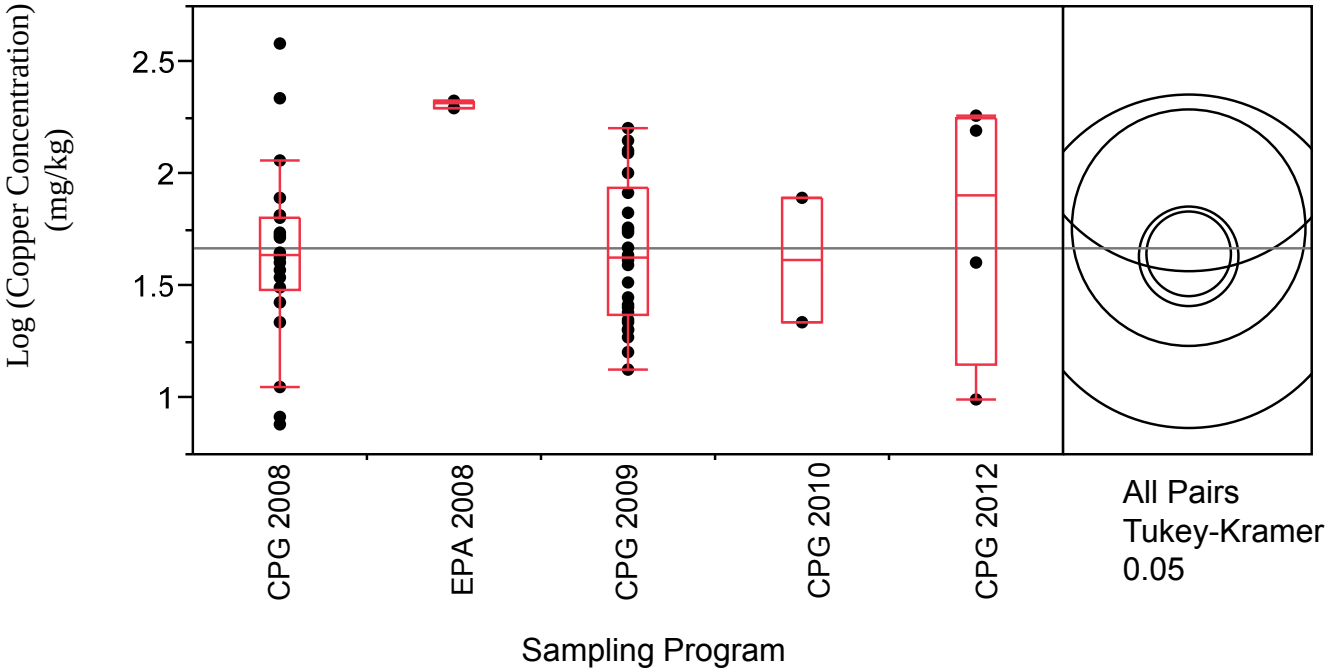
RM8 to RM12



Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles..

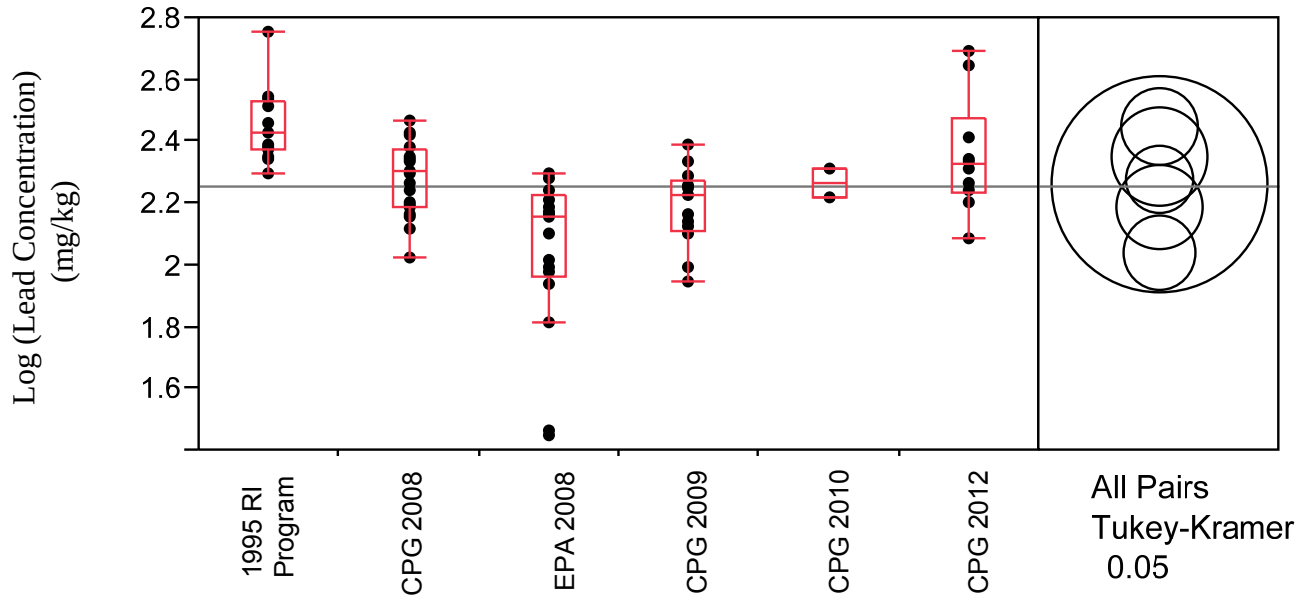


RM12 to RM17.4

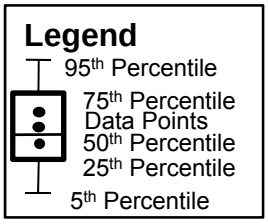


	Copper (0-6 inch) by Sampling Program at RM8 to RM12 and RM12 to RM17.4 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-13b** 2014

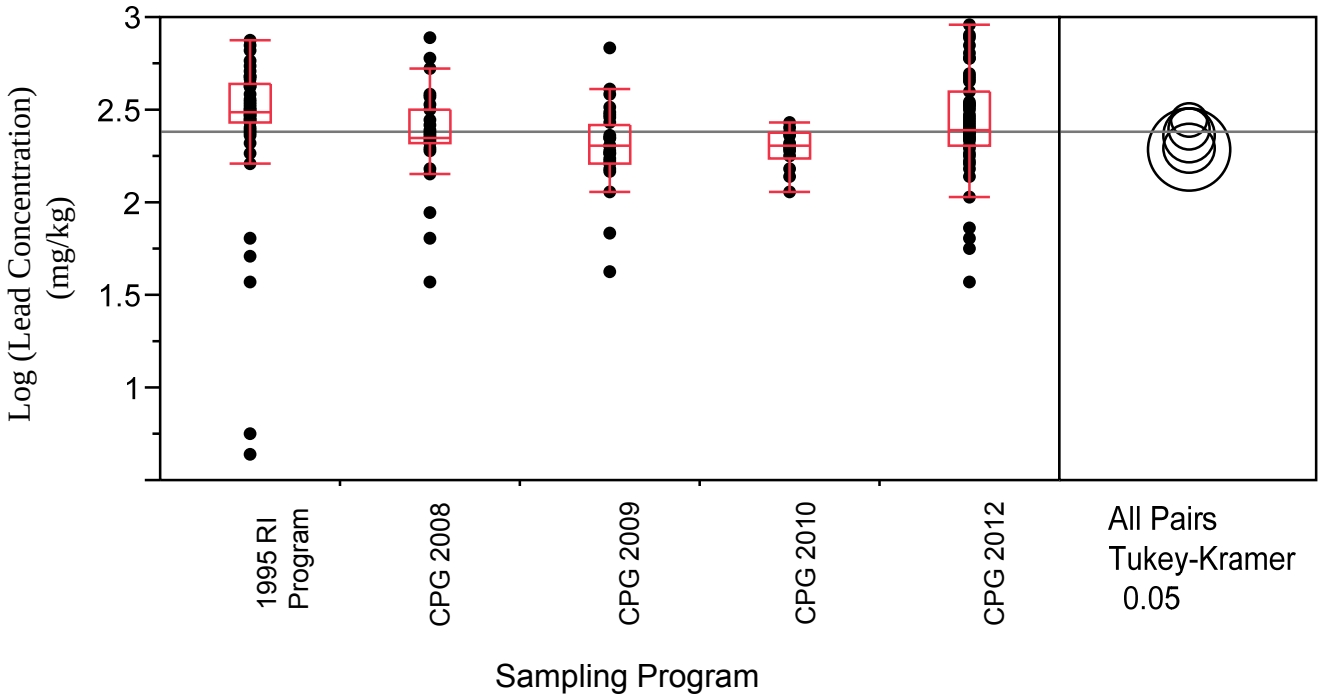
RM0 to RM2



Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles..

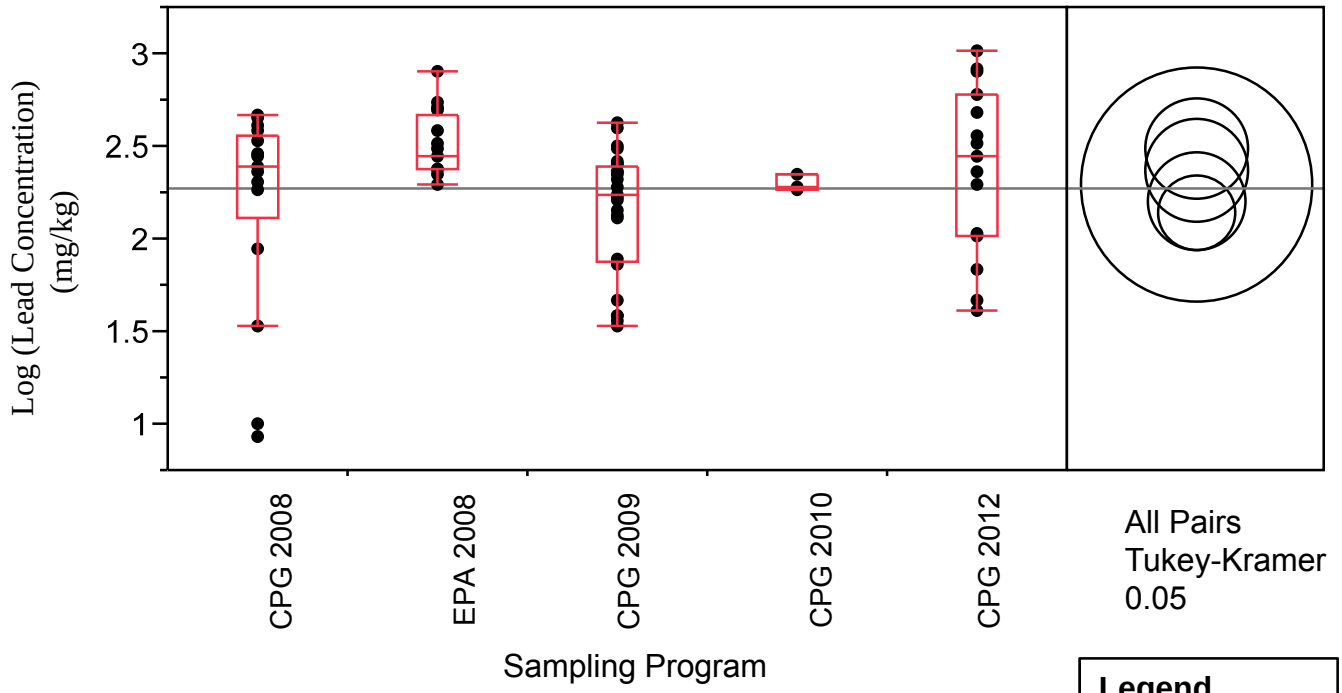


RM2 to RM8

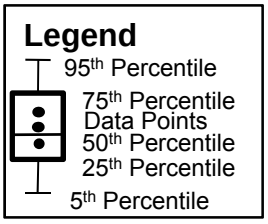


	Lead (0-6 inch) by Sampling Program at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-14a** 2014

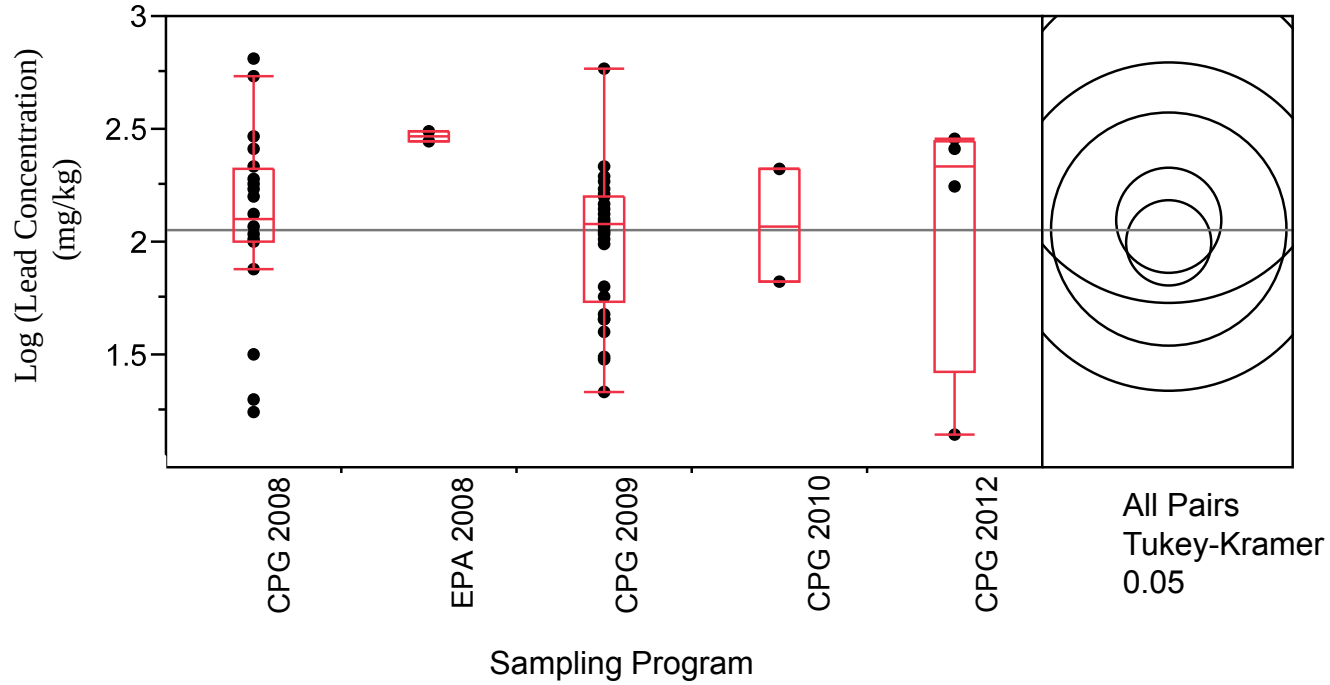
RM8 to RM12



Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles..

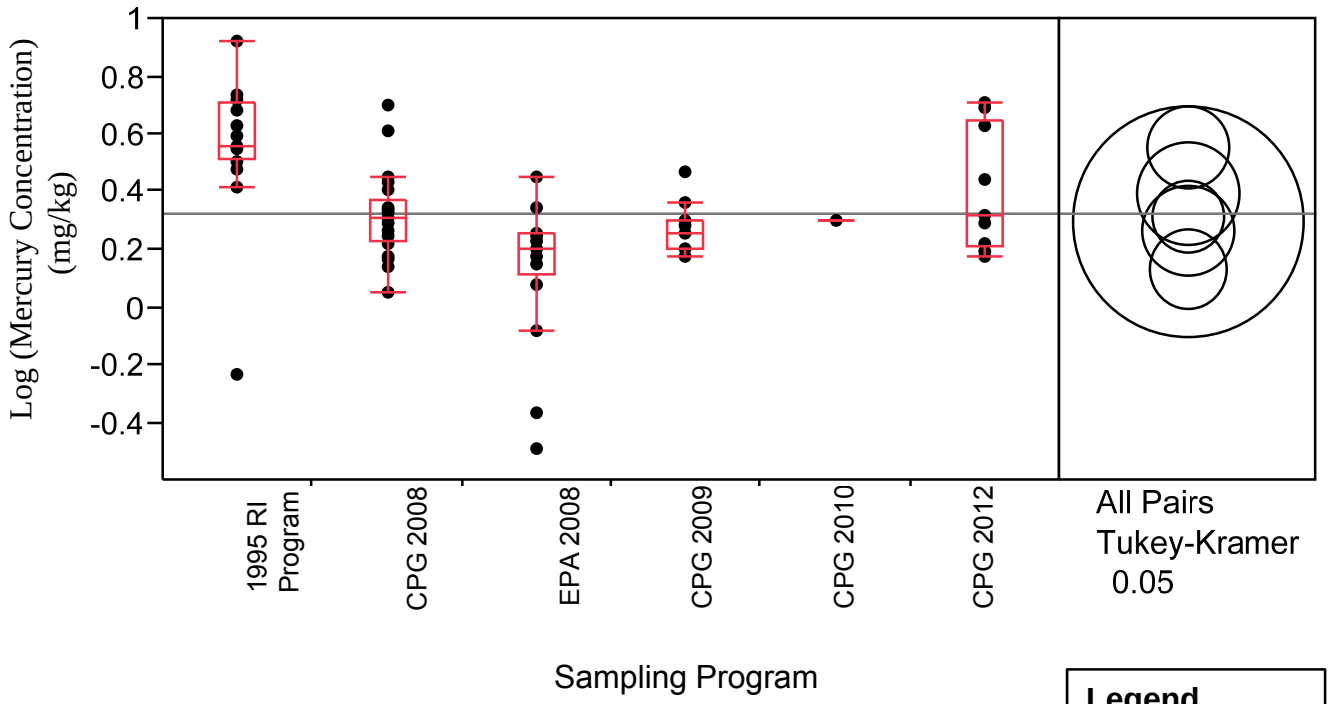


RM12 to RM17.4

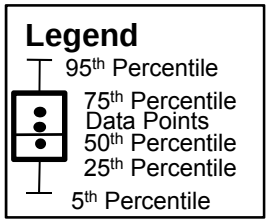


	Lead (0-6 inch) by Sampling Program at RM8 to RM12 and RM12 to RM17.4 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-14b** 2014

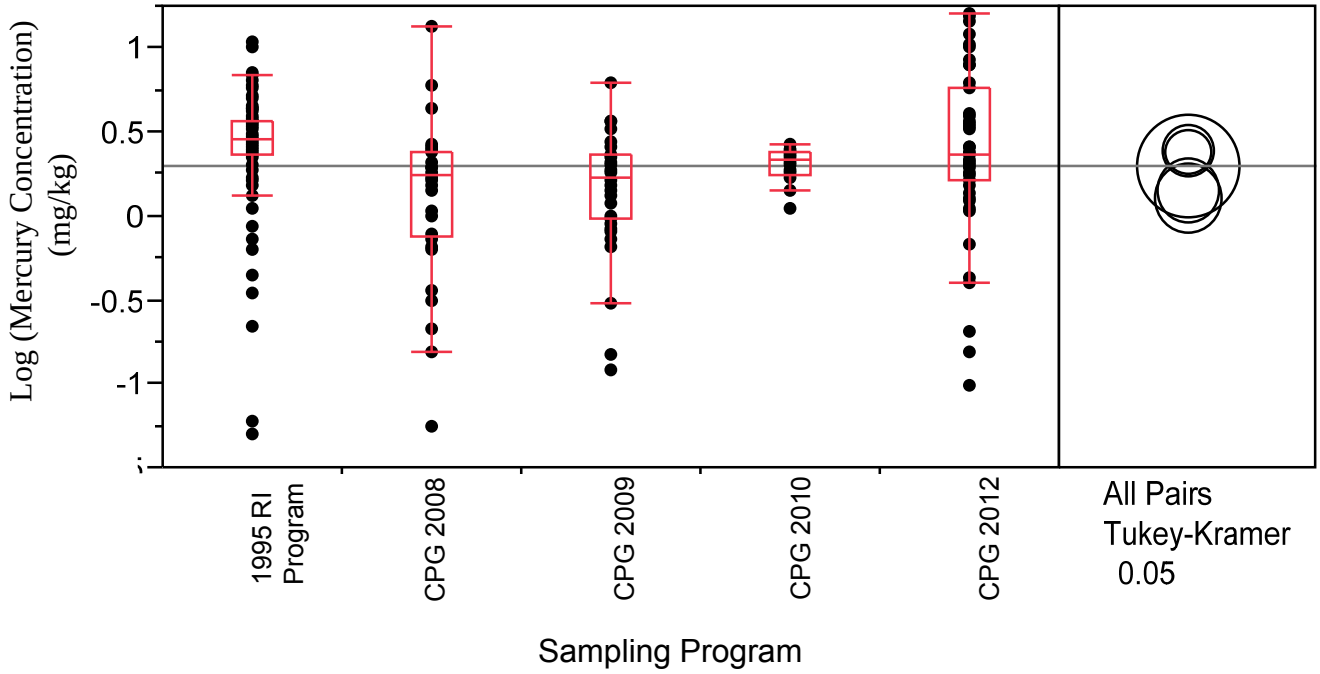
RM0 to RM2



Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles..



RM2 to RM8



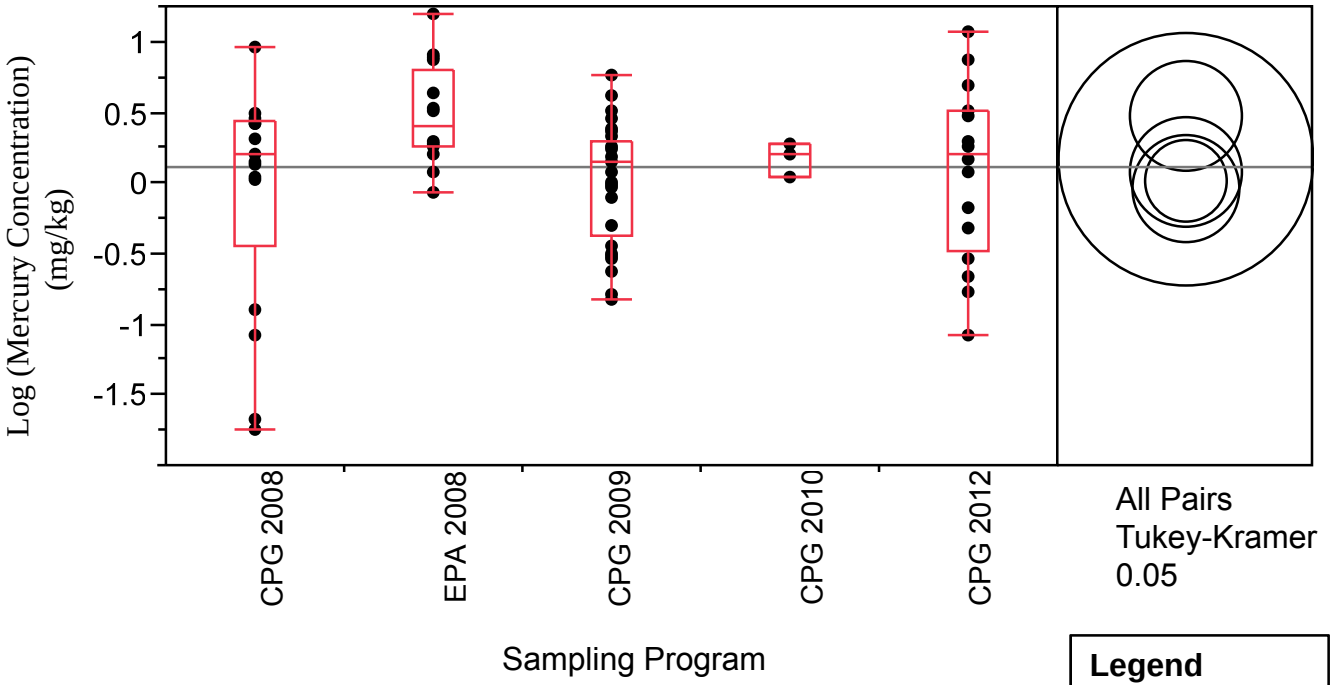
Mercury (0-6 inch) by Sampling Program at RM0 to RM2 and RM2 to RM8

Lower Eight Miles of the Lower Passaic River

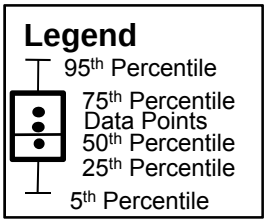
Figure 3.4-15a

2014

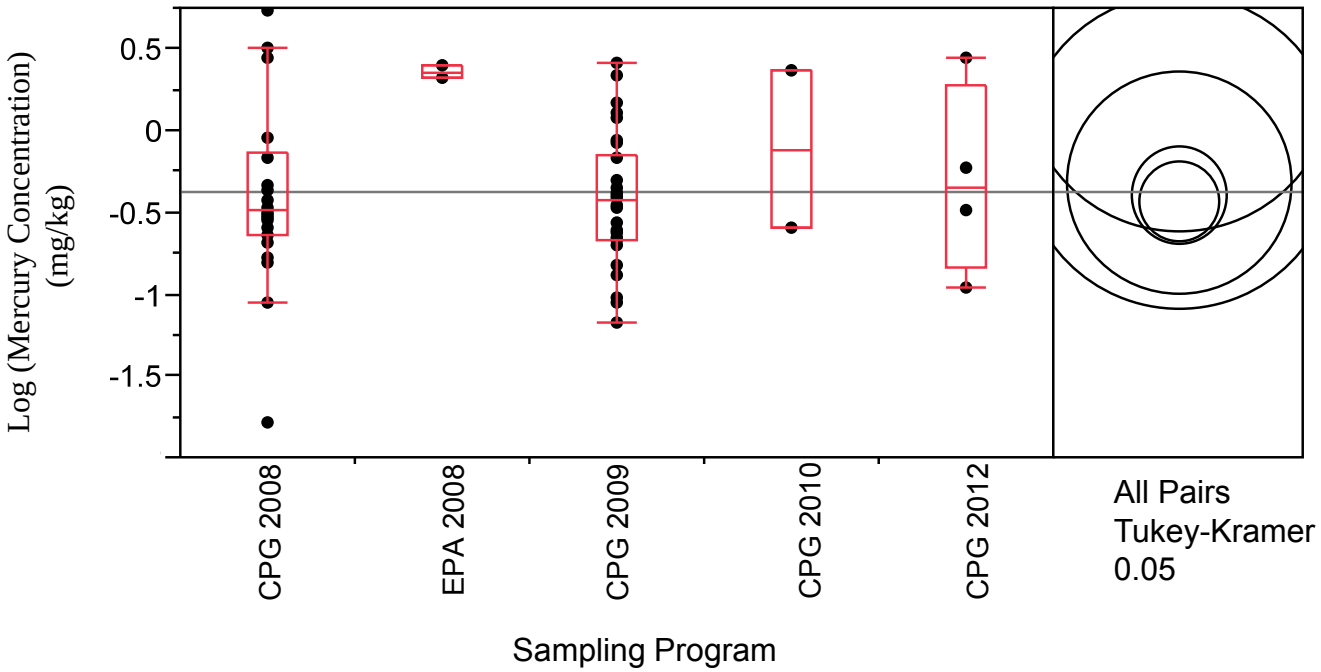
RM8 to RM12



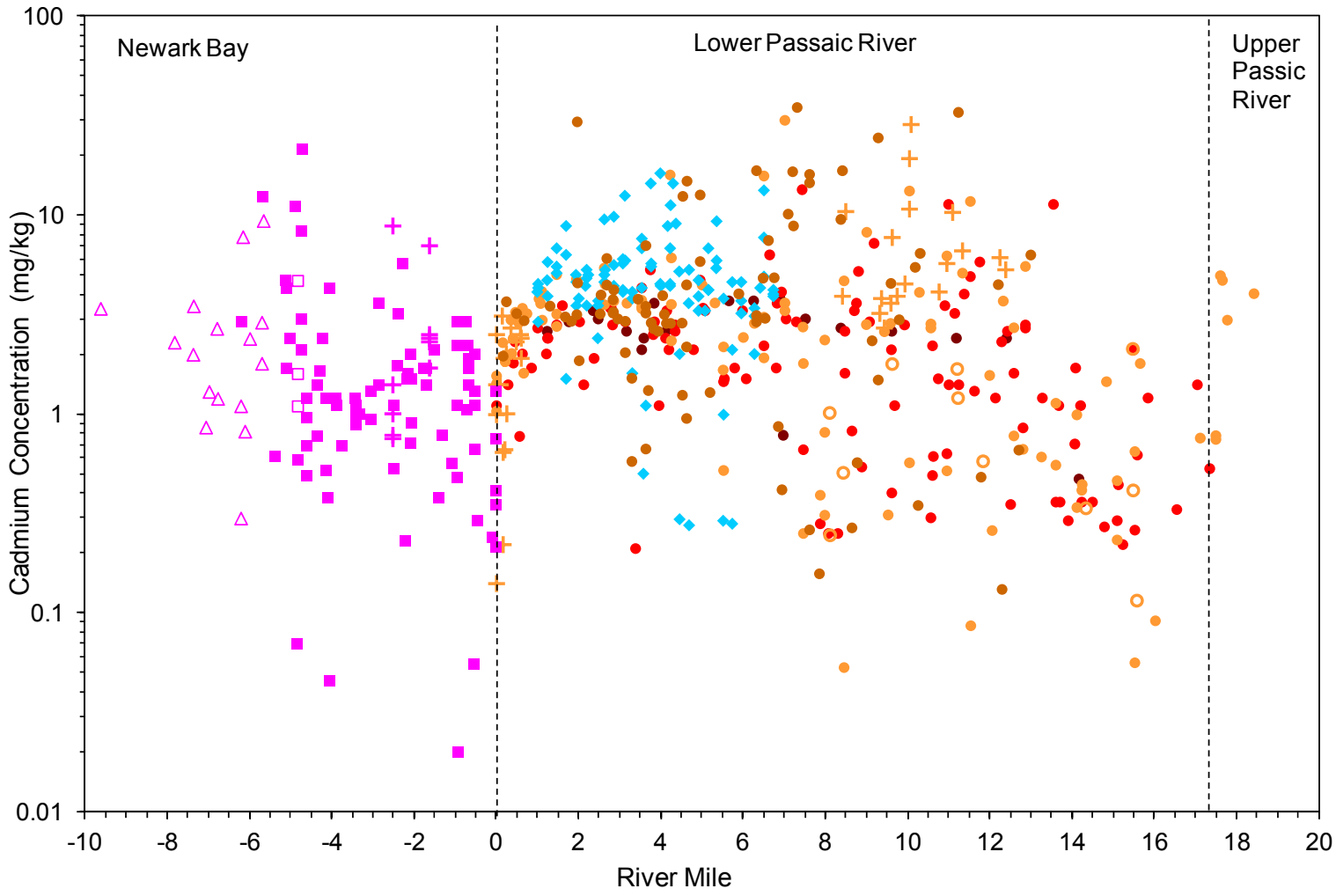
Note: Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles..



RM12 to RM17.4



	Mercury (0-6 inch) by Sampling Program at RM8 to RM12 and RM12 to RM17.4 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-15b** 2014



Legend

- 2012 CPG
- 2010 CPG
- 2009 CPG
- 2008 CPG
- 2008 CPG Tributary Below HoT
- 2008 EPA
- 2005&2007 Newark Bay
- 2005&2007 Shooters Island & Arthur Kill
- 2005&2007 Kill Van Kull
- 2005&2007 Port Elizabeth & Newark
- 1995 TSI

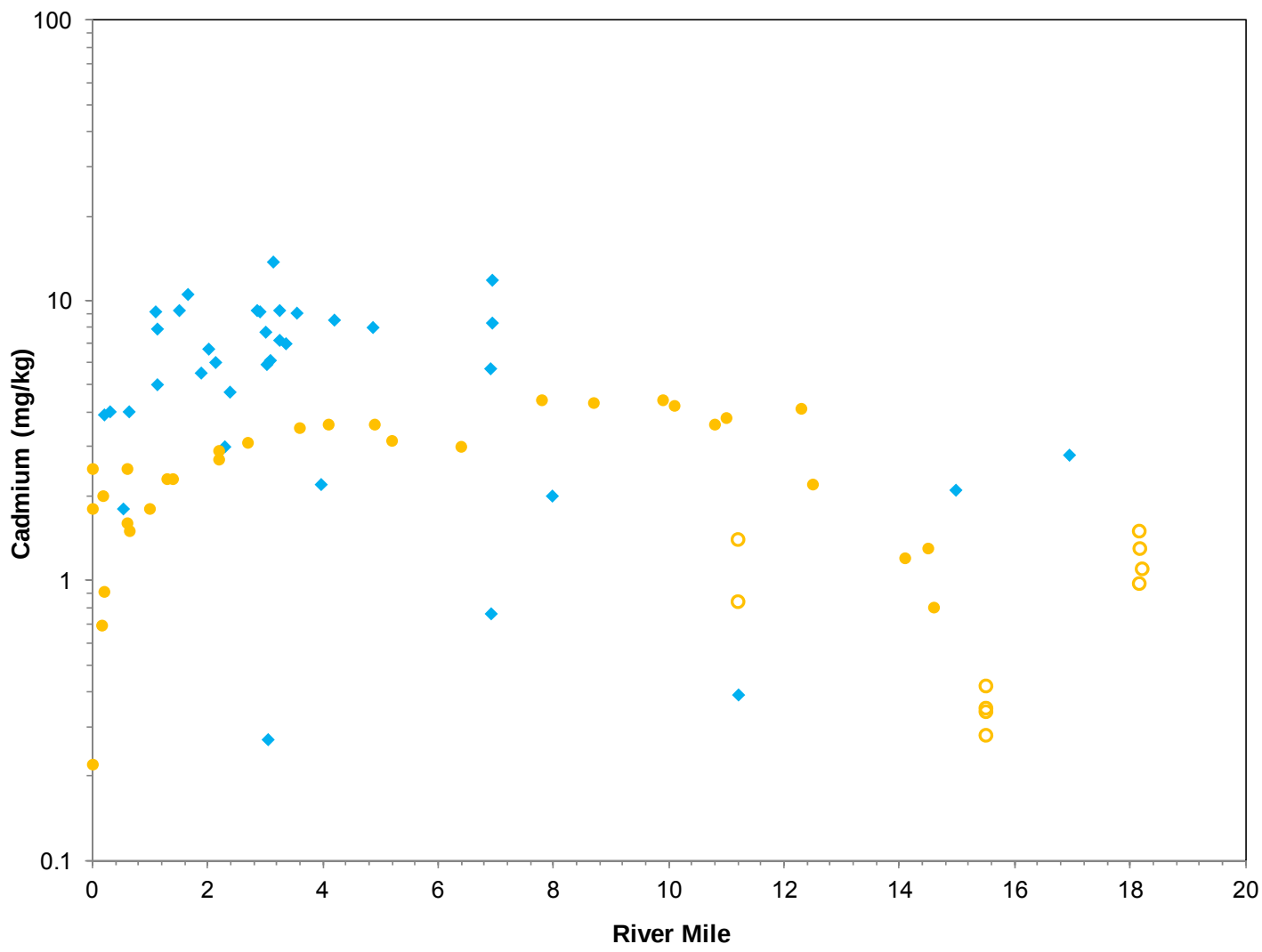
Cadmium Concentration (0-6 inches) *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 3.4-16

2014

R2-0027237



Legend

- 1991-1993
- 2007-2008 EPA
- 2007-2008 EPA Tributary Above HoT

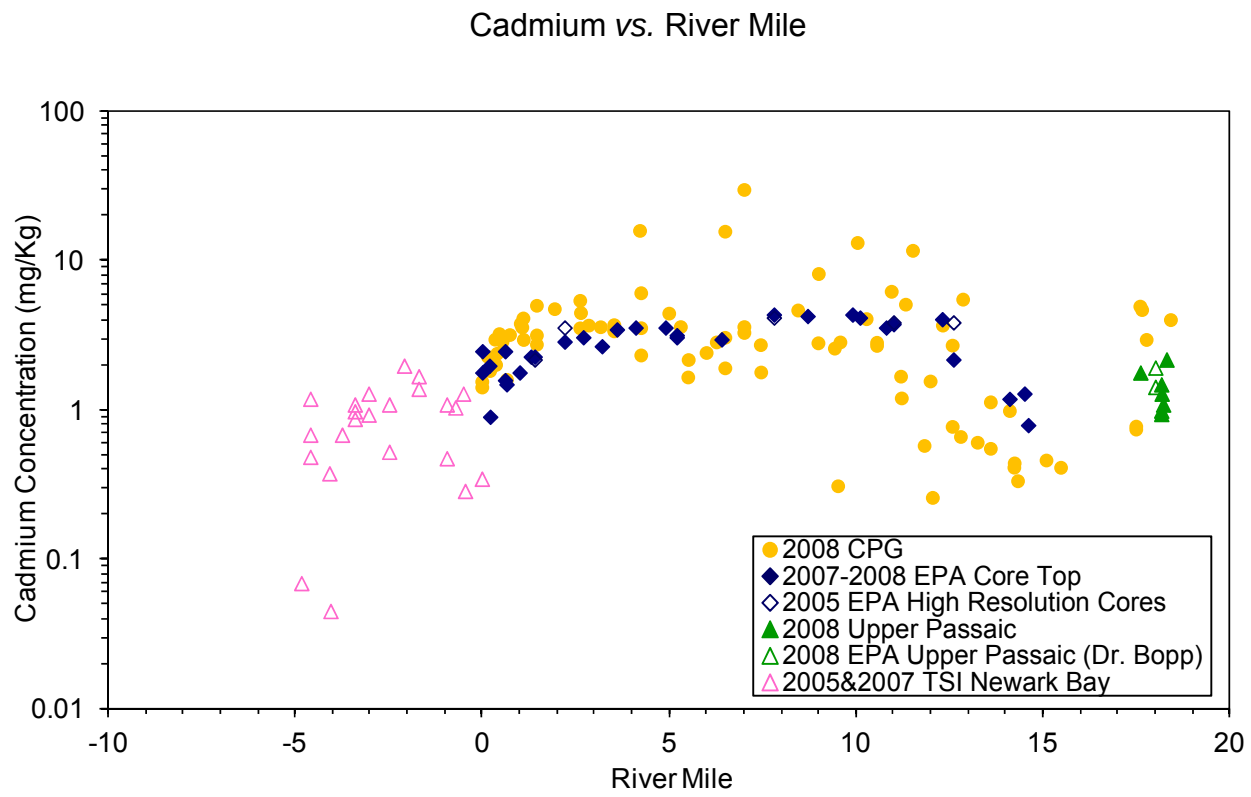
Cadmium Concentration (0 - ≤2 inches) *vs.* River Mile

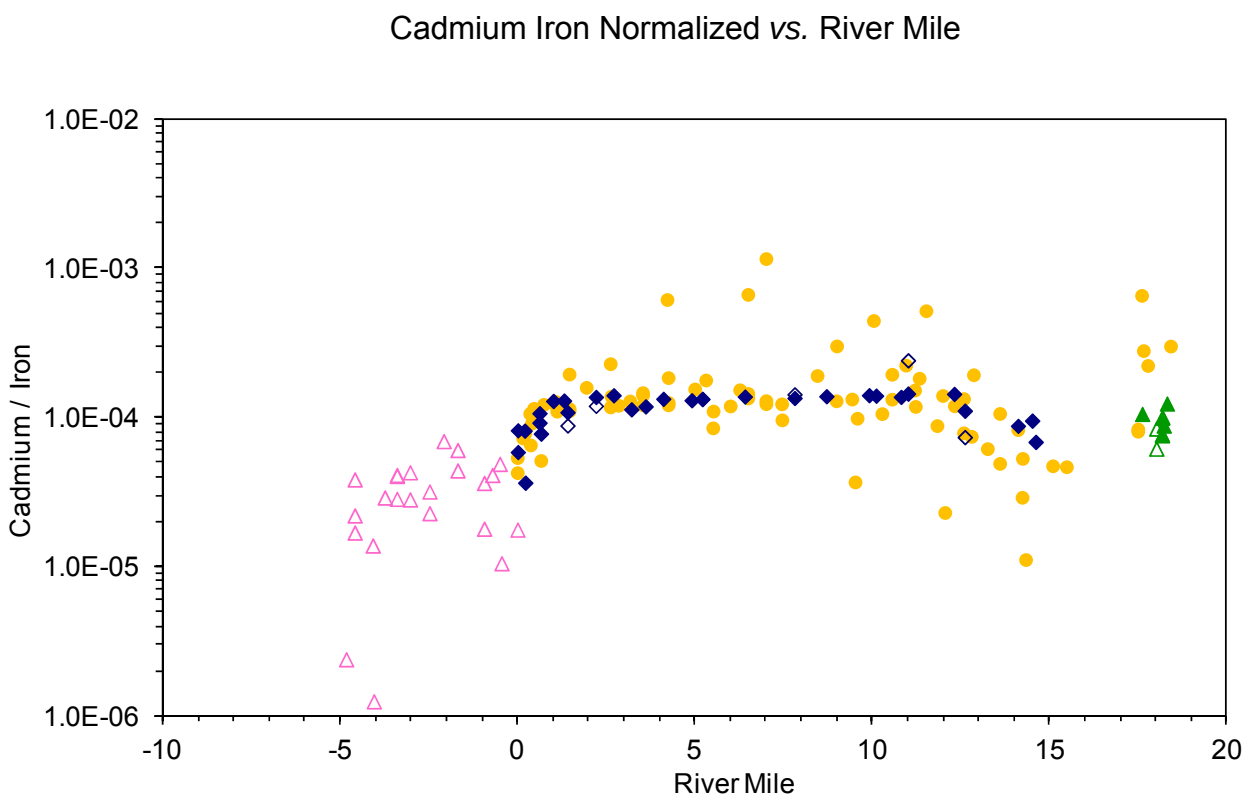
Lower Eight Miles of the Lower Passaic River

Figure 3.4-17

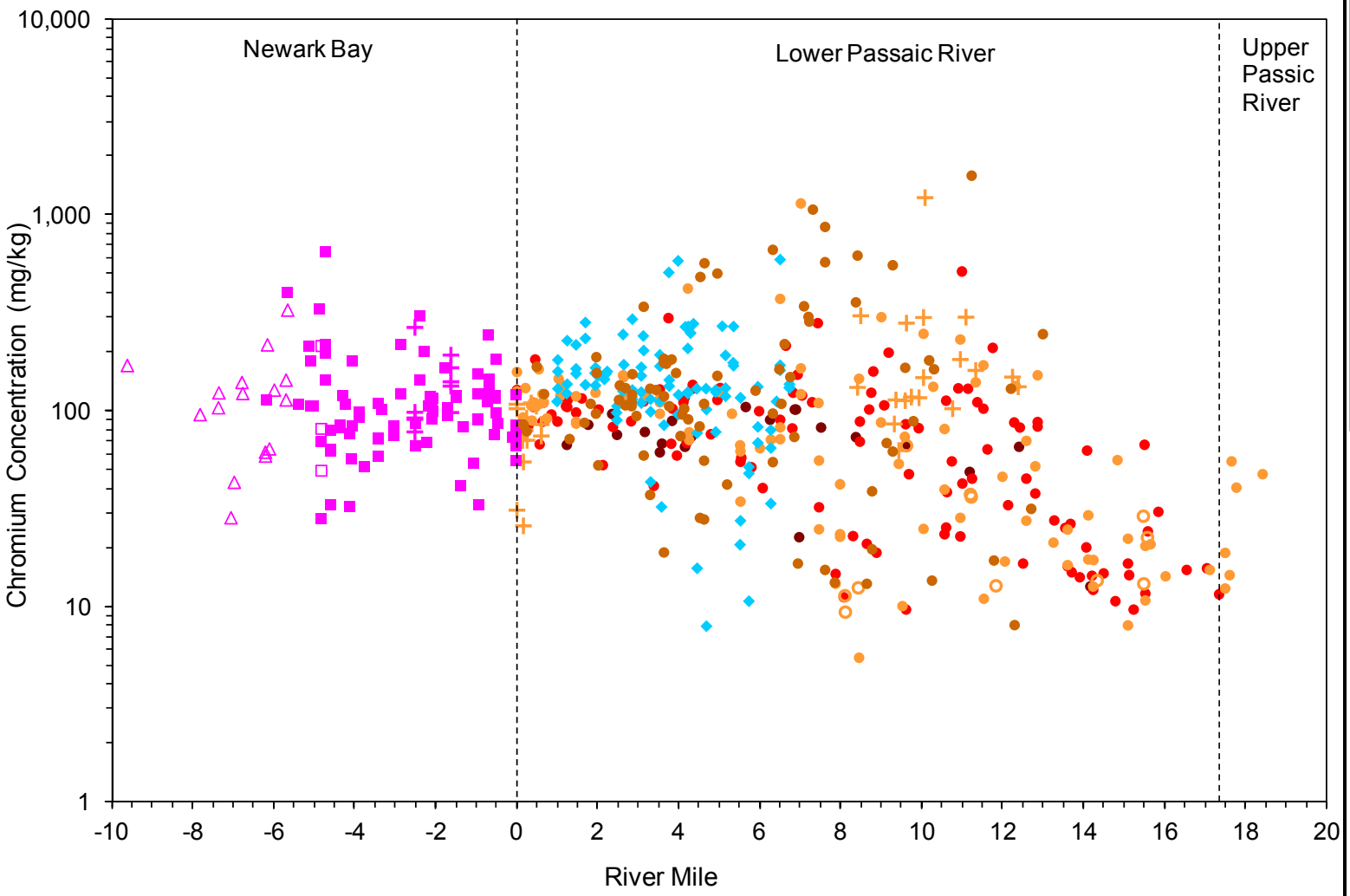
2014

R2-0027238





	Cadmium in Recently-Deposited Sediments in the Lower Passaic River, Newark Bay and the Upper Passaic River *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-18** 2014



Legend

- 2012 CPG
- 2010 CPG
- 2009 CPG
- 2008 CPG
- 2008 CPG Tributary Below HoT
- 2008 EPA
- 2005&2007 Newark Bay
- 2005&2007 Shooters Island & Arthur Kill
- 2005&2007 Kill Van Kull
- 2005&2007 Port Elizabeth & Newark
- 1995 TSI

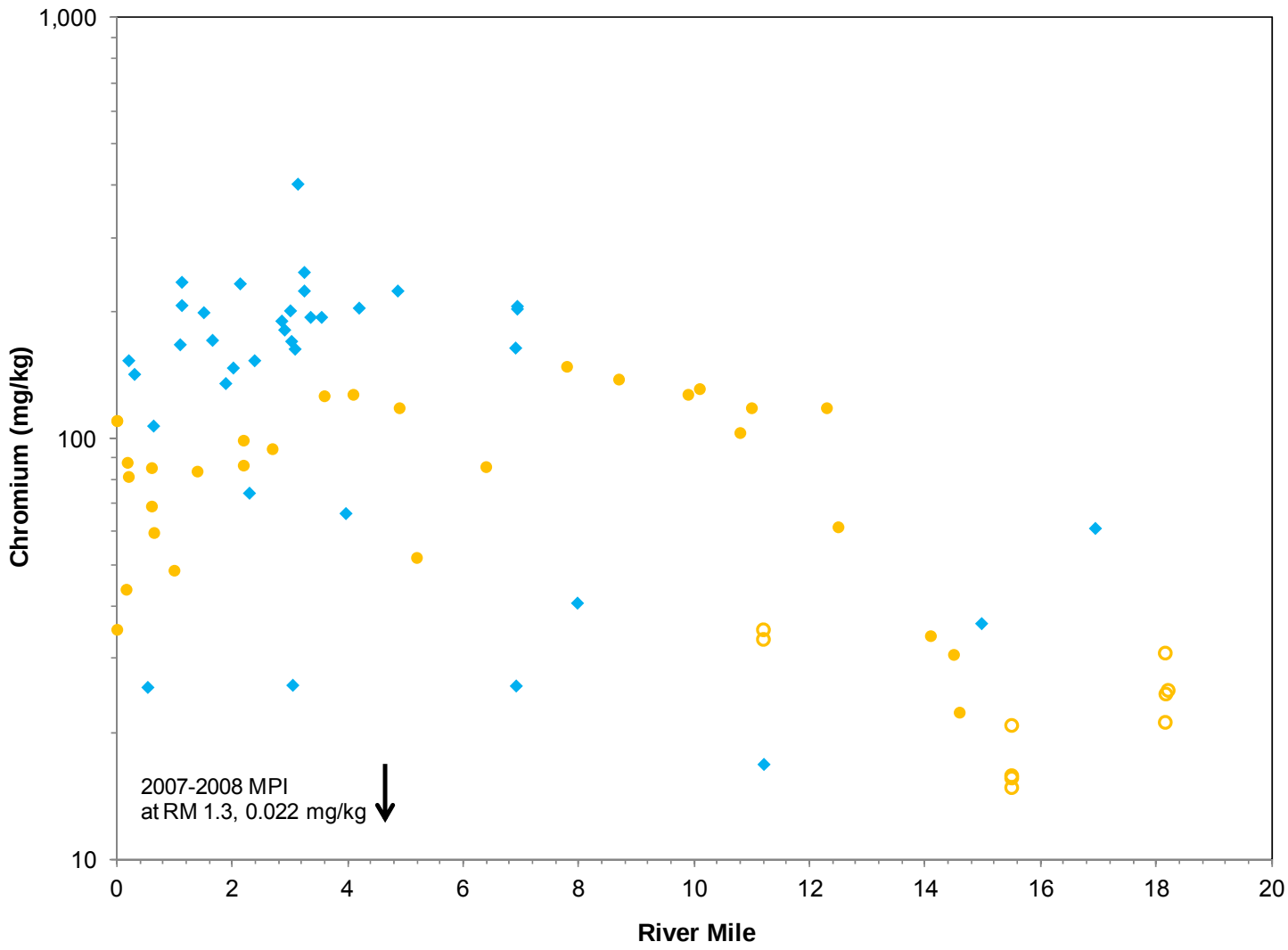
Chromium Concentration (0-6 inches) *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 3.4-19

2014

R2-0027240



Legend

- 1991-1993
- 2007-2008 EPA
- 2007-2008 EPA Tributary Above HoT

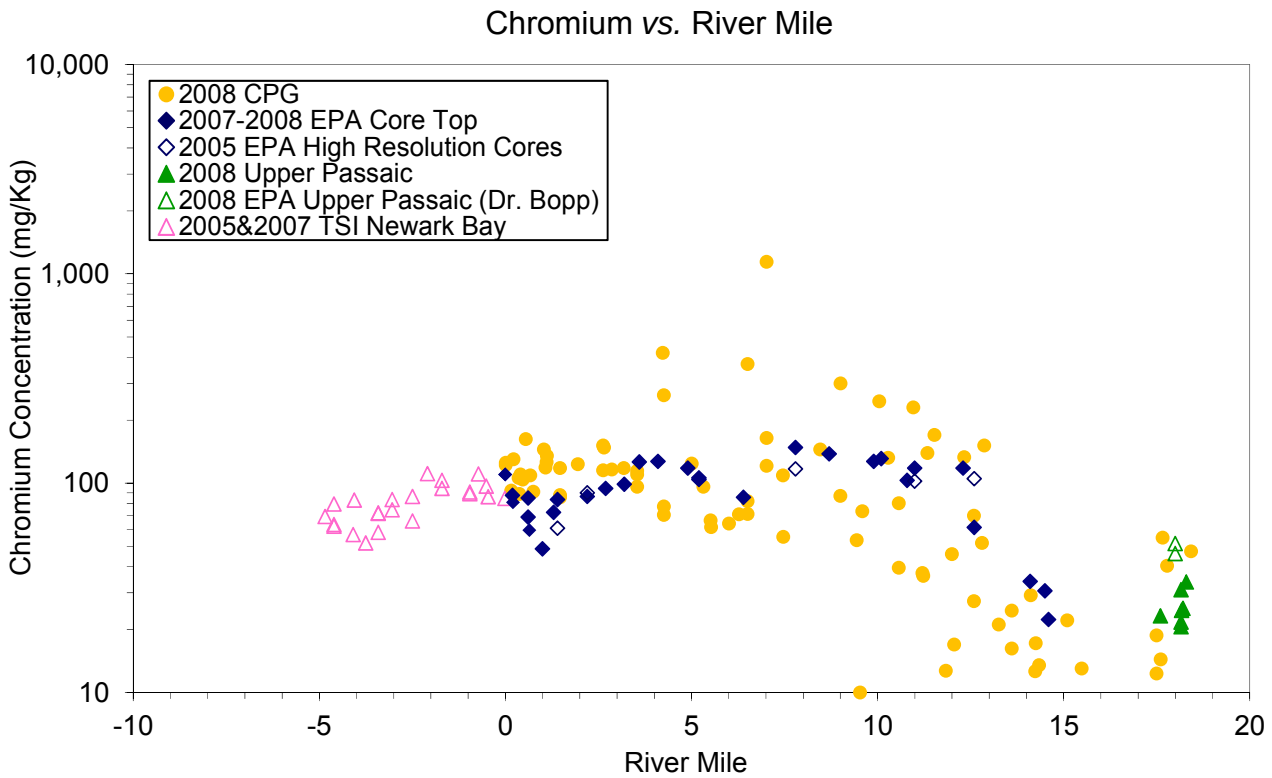
Chromium Concentration (0 - ≤2 inches) *vs.* River Mile

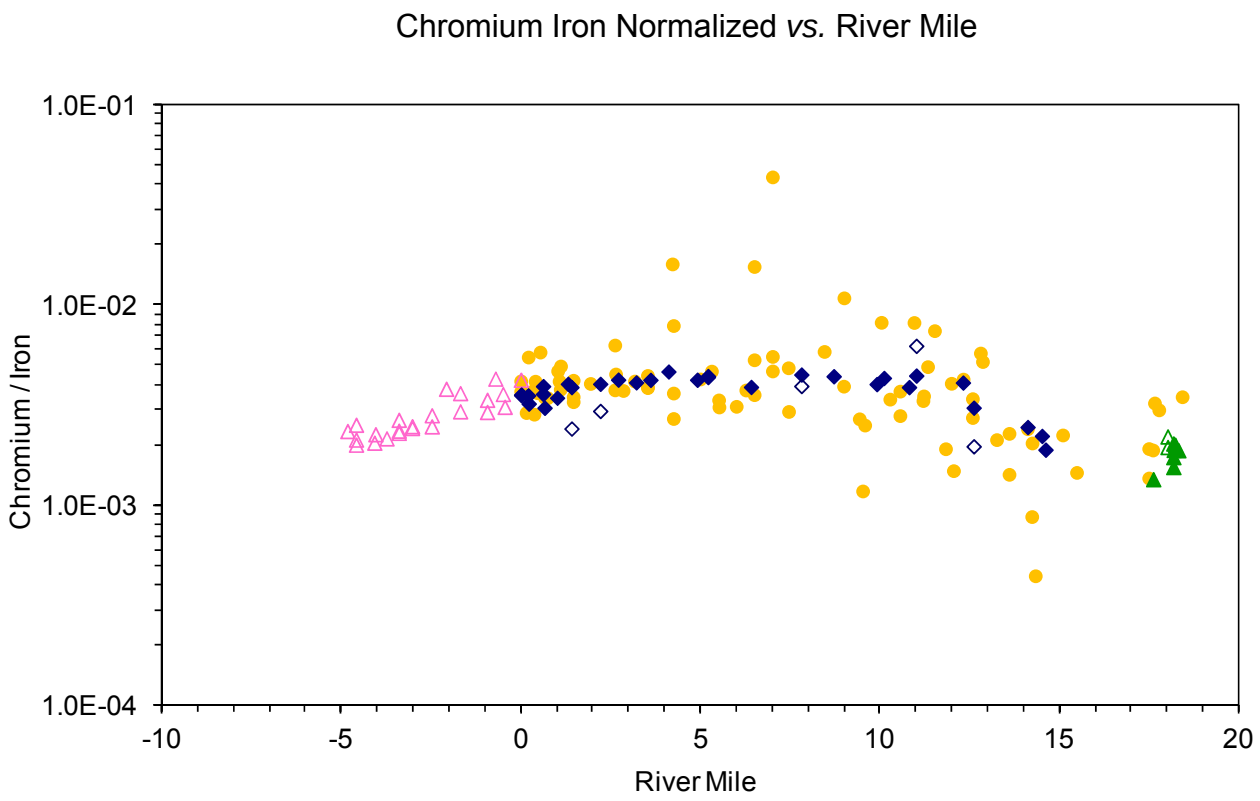
Lower Eight Miles of the Lower Passaic River

Figure 3.4-20

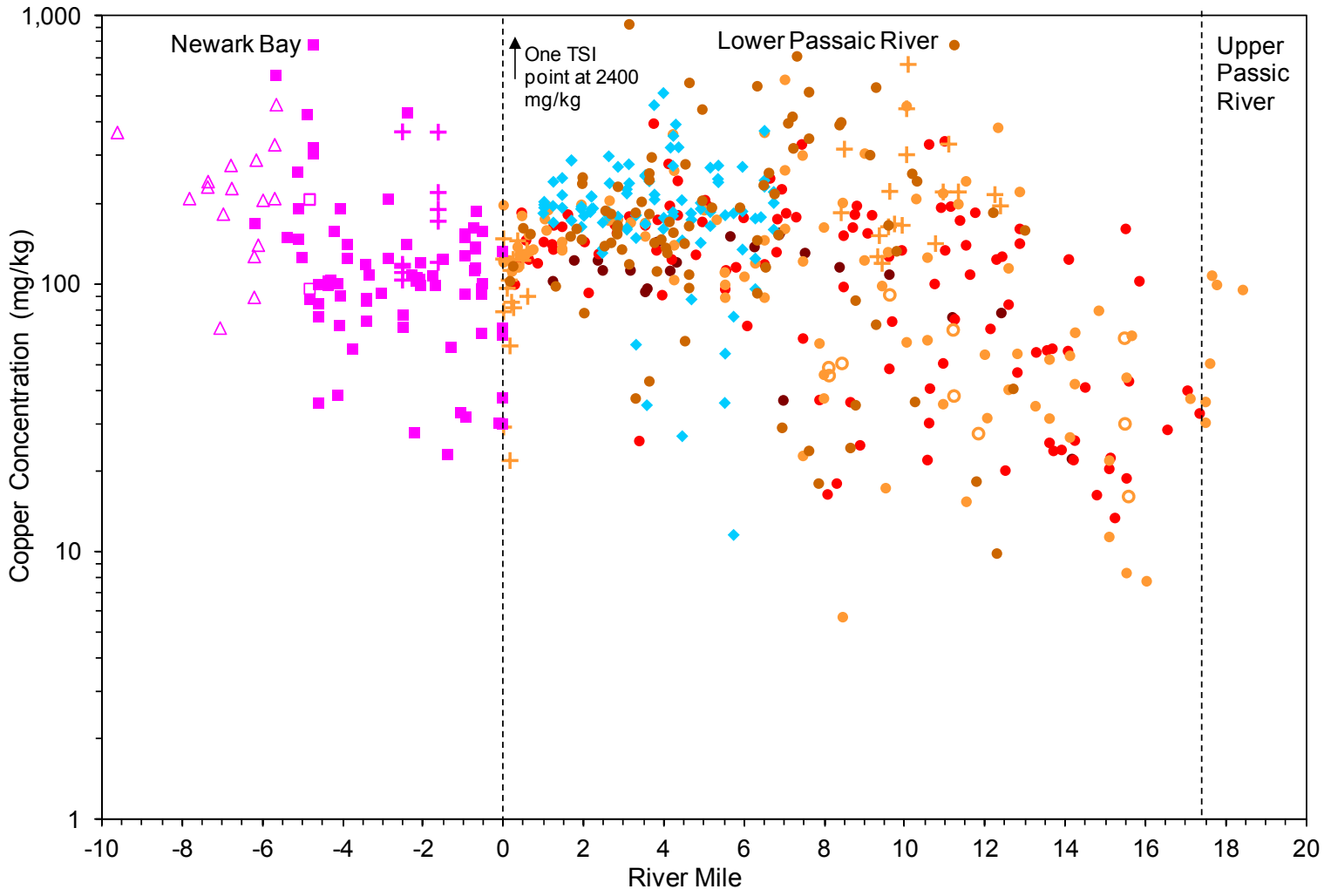
2014

R2-0027241





	Chromium in Recently-Deposited Sediments in the Lower Passaic River, Newark Bay and the Upper Passaic River *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-21** 2014



Legend

- 2012 CPG
- 2010 CPG
- 2009 CPG
- 2008 CPG
- 2008 CPG Tributary Below HoT
- 2008 EPA
- 2005&2007 Newark Bay
- 2005&2007 Shooters Island & Arthur Kill
- 2005&2007 Kill Van Kull
- 2005&2007 Port Elizabeth & Newark
- 1995 TSI

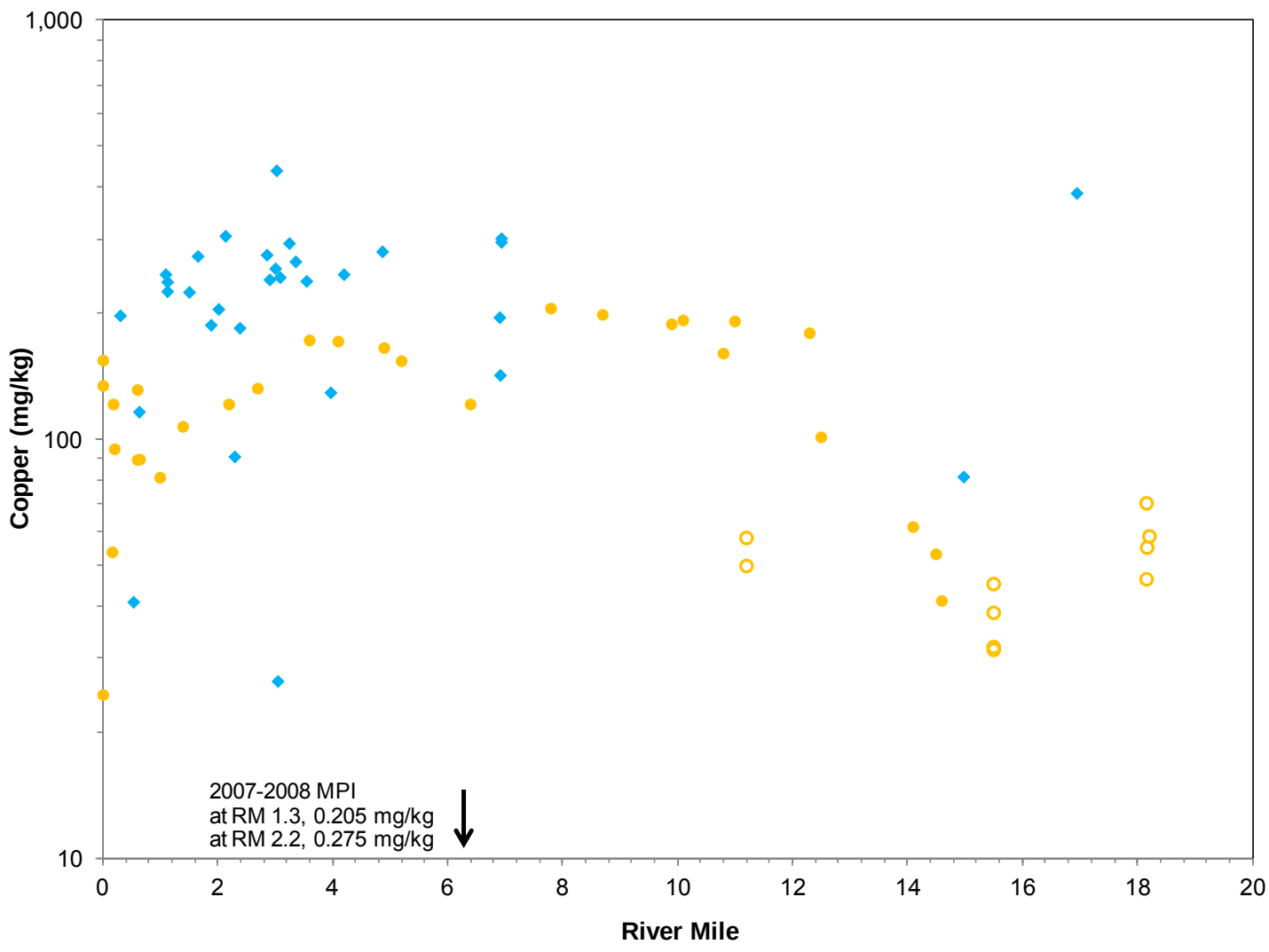
Copper Concentration (0-6 inches) *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 3.4-22

2014

R2-0027243



Legend

- 1991-1993
- 2007-2008 EPA
- 2007-2008 EPA Tributary Above HoT

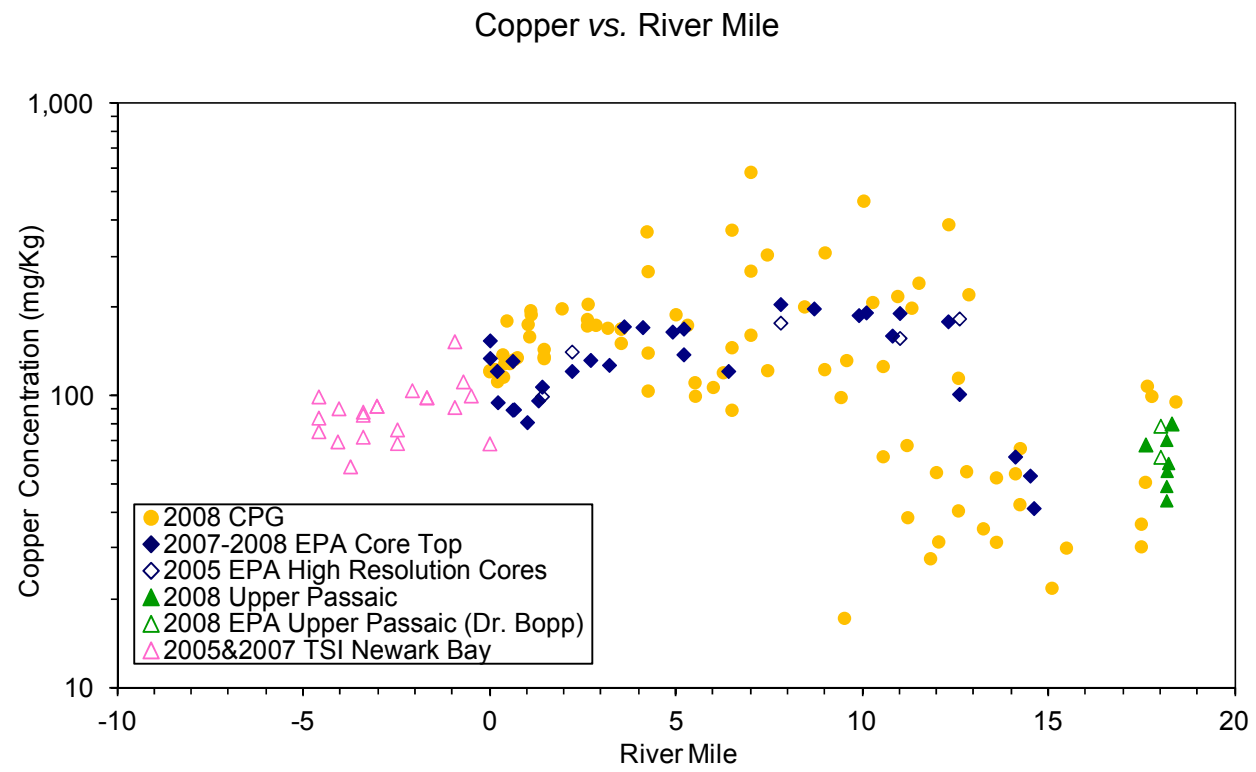
Copper Concentration (0 - ≤2 inches) *vs.* River Mile

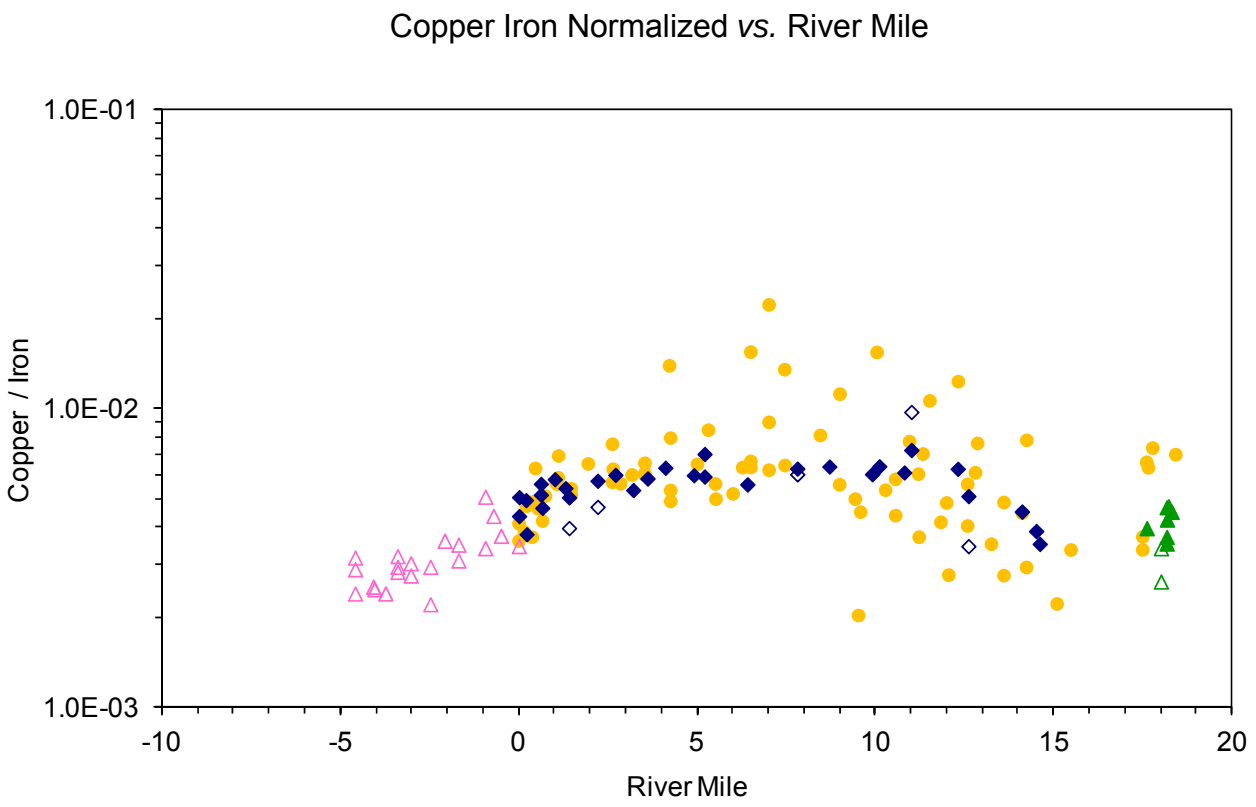
Lower Eight Miles of the Lower Passaic River

Figure 3.4-23

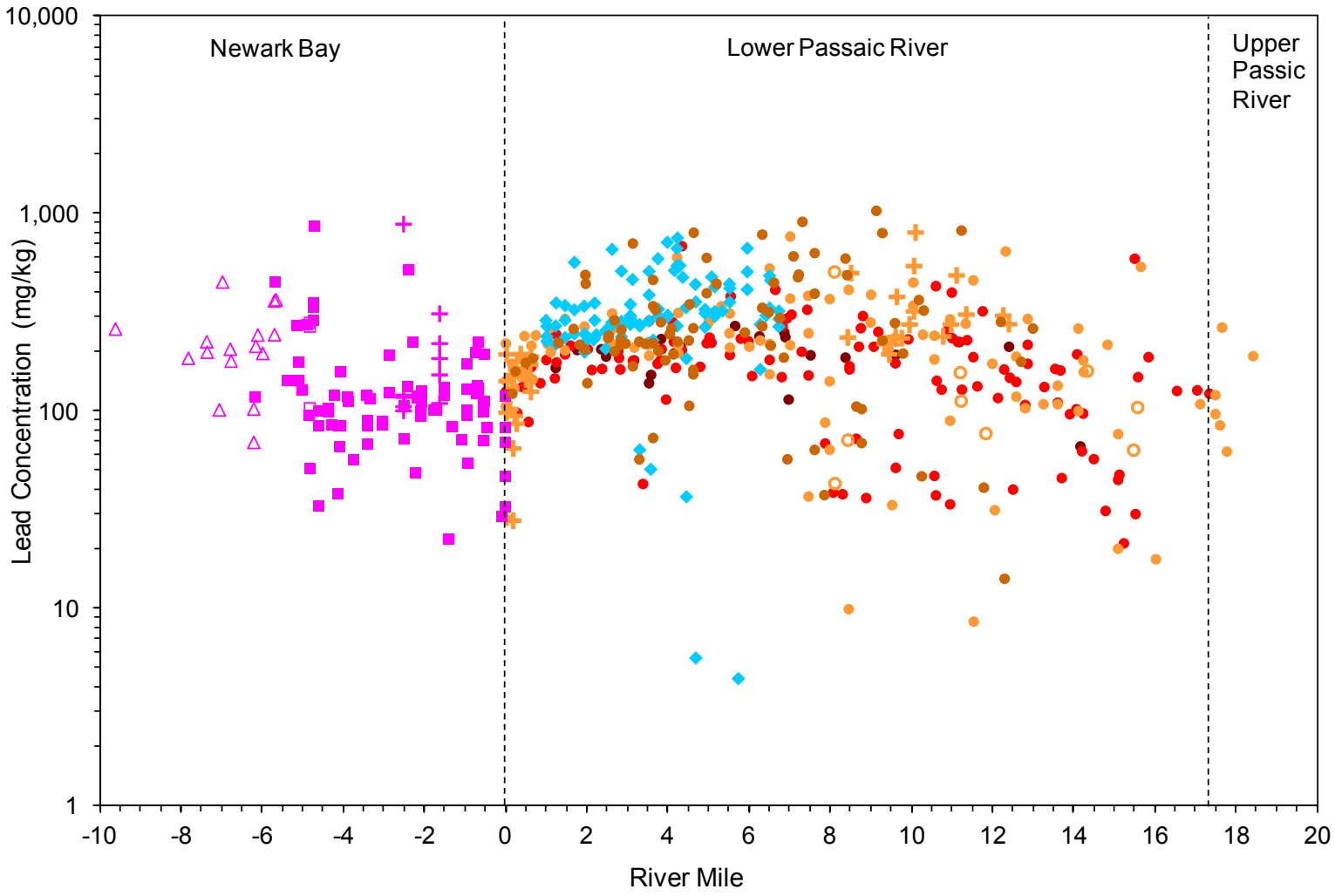
2014

R2-0027244





	Copper in Recently-Deposited Sediments in the Lower Passaic River, Newark Bay and the Upper Passaic River *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-24** 2014



Legend

- 2012 CPG
- 2010 CPG
- 2009 CPG
- 2008 CPG
- 2008 CPG Tributary Below HoT
- 2008 EPA
- 2005&2007 Newark Bay
- 2005&2007 Shooters Island & Arthur Kill
- 2005&2007 Kill Van Kull
- 2005&2007 Port Elizabeth & Newark
- 1995 TSI

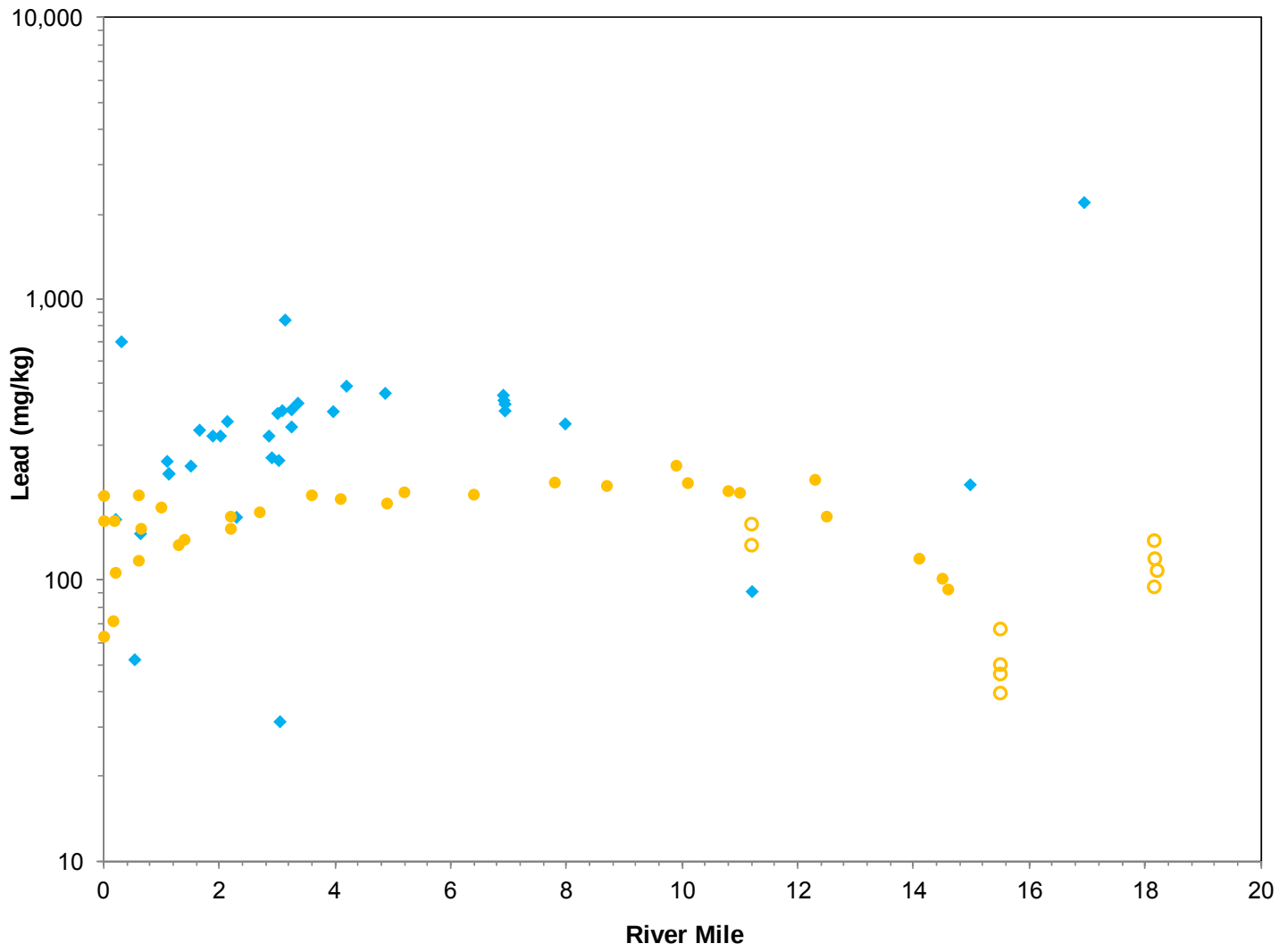
Lead Concentration (0-6 inches) *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 3.4-25

2014

R2-0027246



Legend

- 1991-1993
- 2007-2008 EPA
- 2007-2008 EPA Tributary Above HoT

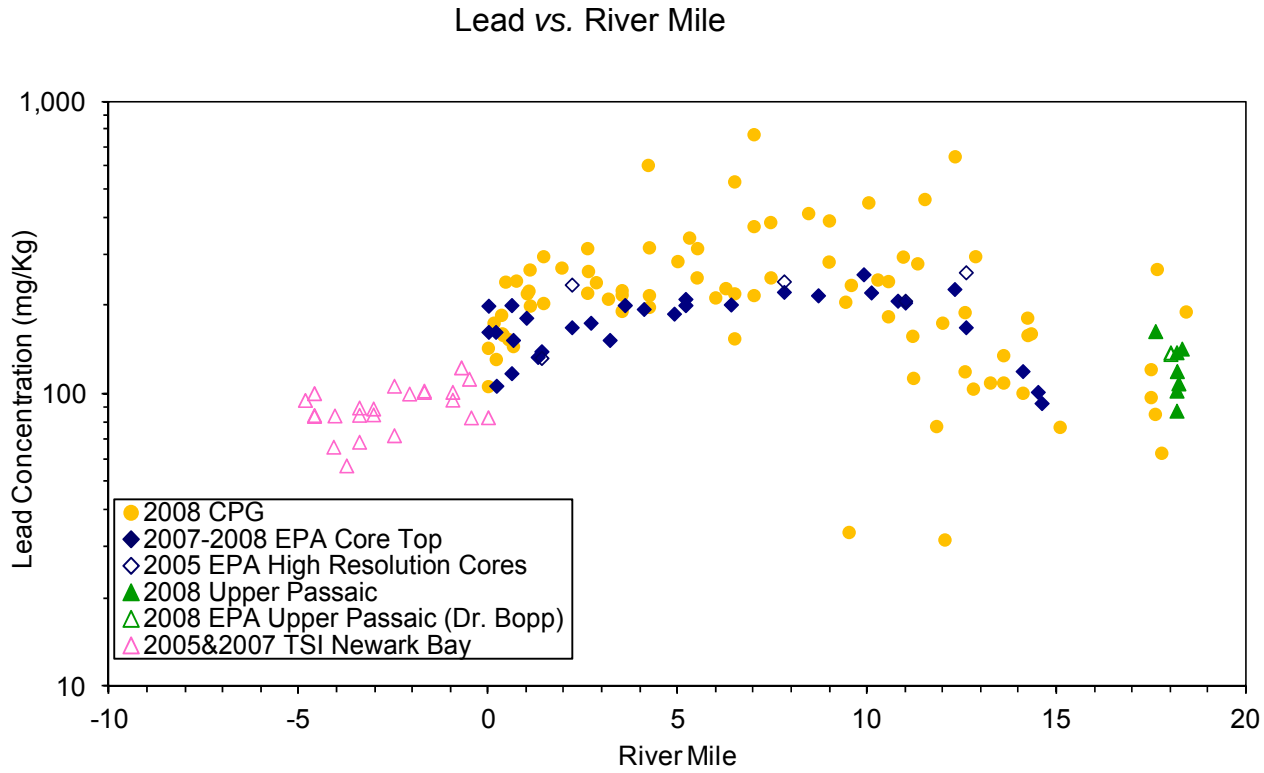
Lead Concentration (0 - ≤2 inches) *vs.* River Mile

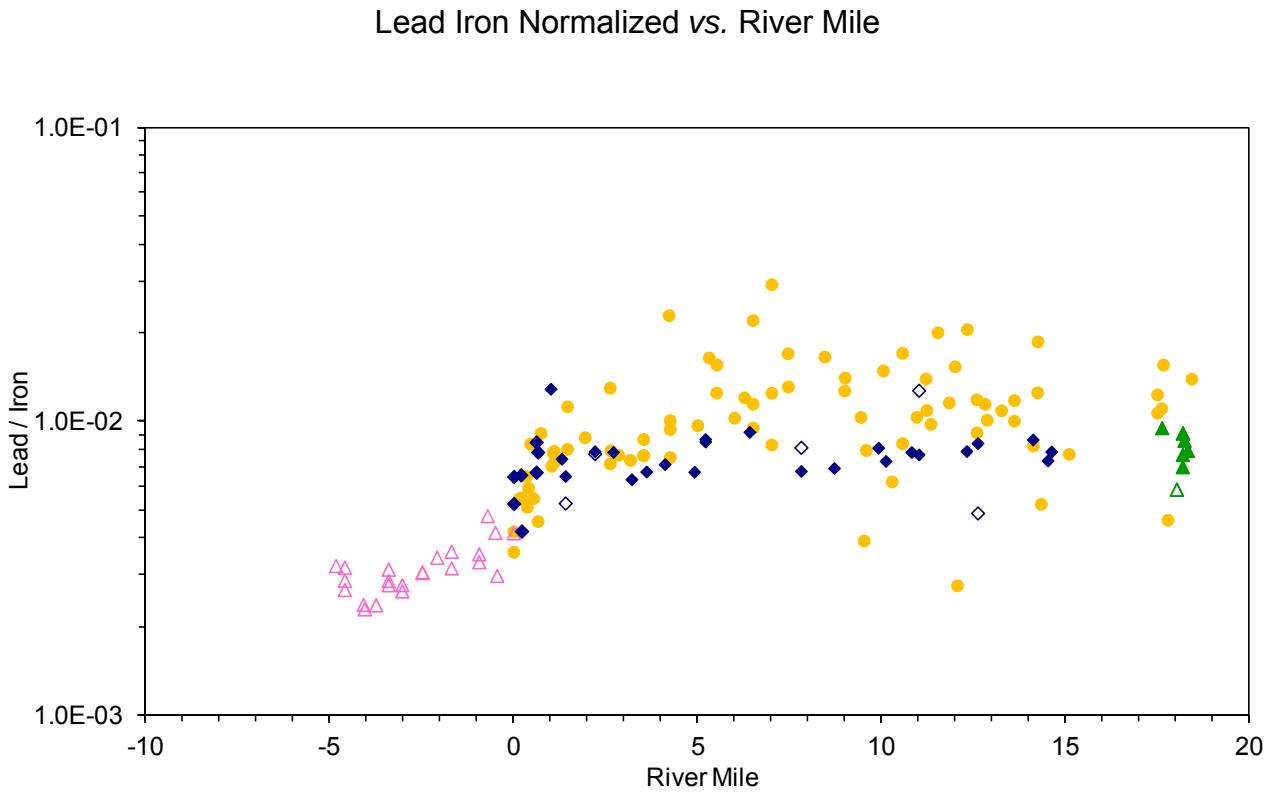
Lower Eight Miles of the Lower Passaic River

Figure 3.4-26

2014

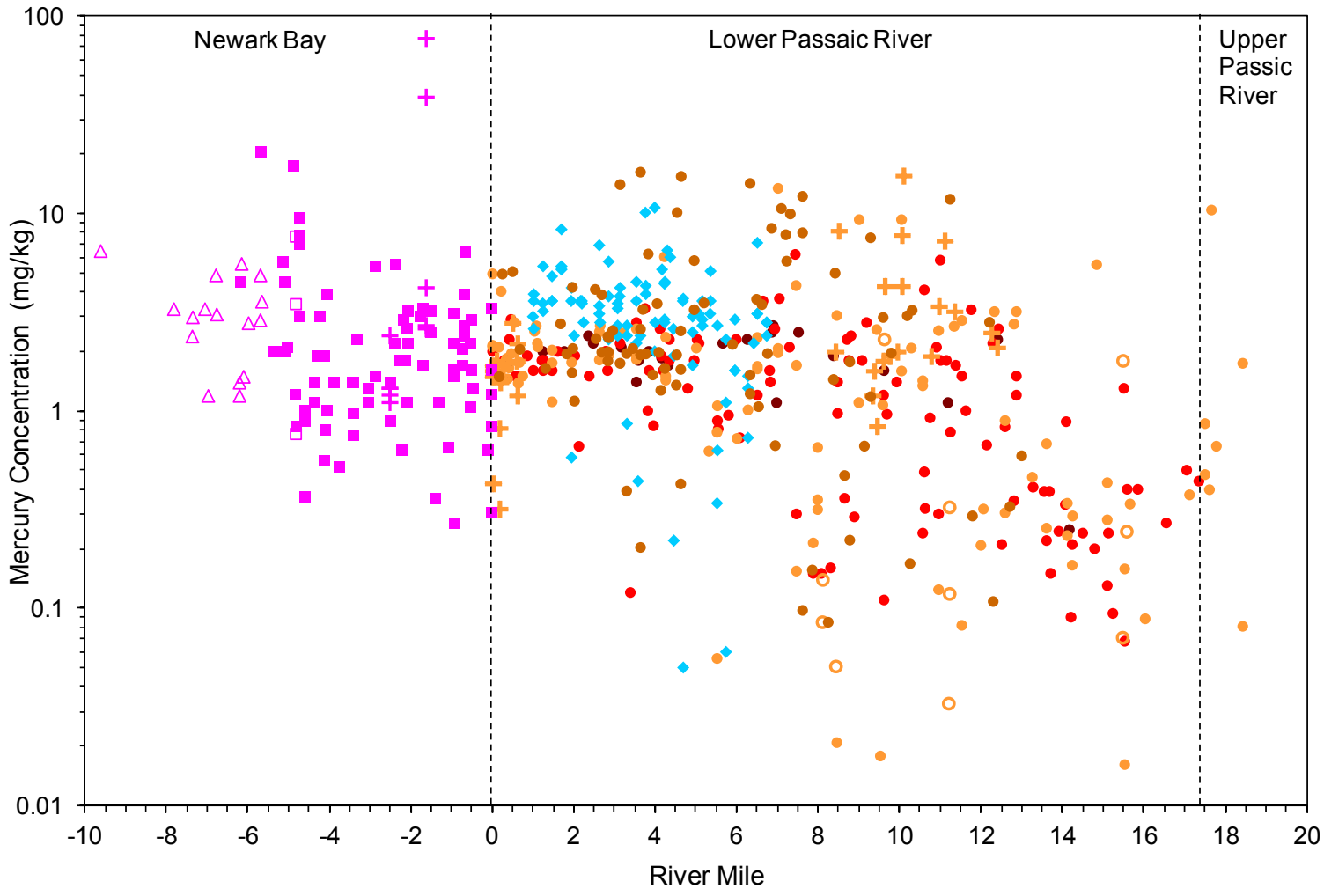
R2-0027247





	Lead in Recently-Deposited Sediments in the Lower Passaic River, Newark Bay and the Upper Passaic River *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-27** 2014

R2-0027248



Legend

- 2012 CPG
- 2010 CPG
- 2009 CPG
- 2008 CPG
- 2008 CPG Tributary Below HoT
- 2008 EPA
- 2005&2007 Newark Bay
- 2005&2007 Shooters Island & Arthur Kill
- 2005&2007 Kill Van Kull
- 2005&2007 Port Elizabeth & Newark
- 1995 TSI

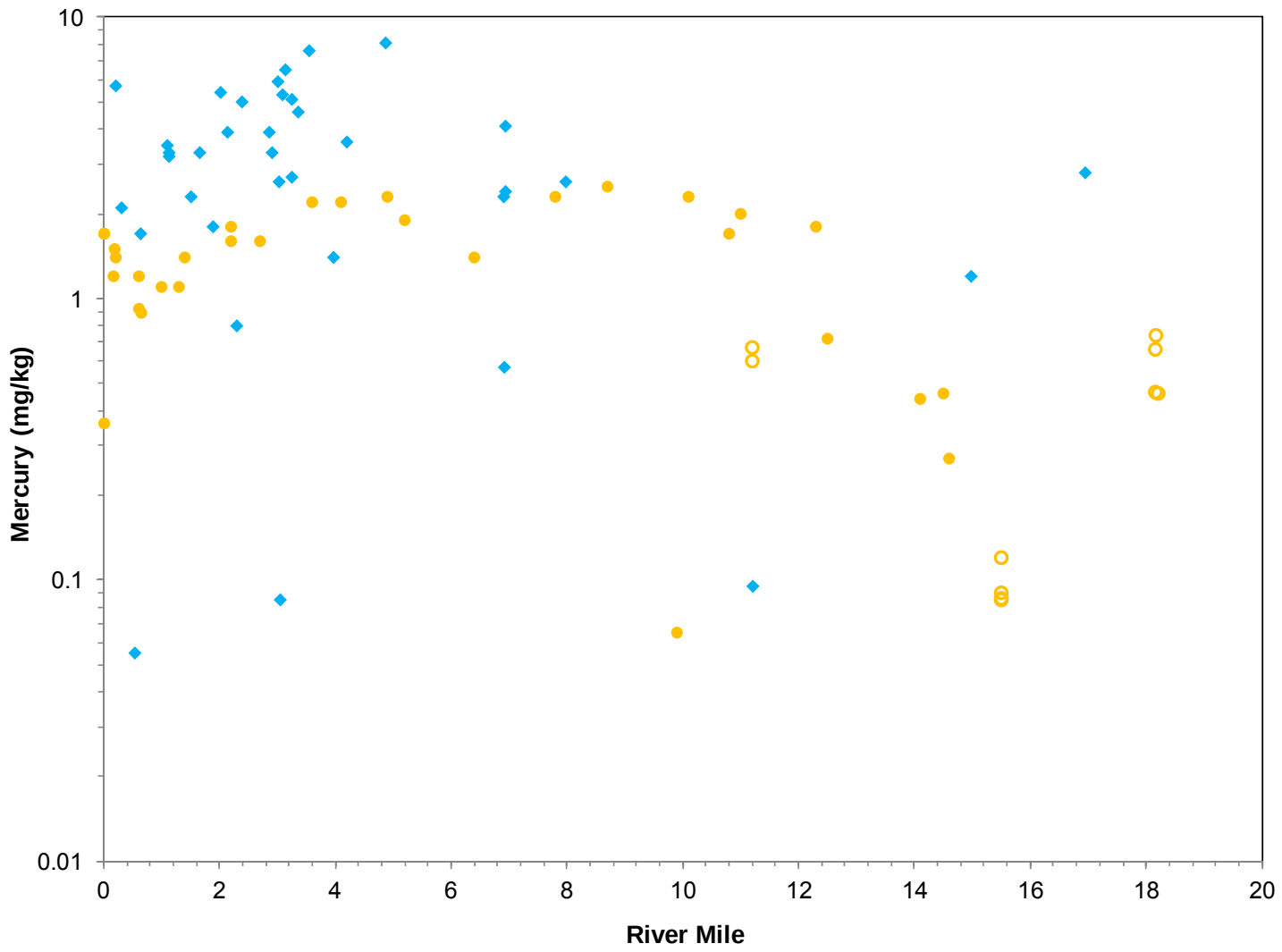
Mercury Concentration (0-6 inches) *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 3.4-28

2014

R2-0027249



Legend

- 1991-1993
- 2007-2008 EPA
- 2007-2008 EPA Tributary Above HoT

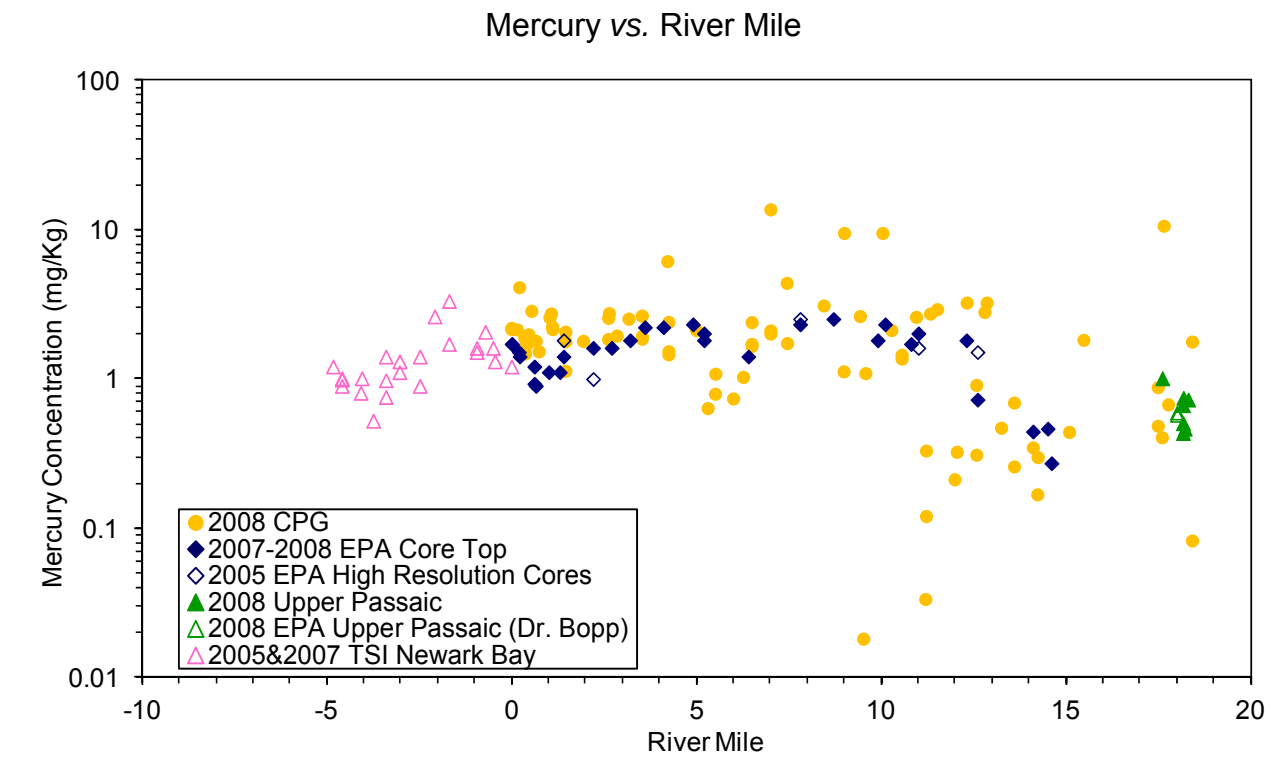
Mercury Concentration (0 - ≤2 inches) *vs.* River Mile

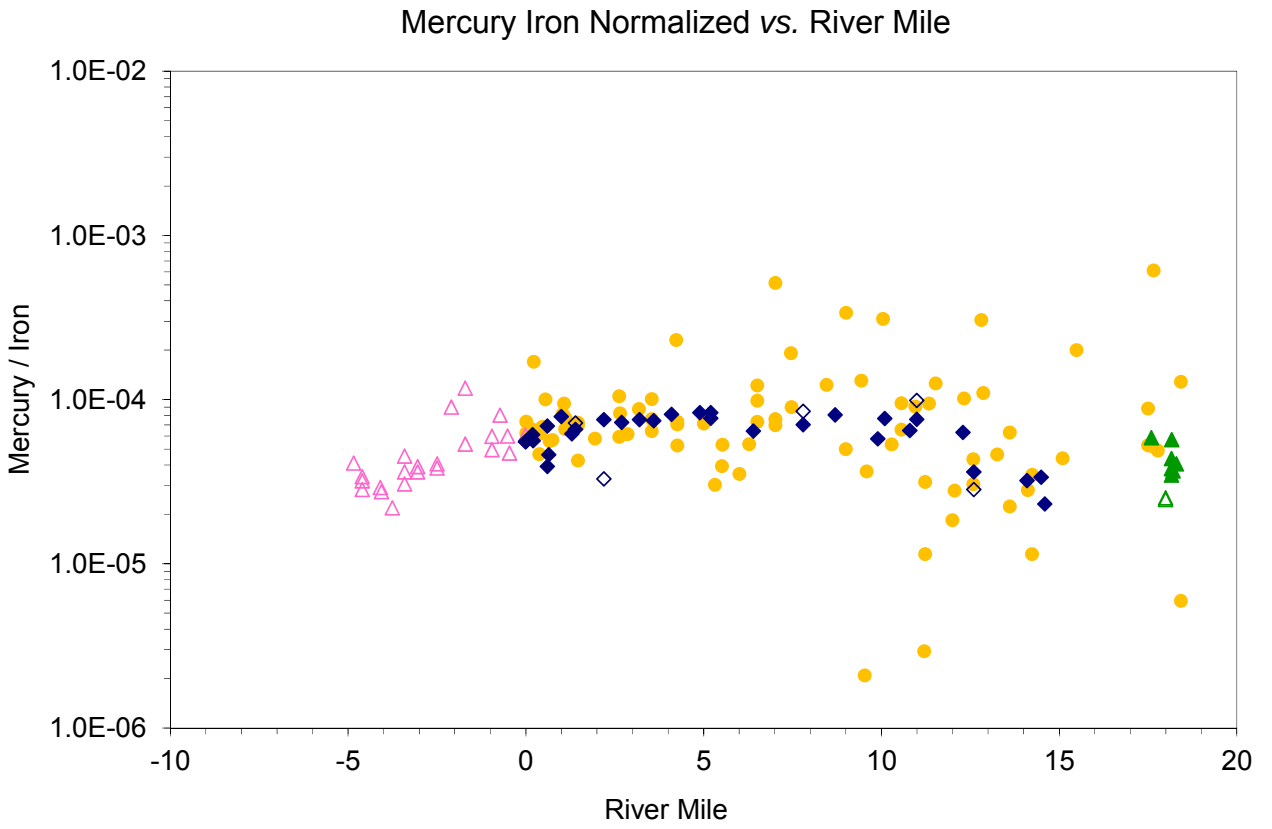
Lower Eight Miles of the Lower Passaic River

Figure 3.4-29

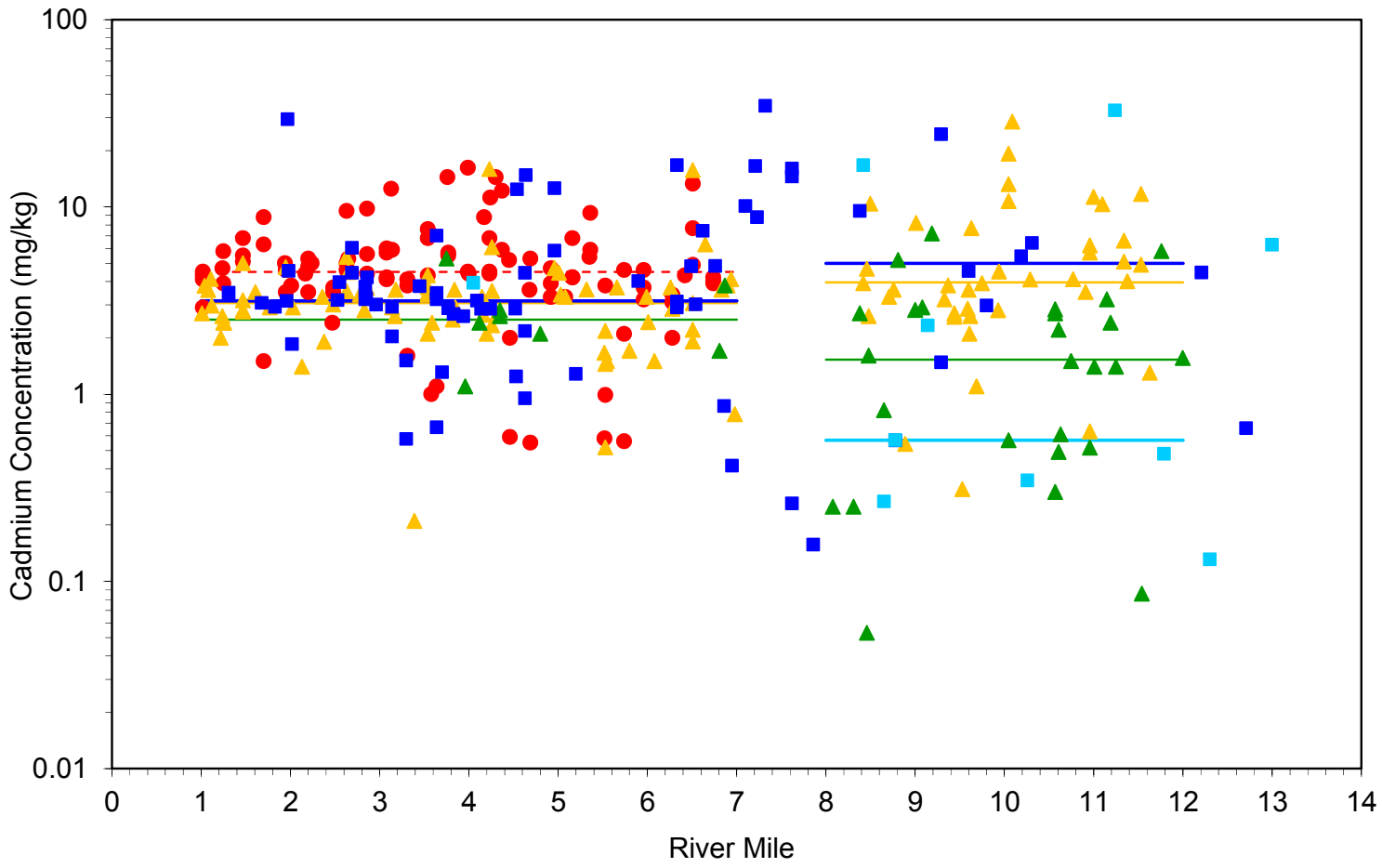
2014

R2-0027250





	Mercury in Recently-Deposited Sediments in the Lower Passaic River, Newark Bay and the Upper Passaic River *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-30** 2014



Legend

- 2012 Fine-Grained
- 2012 Fine-Grained Median
- 2012 Coarse-Grained
- 2012 Coarse-Grained Median
- 2008-2010 Fine-Grained
- 2008-2010 Fine-Grained Median
- 2008-2010 Coarse-Grained
- 2008-2010 Coarse-Grained Median
- 1995
- 1995 Median

Comparison of Cadmium Surface Concentration (0-6 inches)
RM1 to RM7 *vs.* RM8 to RM12

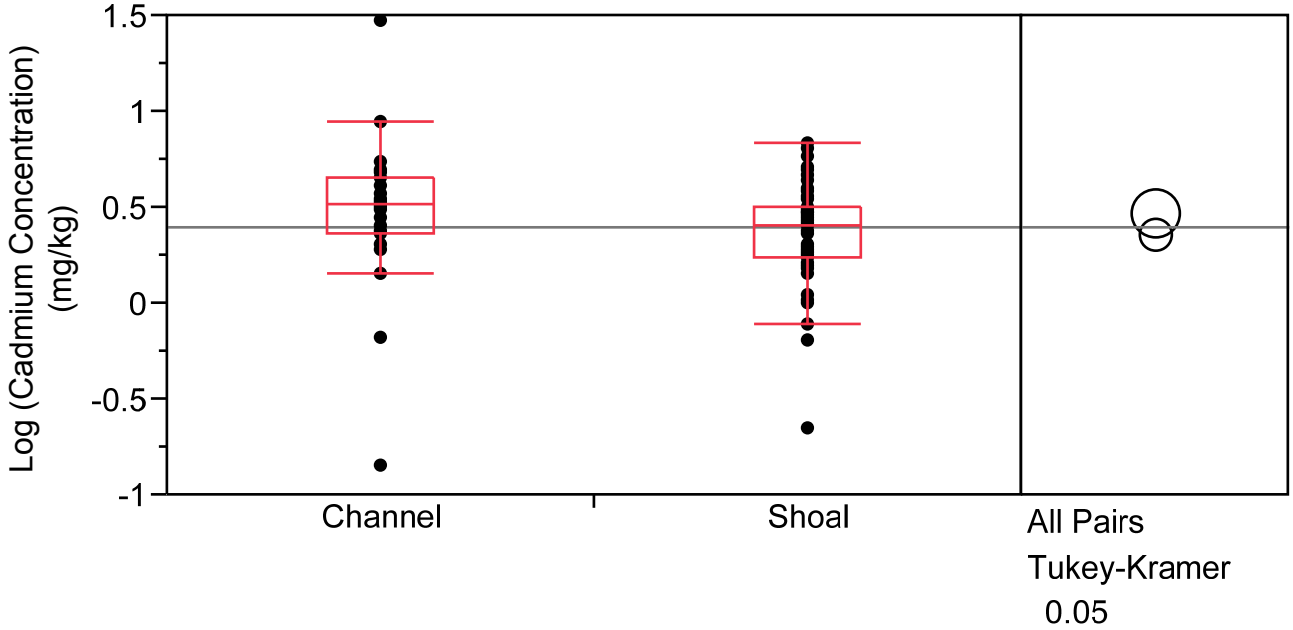
Lower Eight Miles of the Lower Passaic River

Figure 3.4-31

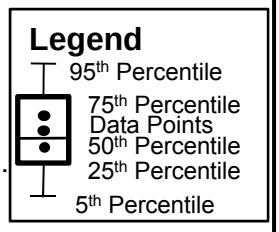
2014

R2-0027252

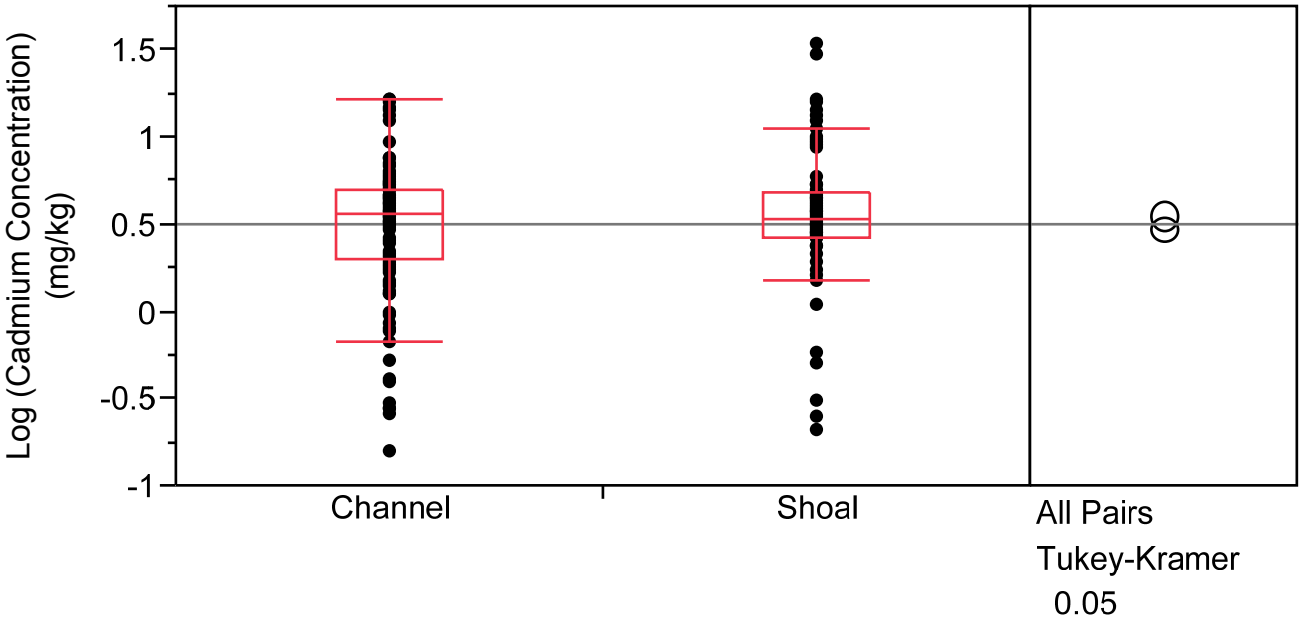
RM0 to RM2



Notes:
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 1995, 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.

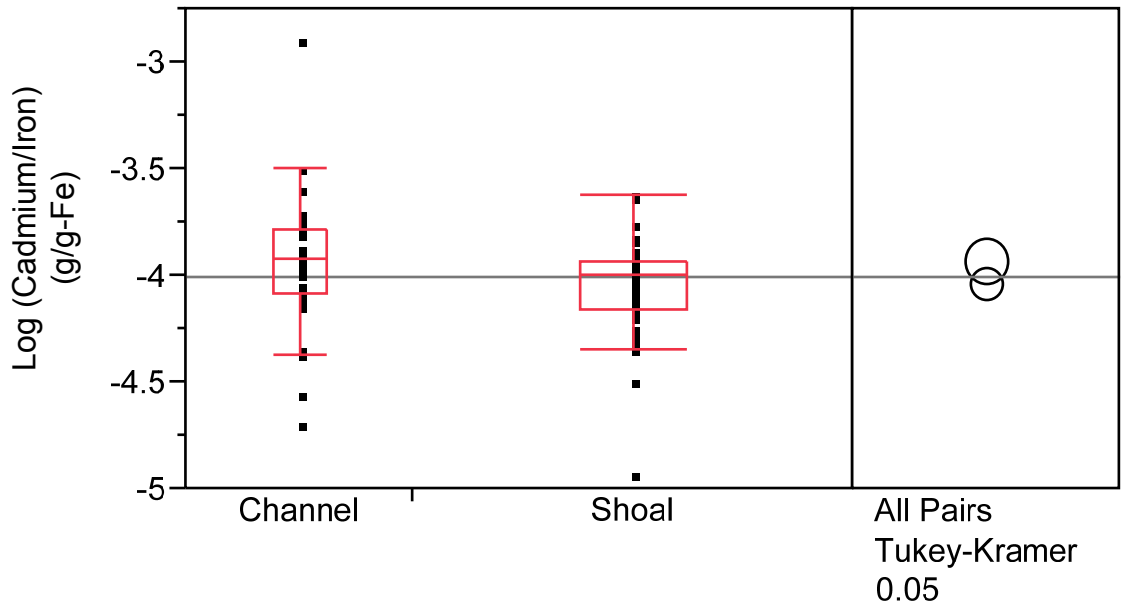


RM2 to RM8

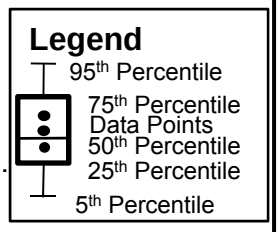


	Cadmium (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-32a** 2014

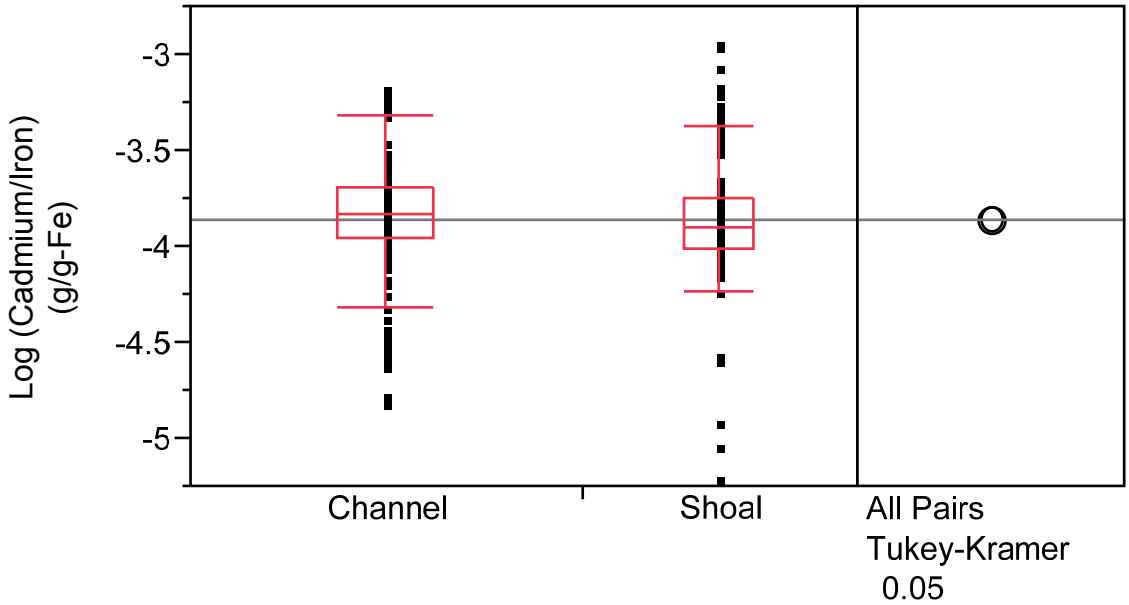
RM0 to RM2



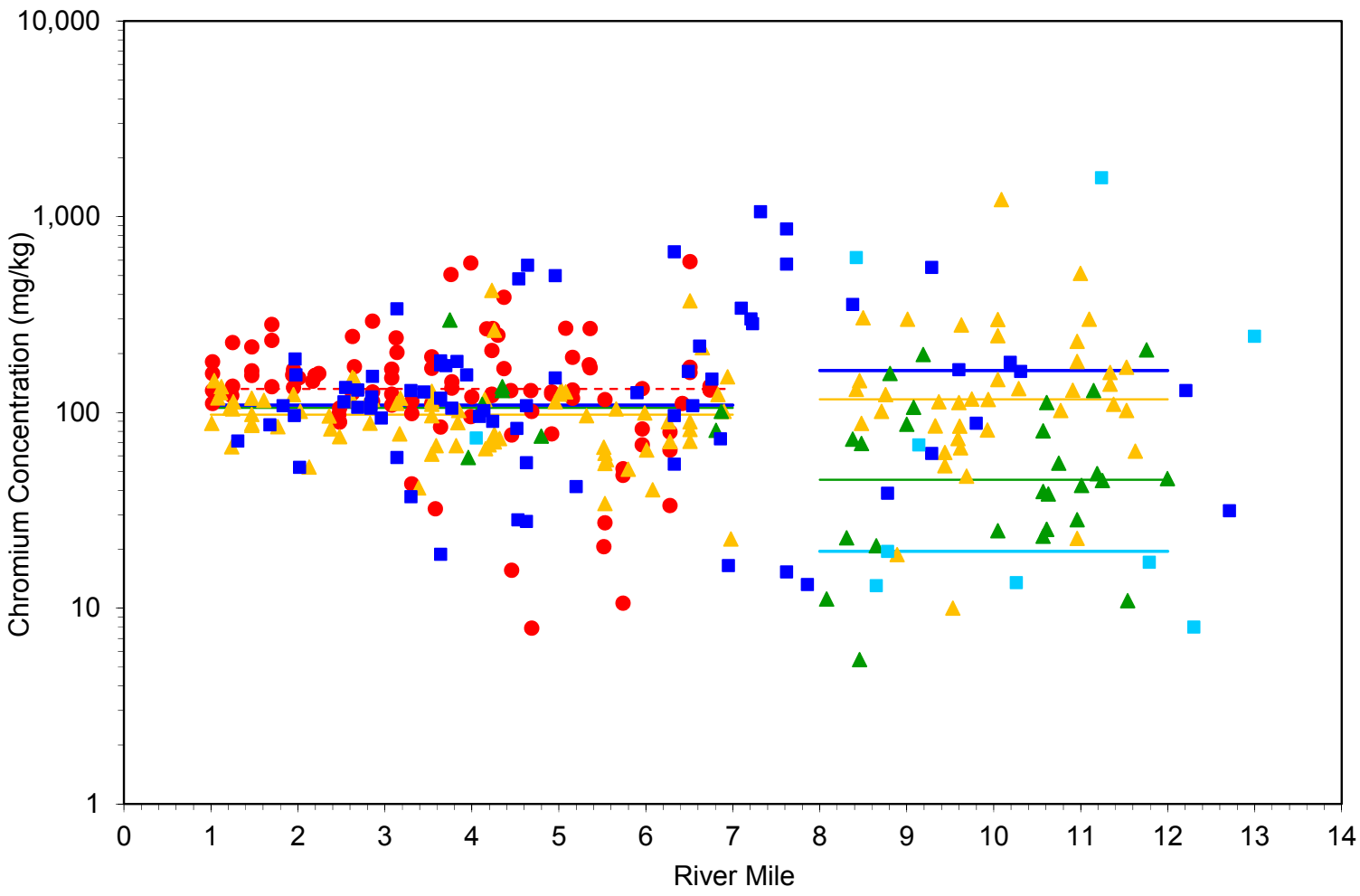
Notes:
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 1995, 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.



RM2 to RM8



	Iron Normalized Cadmium (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-32b** 2014



Legend

- 2012 Fine-Grained
- 2012 Fine-Grained Median
- 2012 Coarse-Grained
- 2012 Coarse-Grained Median
- 2008-2010 Fine-Grained
- 2008-2010 Fine-Grained Median
- 2008-2010 Coarse-Grained
- 2008-2010 Coarse-Grained Median
- 1995
- 1995 Median

Comparison of Chromium Surface Concentration (0-6 inches)
RM1 to RM7 *vs.* RM8 to RM12

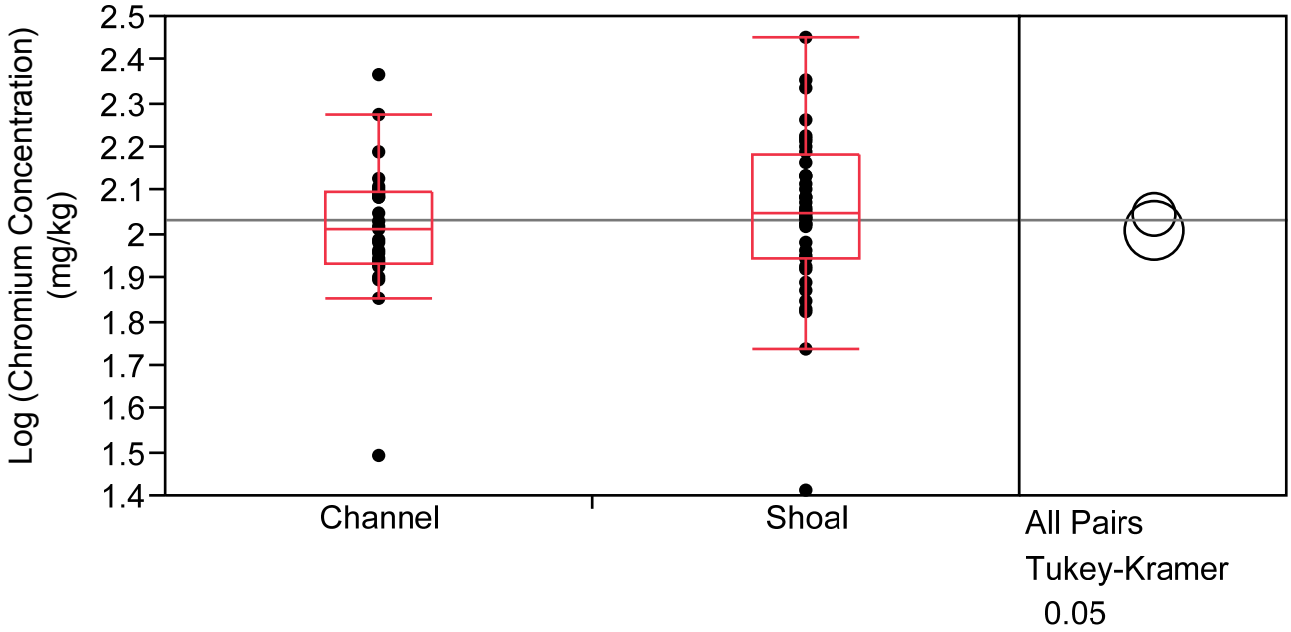
Lower Eight Miles of the Lower Passaic River

Figure 3.4-33

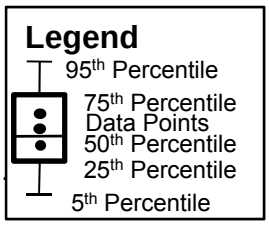
2014

R2-0027255

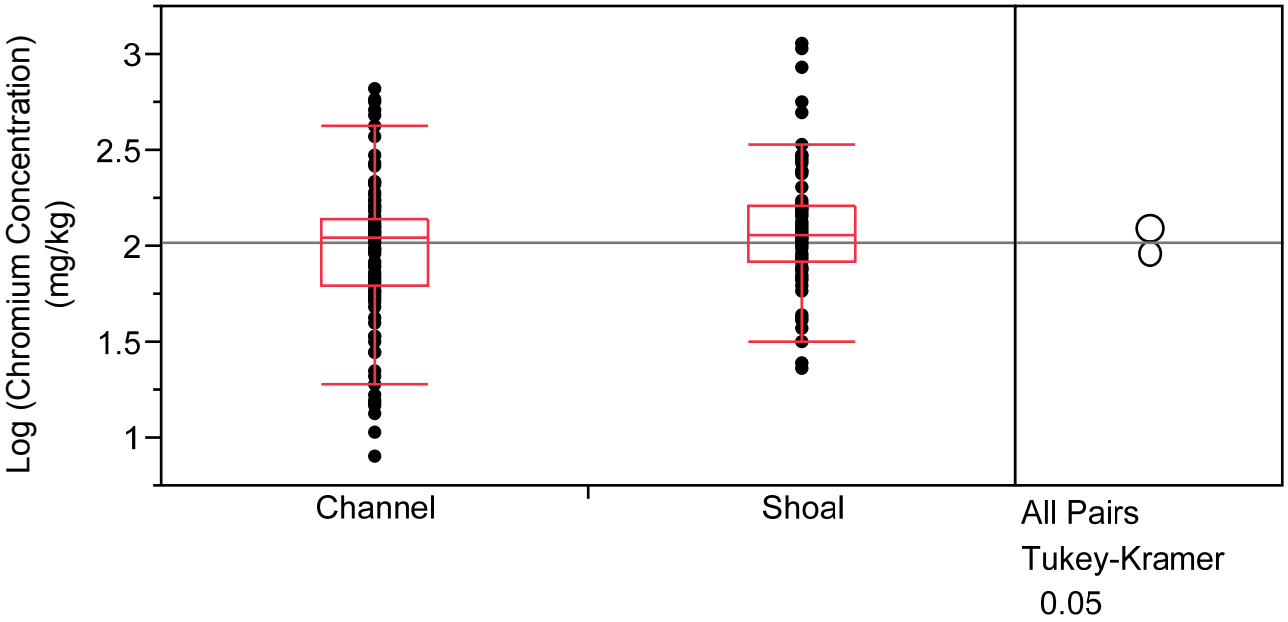
RM0 to RM2



Notes:
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 1995, 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.

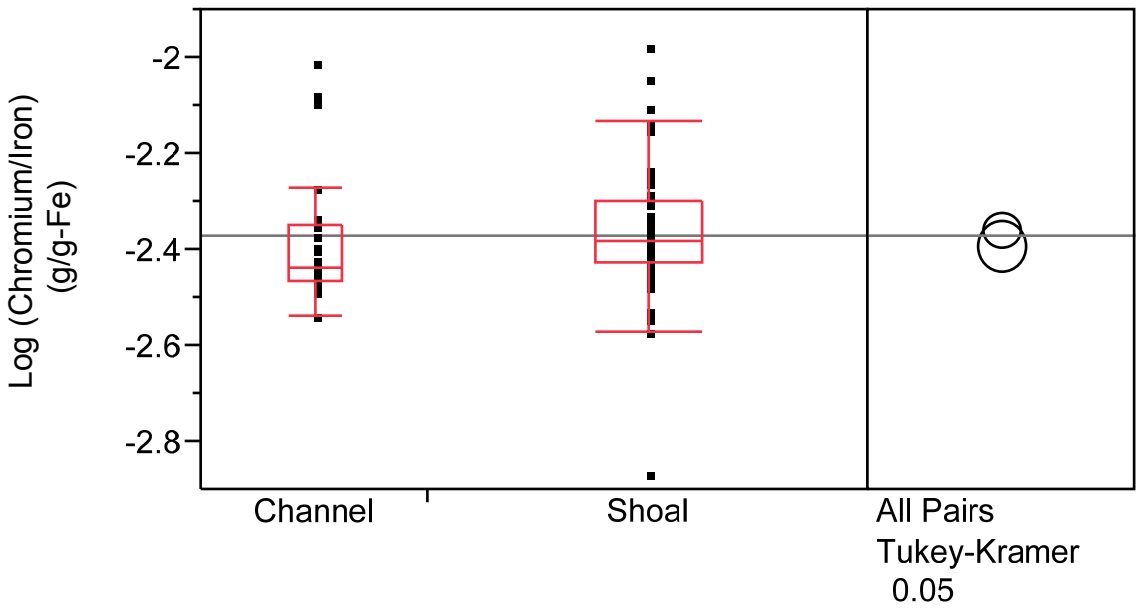


RM2 to RM8

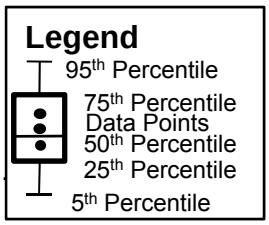


	Chromium (0-6 inch) by Channel and Shoal **at RM0 to RM2 and RM2 to RM8** *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-34a** 2014

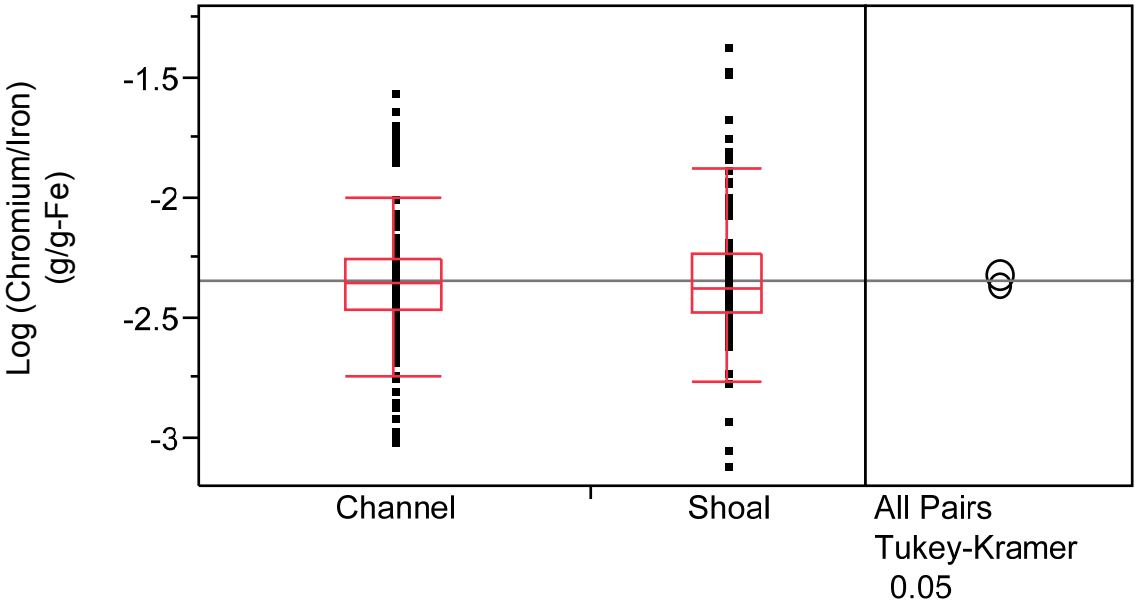
RM0 to RM2



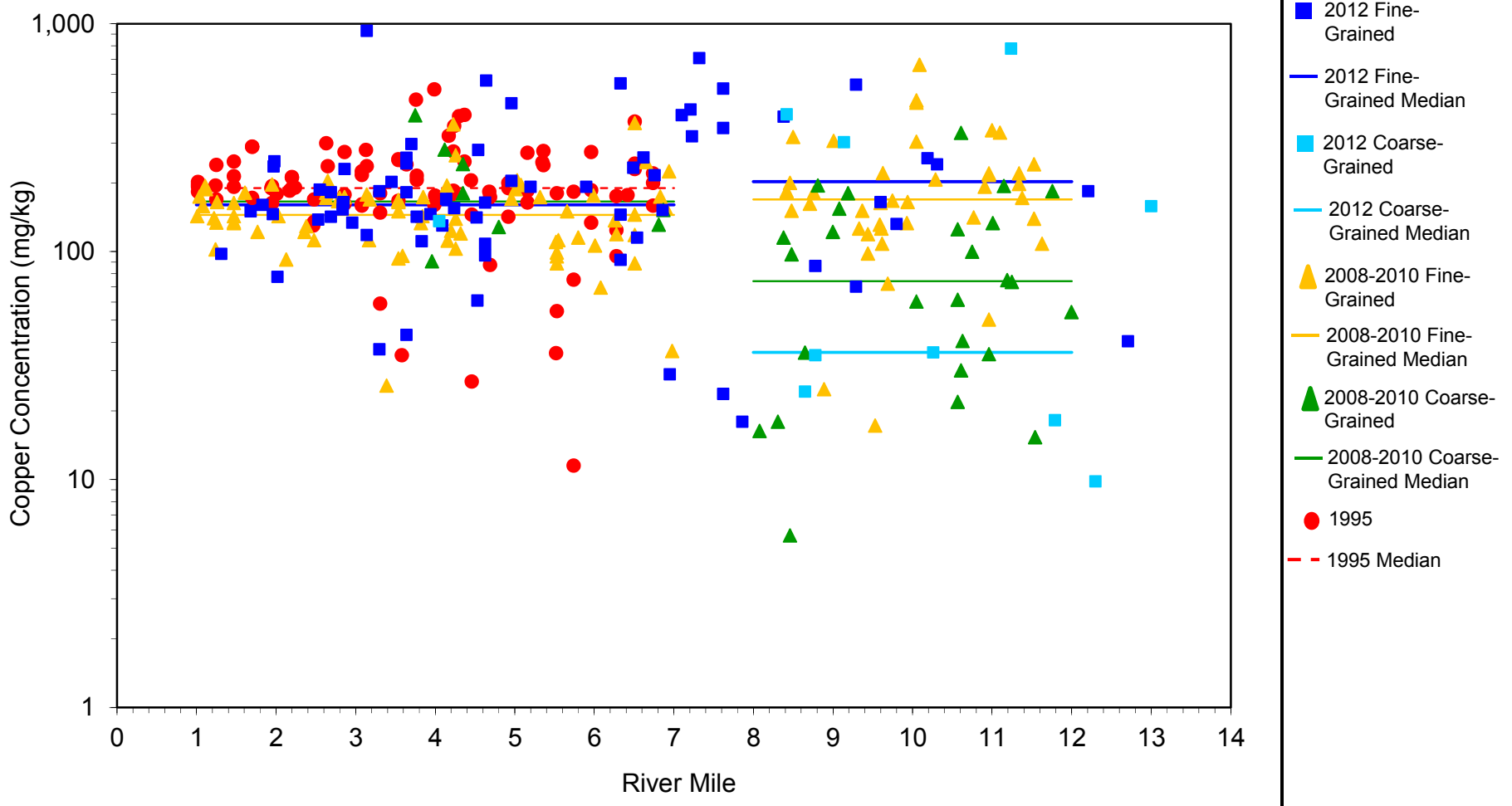
Notes:
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 1995, 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.



RM2 to RM8



	Iron Normalized Chromium (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-34b** 2014



Comparison of Copper Surface Concentration (0-6 inches)
RM1 to RM7 *vs.* RM8 to RM12

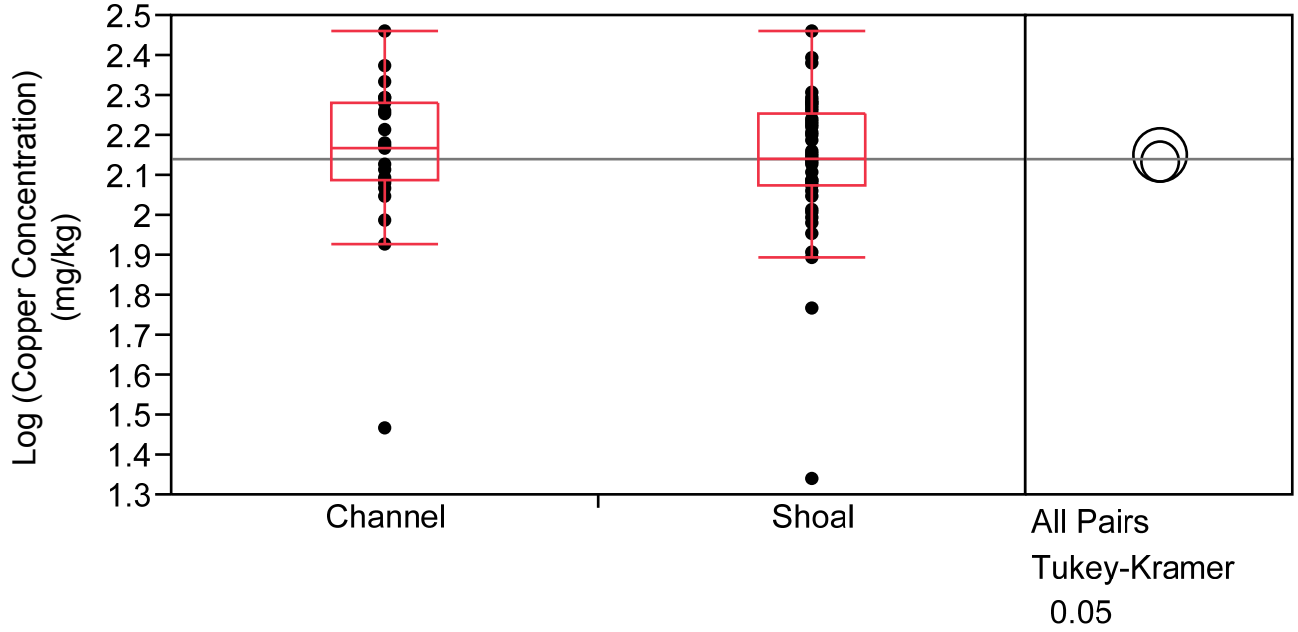
Lower Eight Miles of the Lower Passaic River

Figure 3.4-35

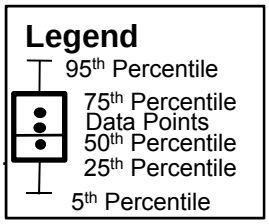
2014

R2-0027258

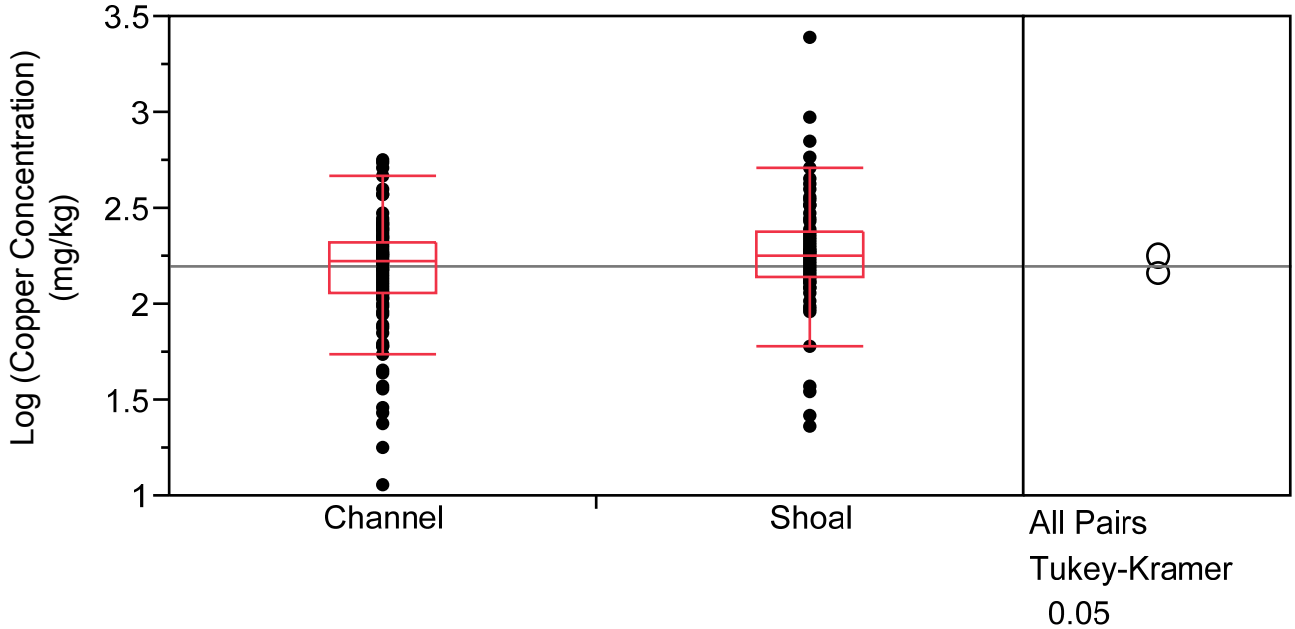
RM0 to RM2



Notes:
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 1995, 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.

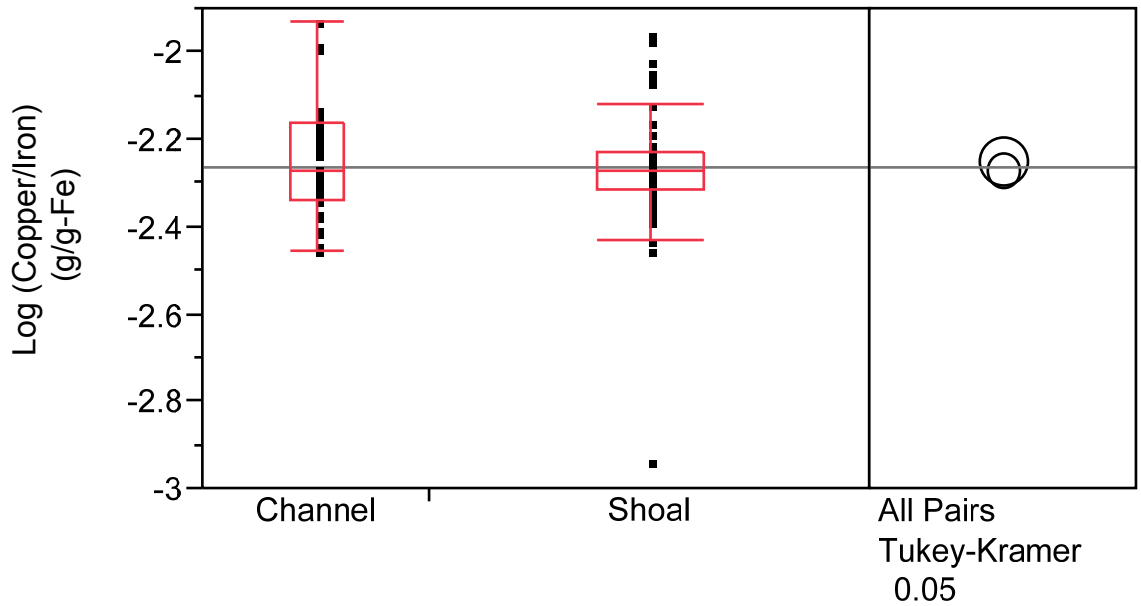


RM2 to RM8

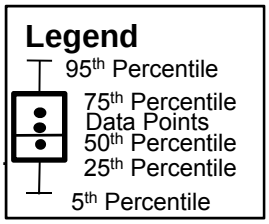


	Copper (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-36a** 2014

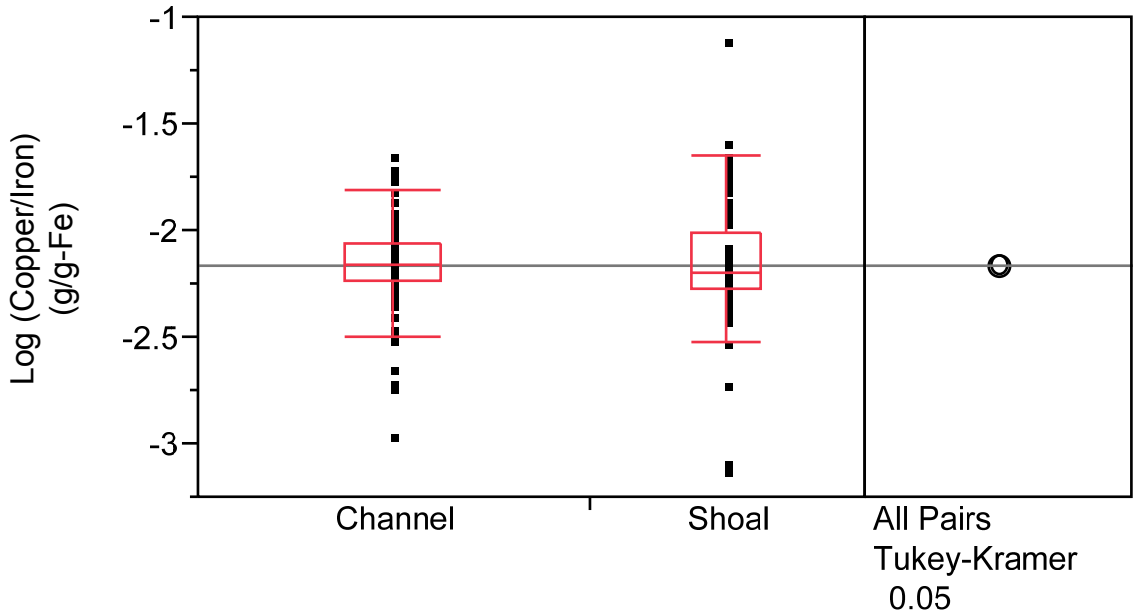
RM0 to RM2



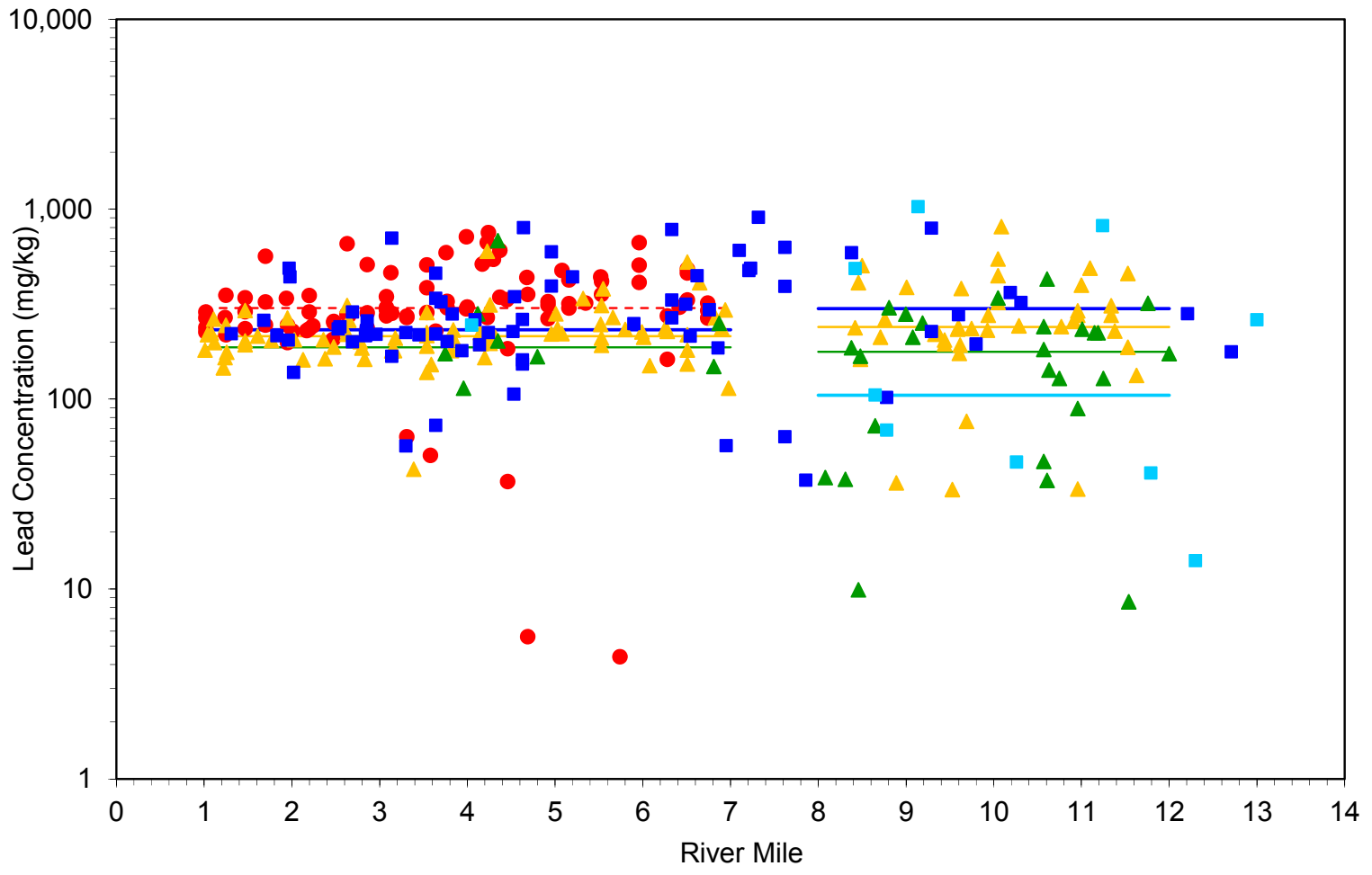
Notes:
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 1995, 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.



RM2 to RM8



	Iron Normalized Copper (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-36b** 2014



Legend

- 2012 Fine-Grained
- 2012 Fine-Grained Median
- 2012 Coarse-Grained
- 2012 Coarse-Grained Median
- 2008-2010 Fine-Grained
- 2008-2010 Fine-Grained Median
- 2008-2010 Coarse-Grained
- 2008-2010 Coarse-Grained Median
- 1995
- 1995 Median

Comparison of Lead Surface Concentration (0-6 inches)
RM1 to RM7 *vs.* RM8 to RM12

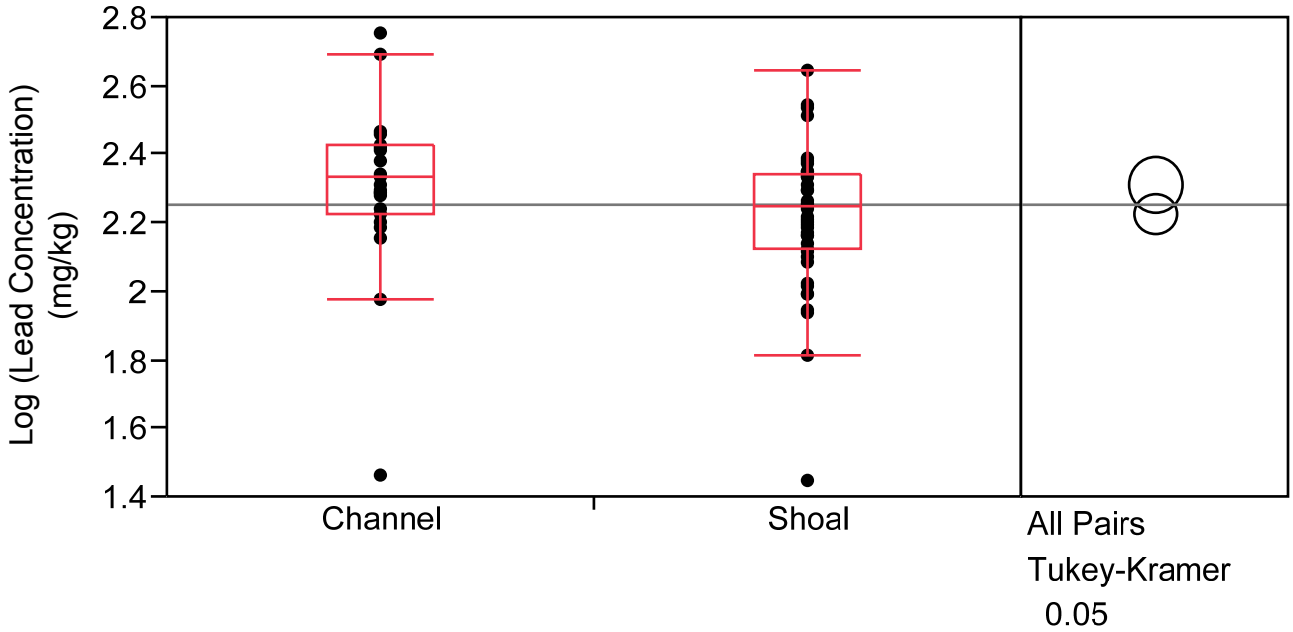
Lower Eight Miles of the Lower Passaic River

Figure 3.4-37

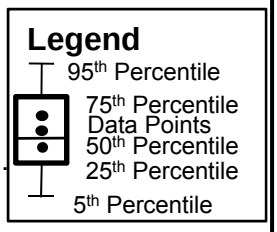
2014

R2-0027261

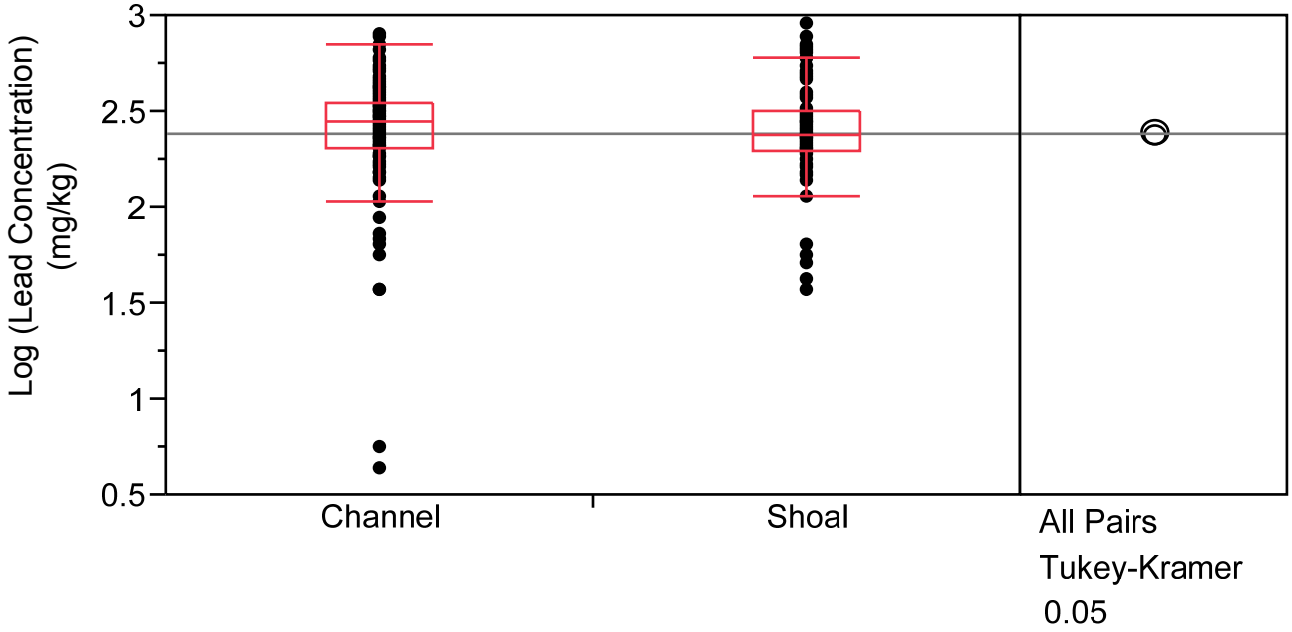
RM0 to RM2



Notes:
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 1995, 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.

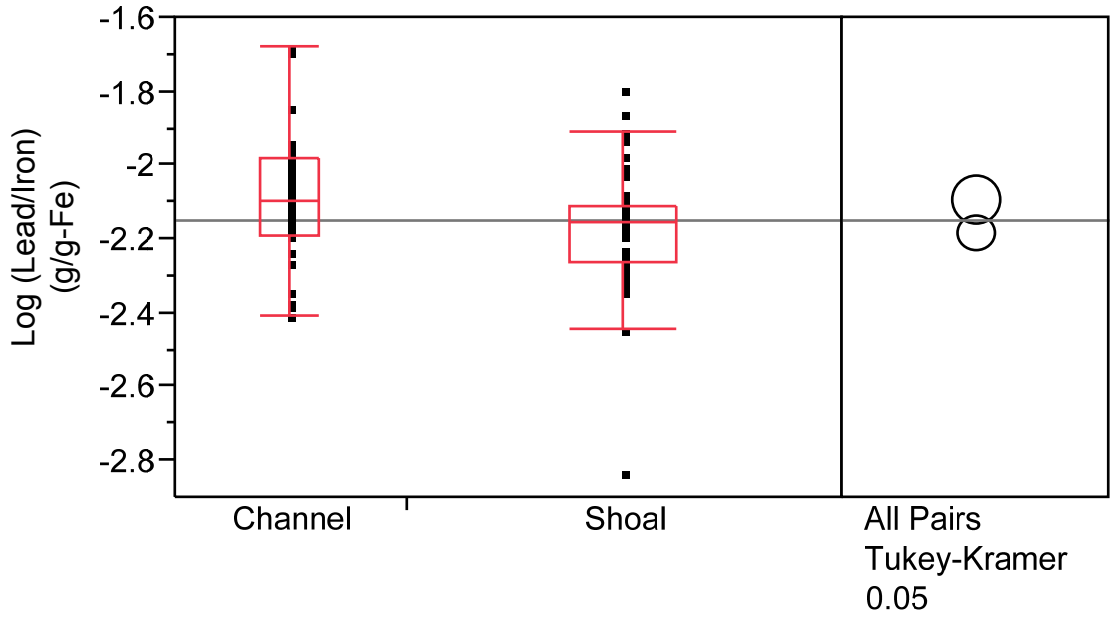


RM2 to RM8

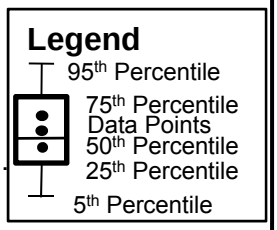


	Lead (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-38a** 2014

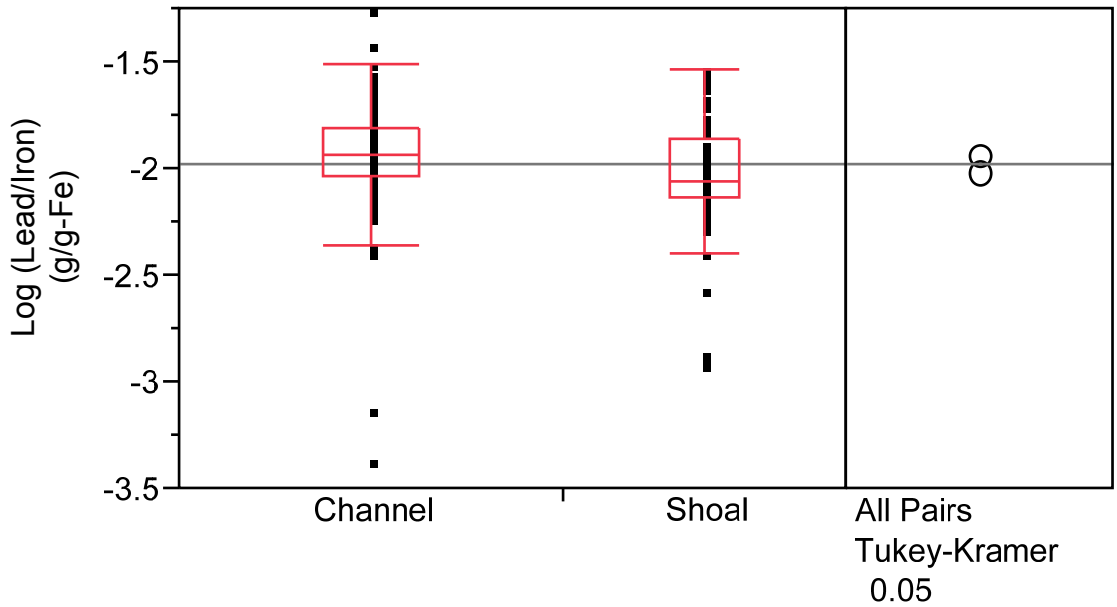
RM0 to RM2



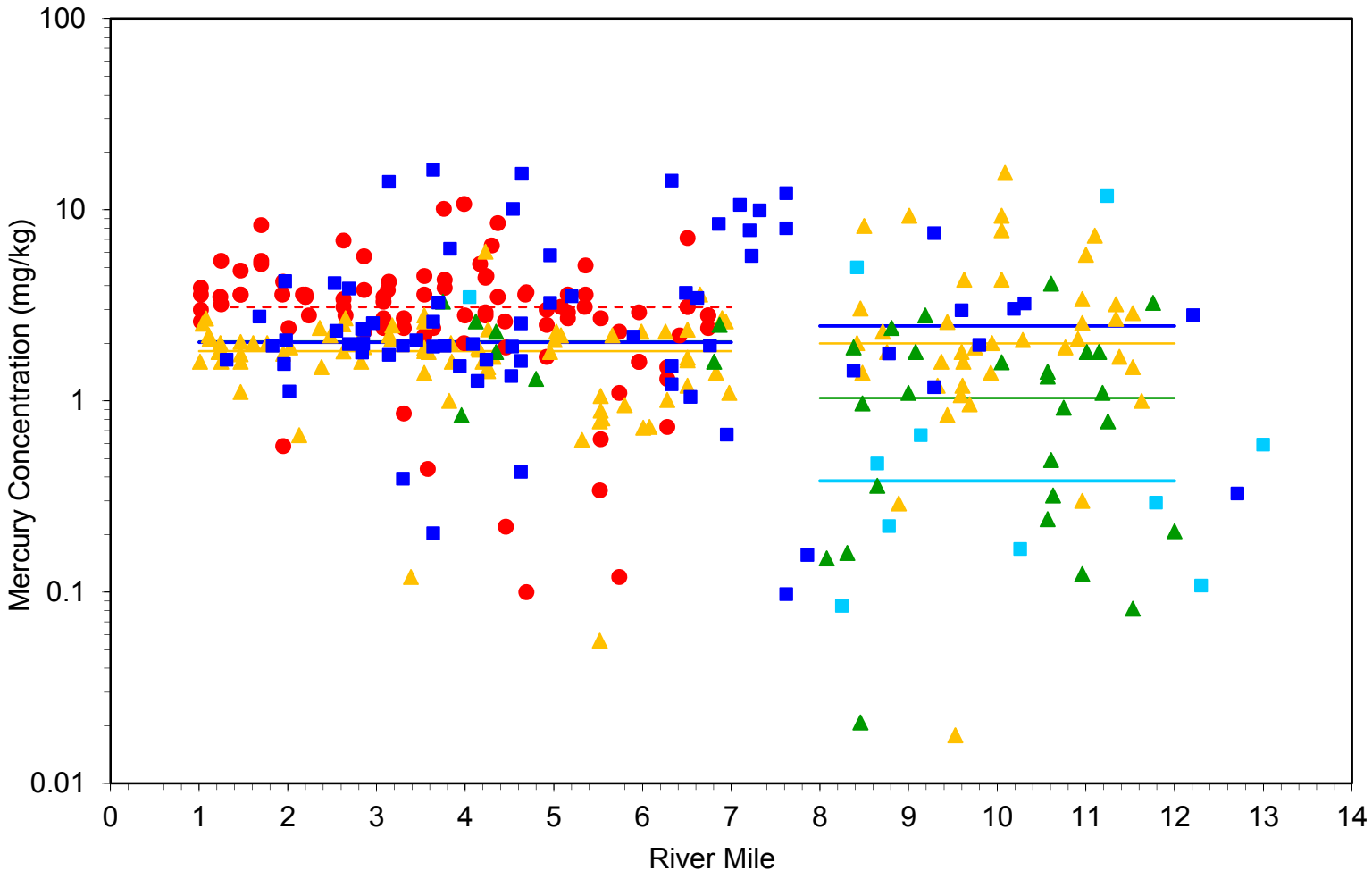
Notes:
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 1995, 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.



RM2 to RM8



	Iron Normalized Lead (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-38b** 2014



Legend

- 2012 Fine-Grained
- 2012 Fine-Grained Median
- 2012 Coarse-Grained
- 2012 Coarse-Grained Median
- 2008-2010 Fine-Grained
- 2008-2010 Fine-Grained Median
- 2008-2010 Coarse-Grained
- 2008-2010 Coarse-Grained Median
- 1995
- 1995 Median

Comparison of Mercury Surface Concentration (0-6 inches)
RM1 to RM7 *vs.* RM8 to RM12

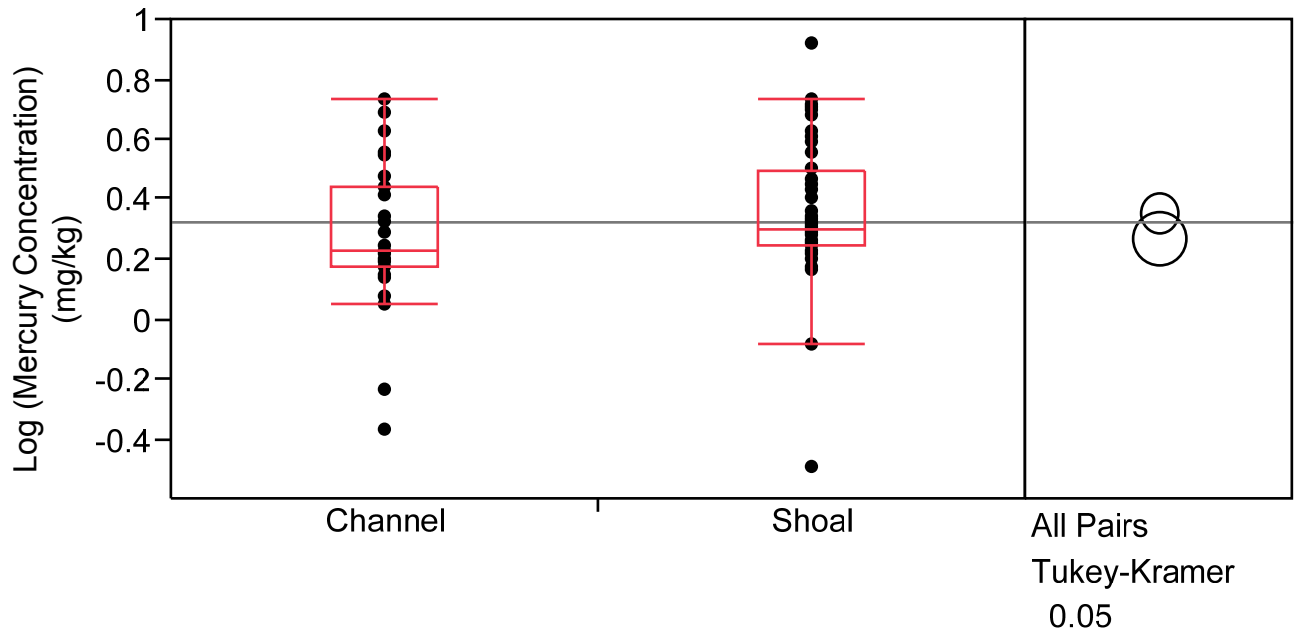
Lower Eight Miles of the Lower Passaic River

Figure 3.4-39

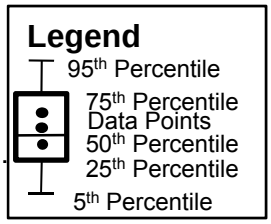
2014

R2-0027264

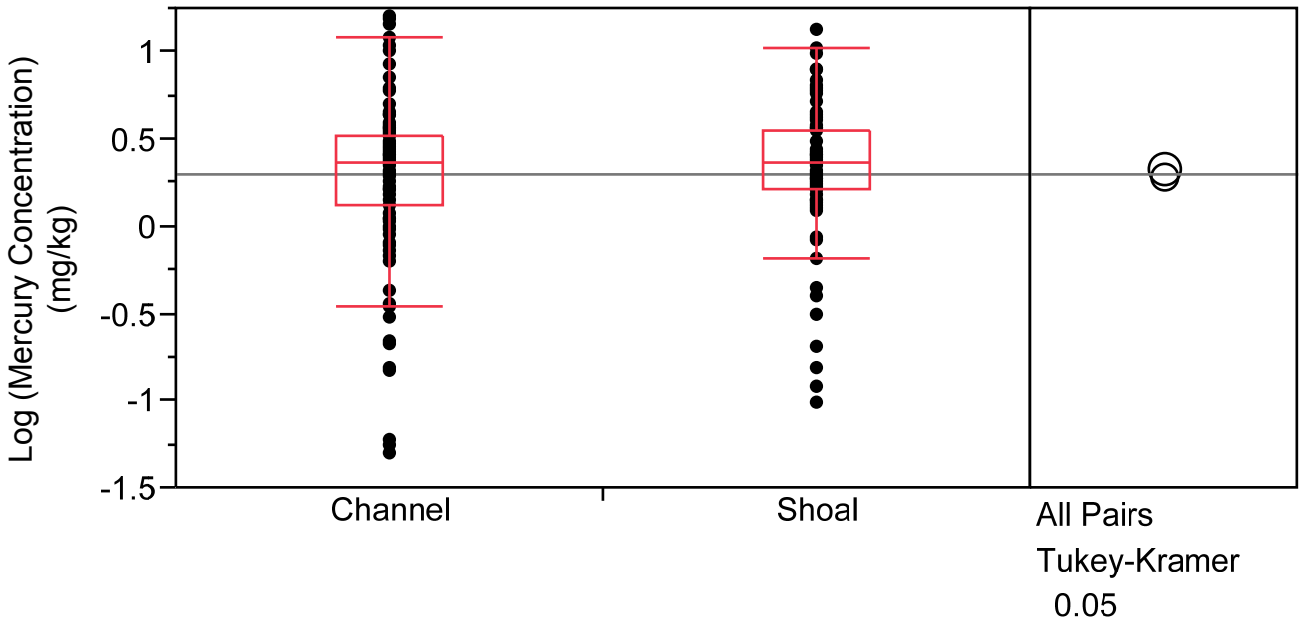
RM0 to RM2



Notes:
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 1995, 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.

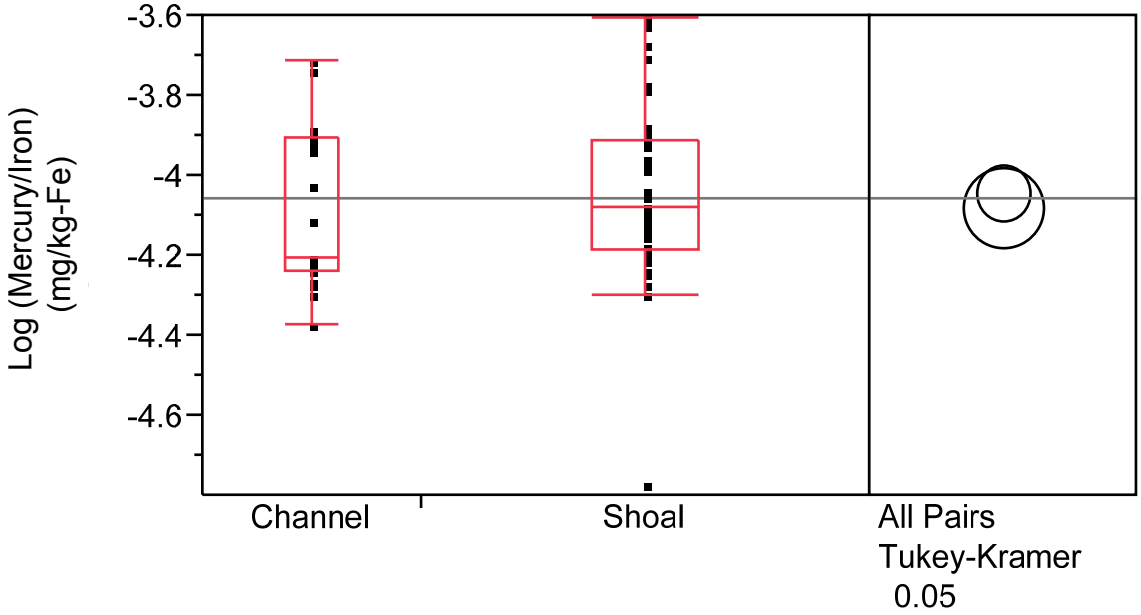


RM2 to RM8

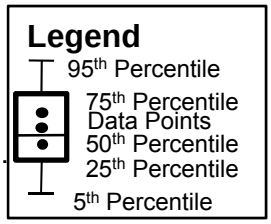


	Mercury (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-40a** 2014

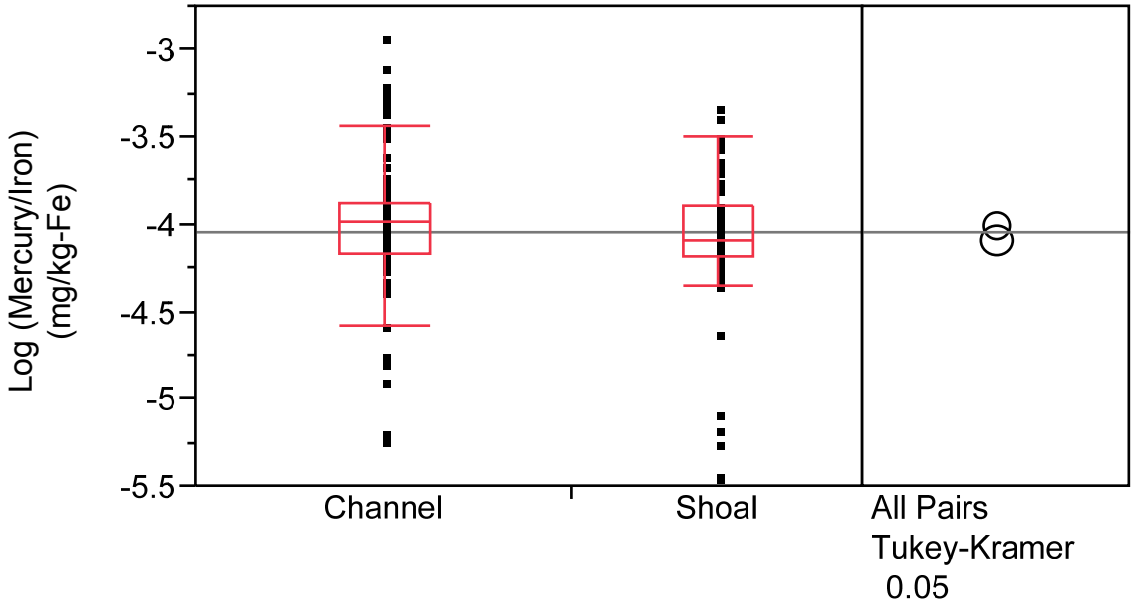
RM0 to RM2



Notes:
1) Horizontal line represents the mean log concentration across all data points, equivalent to the untransformed median concentration.
See text for explanation of Tukey-Kramer circles.
2) Data included 1995, 2008 EPA, 2008 CPG, 2009 CPG, 2010 CPG and 2012 CPG.



RM2 to RM8



	Iron Normalized Mercury (0-6 inch) by Channel and Shoal at RM0 to RM2 and RM2 to RM8 *Lower Eight Miles of the Lower Passaic River*	**Figure 3.4-40b** 2014

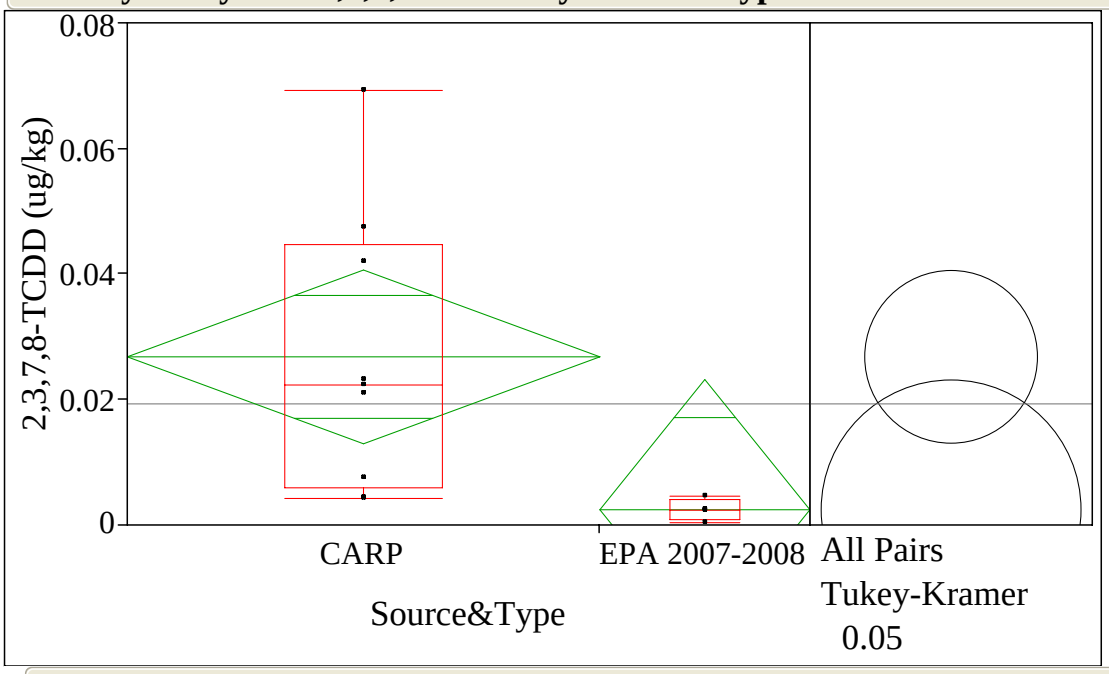
ATTACHMENTS

ATTACHMENT A

Tukey-Kramer Honestly Significant Difference (HSD) Statistical Test for CSOs and SWOs Suspended Matter Concentrations for CARP and 2007-2008 USEPA Data

5/2/2008 12:40PM

Oneway Analysis of 2,3,7,8-TCDD By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	0.004232	0.004232	0.005924	0.022295	0.044672	0.069231	0.069231
EPA 2007-2008	0.000357	0.000357	0.000838	0.002365	0.004058	0.004593	0.004593

Oneway Anova

Summary of Fit

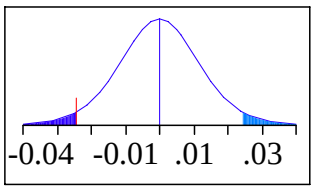
Rsquare	0.29565
Adj Rsquare	0.231618
Root Mean Square Error	0.018869
Mean of Response	0.019289
Observations (or Sum Wgts)	13

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	-0.02437	t Ratio	-2.14877
Std Err Dif	0.01134	DF	11
Upper CL Dif	0.00059	Prob > |t|	0.0548
Lower CL Dif	-0.04932	Prob > t	0.9726
Confidence	0.95	Prob < t	0.0274*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	0.00164399	0.001644	4.6172	0.0548
Error	11	0.00391661	0.000356		
C. Total	12	0.00556059			

R2-0027269

Oneway Analysis of 2,3,7,8-TCDD By Source&Type

Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	9	0.026786	0.00629	0.0129	0.04063
EPA 2007-2008	4	0.002420	0.00943	-0.0183	0.02319

Std Error uses a pooled estimate of error variance

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.20097	0.05

Abs(Dif)-LSD

	CARP	EPA 2007-2008
CARP	-0.01958	-0.00059
EPA 2007-2008	-0.00059	-0.02937

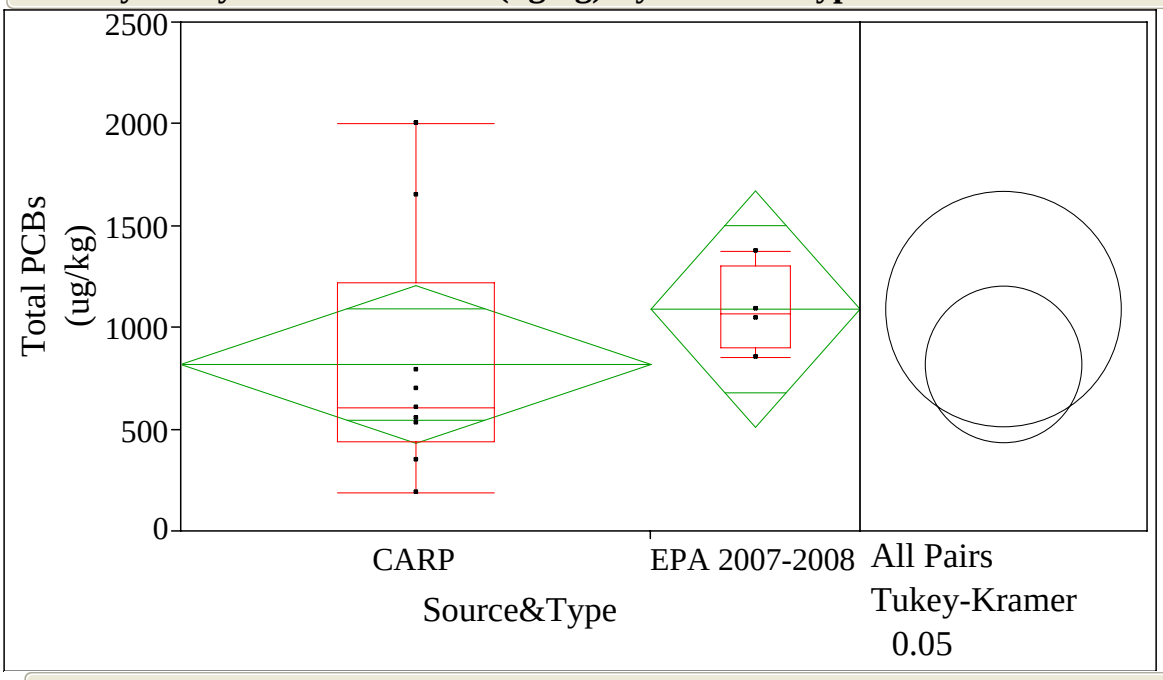
Positive values show pairs of means that are significantly different.

Level		Mean
CARP	A	0.02678551
EPA 2007-2008	A	0.00242032

Levels not connected by same letter are significantly different.

5/2/2008 12:25PM

Oneway Analysis of Total PCBs (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	186.7627	186.7627	437.9439	604.4065	1219.294	2001.053	2001.053
EPA 2007-2008	852.0415	852.0415	900.0061	1066.462	1301.997	1372.988	1372.988

Oneway Anova

Summary of Fit

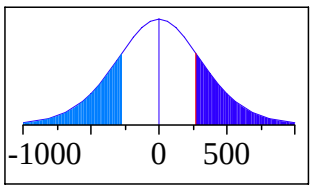
Rsquare	0.062709
Adj Rsquare	-0.0225
Root Mean Square Error	527.7826
Mean of Response	901.1236
Observations (or Sum Wgts)	13

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	272.08	t Ratio	0.857877
Std Err Dif	317.16	DF	11
Upper CL Dif	970.14	Prob > |t|	0.4093
Lower CL Dif	-425.98	Prob > t	0.2046
Confidence	0.95	Prob < t	0.7954



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	205003.0	205003	0.7360	0.4093
Error	11	3064099.7	278555		
C. Total	12	3269102.7			

Oneway Analysis of Total PCBs (ug/kg) By Source&Type

Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	9	817.41	175.93	430.19	1204.6
EPA 2007-2008	4	1089.49	263.89	508.67	1670.3

Std Error uses a pooled estimate of error variance

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.20097	0.05

Abs(Dif)-LSD

	EPA 2007-2008	CARP
EPA 2007-2008	-821.40	-425.97
CARP	-425.97	-547.60

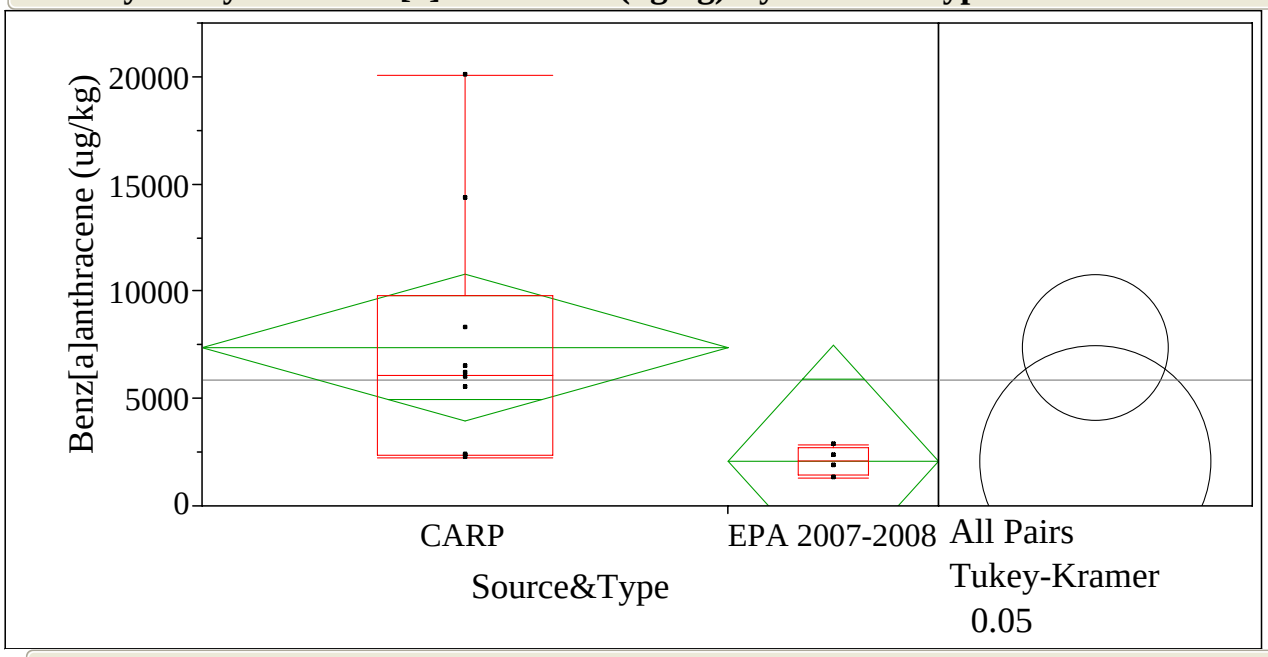
Positive values show pairs of means that are significantly different.

Level		Mean
EPA 2007-2008	A	1089.4884
CARP	A	817.4059

Levels not connected by same letter are significantly different.

5/2/2008 12:52PM

Oneway Analysis of Benz[a]anthracene (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	2234.328	2244.36	2358.459	6080.319	9794.059	19486.47	20060.05
EPA 2007-2008	1297.03	1297.03	1436.148	2091.587	2712.67	2840.336	2840.336

Oneway Anova

Summary of Fit

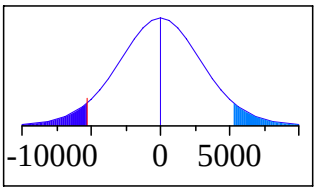
Rsquare	0.213109
Adj Rsquare	0.147534
Root Mean Square Error	4965.598
Mean of Response	5862.918
Observations (or Sum Wgts)	14

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	-5296	t Ratio	-1.80274
Std Err Dif	2938	DF	12
Upper CL Dif	1105	Prob > |t|	0.0966
Lower CL Dif	-11697	Prob > t	0.9517
Confidence	0.95	Prob < t	0.0483*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	80132892	80132892	3.2499	0.0966
Error	12	295886020	24657168		
C. Total	13	376018912			

Oneway Analysis of Benz[a]anthracene (ug/kg) By Source&Type

Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	10	7376.03	1570.3	3955	10797
EPA 2007-2008	4	2080.13	2482.8	-3329	7490

Std Error uses a pooled estimate of error variance

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.17880	0.05

Abs(Dif)-LSD

	CARP	EPA 2007-2008
CARP	-4838.4	-1104.7
EPA 2007-2008	-1104.7	-7650.2

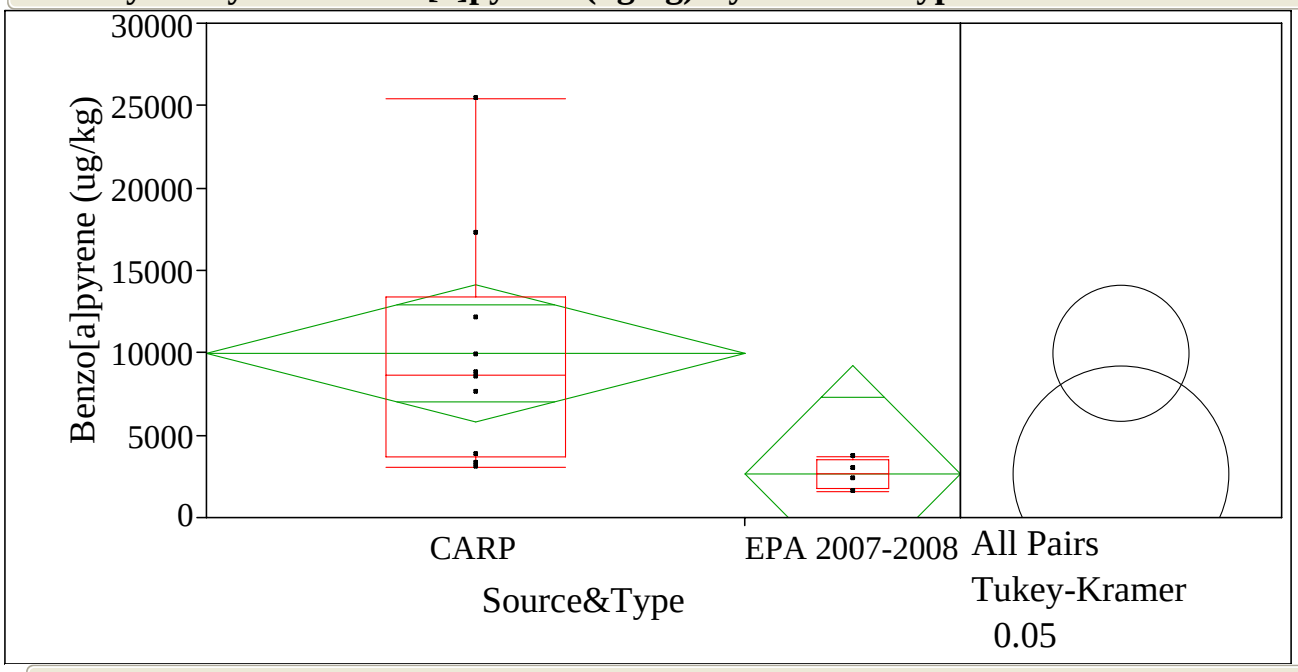
Positive values show pairs of means that are significantly different.

Level		Mean
CARP	A	7376.0306
EPA 2007-2008	A	2080.1348

Levels not connected by same letter are significantly different.

R2-0027274

Oneway Analysis of Benzo[a]pyrene (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	3047.38	3071.275	3680.379	8646.221	13390.4	24596.34	25412.95
EPA 2007-2008	1574.257	1574.257	1766.68	2655.491	3508.565	3689.076	3689.076

Oneway Anova

Summary of Fit

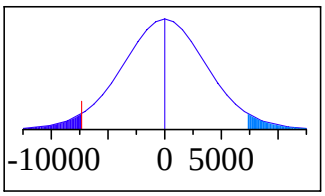
Rsquare	0.259058
Adj Rsquare	0.197313
Root Mean Square Error	6042.34
Mean of Response	7873.655
Observations (or Sum Wgts)	14

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	-7322	t Ratio	-2.04832
Std Err Dif	3575	DF	12
Upper CL Dif	466	Prob > |t|	0.0631
Lower CL Dif	-15111	Prob > t	0.9685
Confidence	0.95	Prob < t	0.0315*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	153180684	153180684	4.1956	0.0631
Error	12	438118541	36509878		
C. Total	13	591299225			

Oneway Analysis of Benzo[a]pyrene (ug/kg) By Source&Type

Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	10	9965.68	1910.8	5803	14129
EPA 2007-2008	4	2643.58	3021.2	-3939	9226

Std Error uses a pooled estimate of error variance

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.17880	0.05

Abs(Dif)-LSD

	CARP	EPA 2007-2008
CARP	-5887.6	-466.4
EPA 2007-2008	-466.4	-9309.1

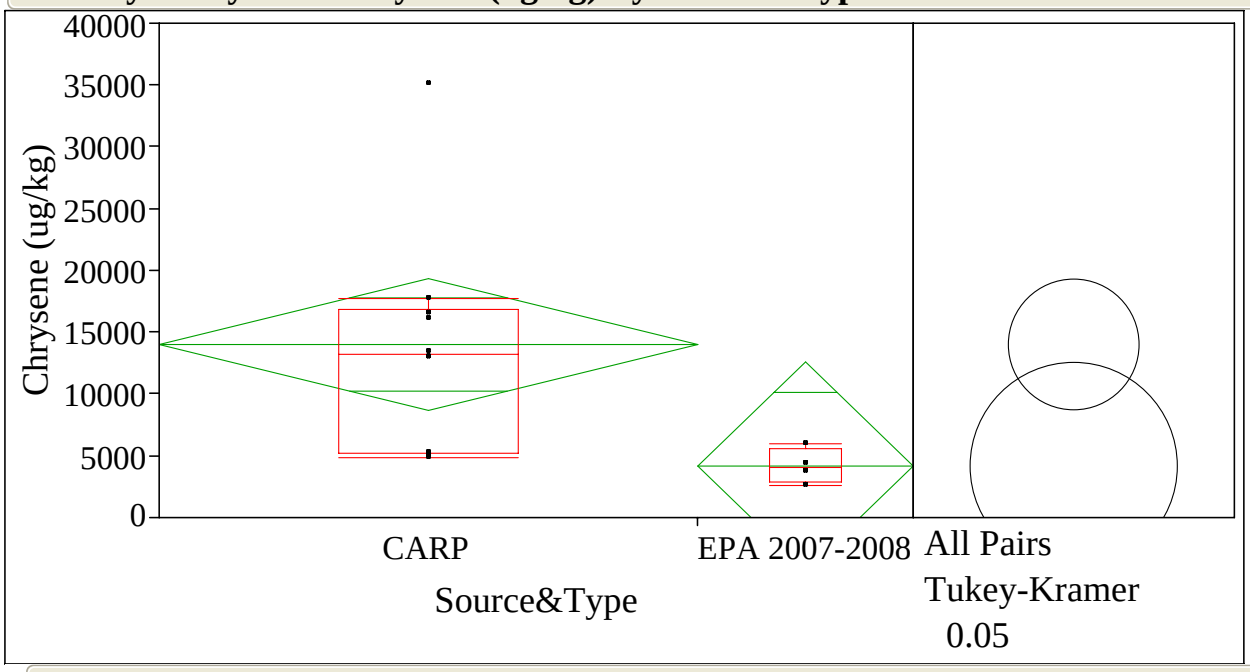
Positive values show pairs of means that are significantly different.

Level		Mean
CARP	A	9965.6850
EPA 2007-2008	A	2643.5788

Levels not connected by same letter are significantly different.

R2-0027276

Oneway Analysis of Chrysene (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	4850.132	4870.321	5205.9	13207.73	16835.59	33361.22	35098.66
EPA 2007-2008	2599.01	2599.01	2883.971	4056.24	5574.499	5974.79	5974.79

Oneway Anova

Summary of Fit

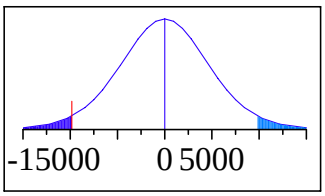
Rsquare	0.277627
Adj Rsquare	0.21743
Root Mean Square Error	7737.665
Mean of Response	11193.51
Observations (or Sum Wgts)	14

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	-9831	t Ratio	-2.14754
Std Err Dif	4578	DF	12
Upper CL Dif	143	Prob > |t|	0.0529
Lower CL Dif	-19805	Prob > t	0.9736
Confidence	0.95	Prob < t	0.0264*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	276122812	276122812	4.6119	0.0529
Error	12	718457521	59871460		
C. Total	13	994580334			

Oneway Analysis of Chrysene (ug/kg) By Source&Type

Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	10	14002.3	2446.9	8671	19334
EPA 2007-2008	4	4171.6	3868.8	-4258	12601

Std Error uses a pooled estimate of error variance

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.17880	0.05

Abs(Dif)-LSD

	CARP	EPA 2007-2008
CARP	-7539	-143
EPA 2007-2008	-143	-11921

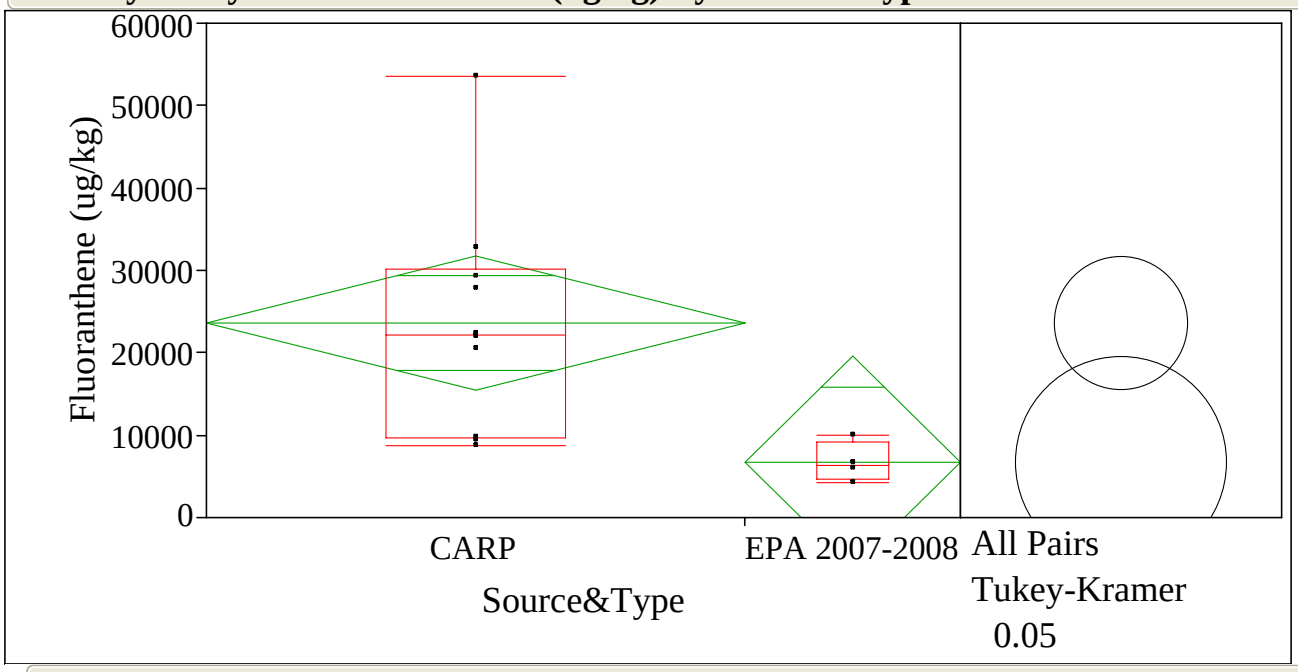
Positive values show pairs of means that are significantly different.

Level		Mean
CARP	A	14002.286
EPA 2007-2008	A	4171.570

Levels not connected by same letter are significantly different.

R2-0027278

Oneway Analysis of Fluoranthene (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	8719.551	8787.924	9660.618	22150.9	30149.99	51470.92	53550.18
EPA 2007-2008	4232.673	4232.673	4669.728	6331.105	9170.33	10000	10000

Oneway Anova

Summary of Fit

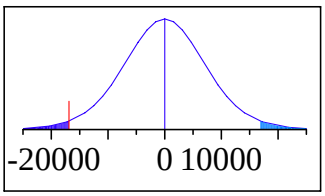
Rsquare	0.326873
Adj Rsquare	0.270779
Root Mean Square Error	11822.05
Mean of Response	18783.25
Observations (or Sum Wgts)	14

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	-16883	t Ratio	-2.41397
Std Err Dif	6994	DF	12
Upper CL Dif	-1645	Prob > |t|	0.0327*
Lower CL Dif	-32122	Prob > t	0.9837
Confidence	0.95	Prob < t	0.0163*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	814419921	814419921	5.8272	0.0327*
Error	12	1677129450	139760788		
C. Total	13	2491549371			

Oneway Analysis of Fluoranthene (ug/kg) By Source&Type

Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	10	23607.1	3738.5	15462	31752
EPA 2007-2008	4	6723.7	5911.0	-6155	19603

Std Error uses a pooled estimate of error variance

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.17880	0.05

Abs(Dif)-LSD

	CARP	EPA 2007-2008
CARP	-11519	1645
EPA 2007-2008	1645	-18214

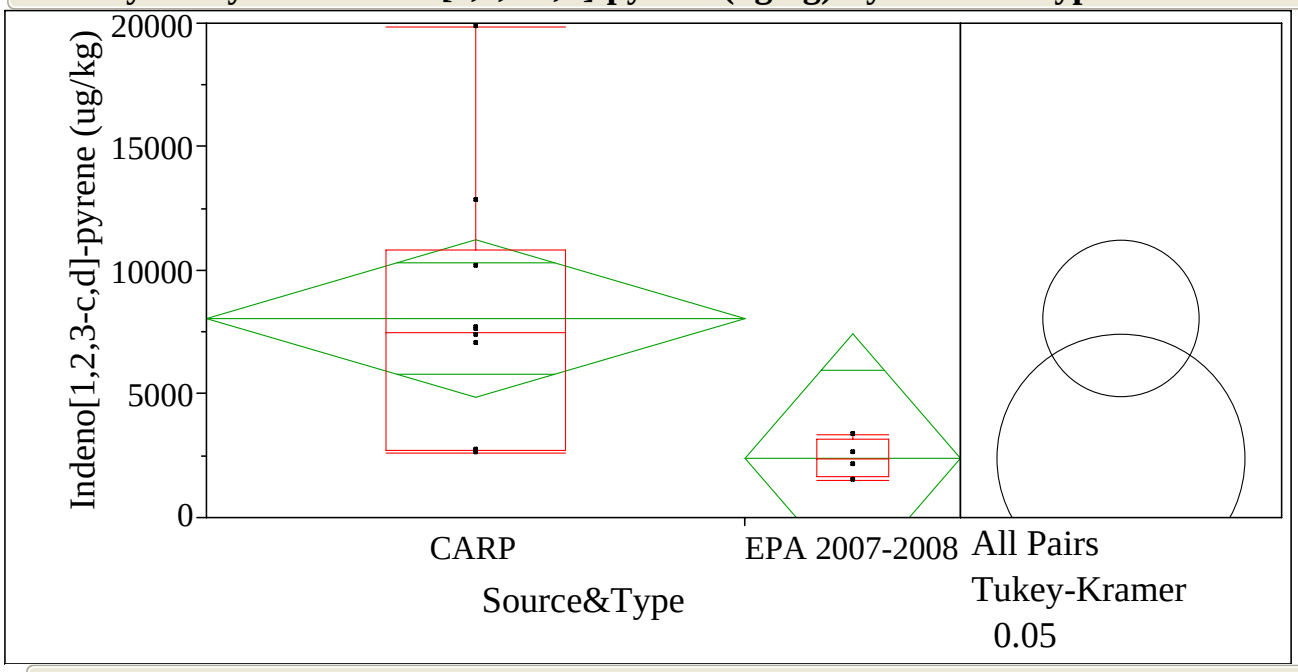
Positive values show pairs of means that are significantly different.

Level		Mean
CARP	A	23607.055
EPA 2007-2008	B	6723.721

Levels not connected by same letter are significantly different.

R2-0027280

Oneway Analysis of Indeno[1,2,3-c,d]-pyrene (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	2608.104	2616.592	2717.837	7484.601	10824.88	19141.31	19843.61
EPA 2007-2008	1502.475	1502.475	1658.704	2371.387	3168.552	3352.941	3352.941

Oneway Anova

Summary of Fit

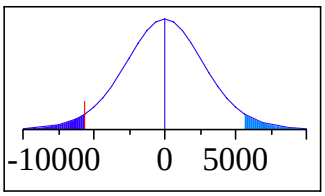
Rsquare	0.262455
Adj Rsquare	0.200993
Root Mean Square Error	4624.45
Mean of Response	6437.765
Observations (or Sum Wgts)	14

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	-5654	t Ratio	-2.06644
Std Err Dif	2736	DF	12
Upper CL Dif	307	Prob > |t|	0.0611
Lower CL Dif	-11614	Prob > t	0.9695
Confidence	0.95	Prob < t	0.0305*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	91320343	91320343	4.2702	0.0611
Error	12	256626408	21385534		
C. Total	13	347946752			

Oneway Analysis of Indeno[1,2,3-c,d]-pyrene (ug/kg) By Source&Type

Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	10	8053.05	1462.4	4867	11239
EPA 2007-2008	4	2399.55	2312.2	-2638	7437

Std Error uses a pooled estimate of error variance

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.17880	0.05

Abs(Dif)-LSD

	CARP	EPA 2007-2008
CARP	-4506.0	-307.4
EPA 2007-2008	-307.4	-7124.6

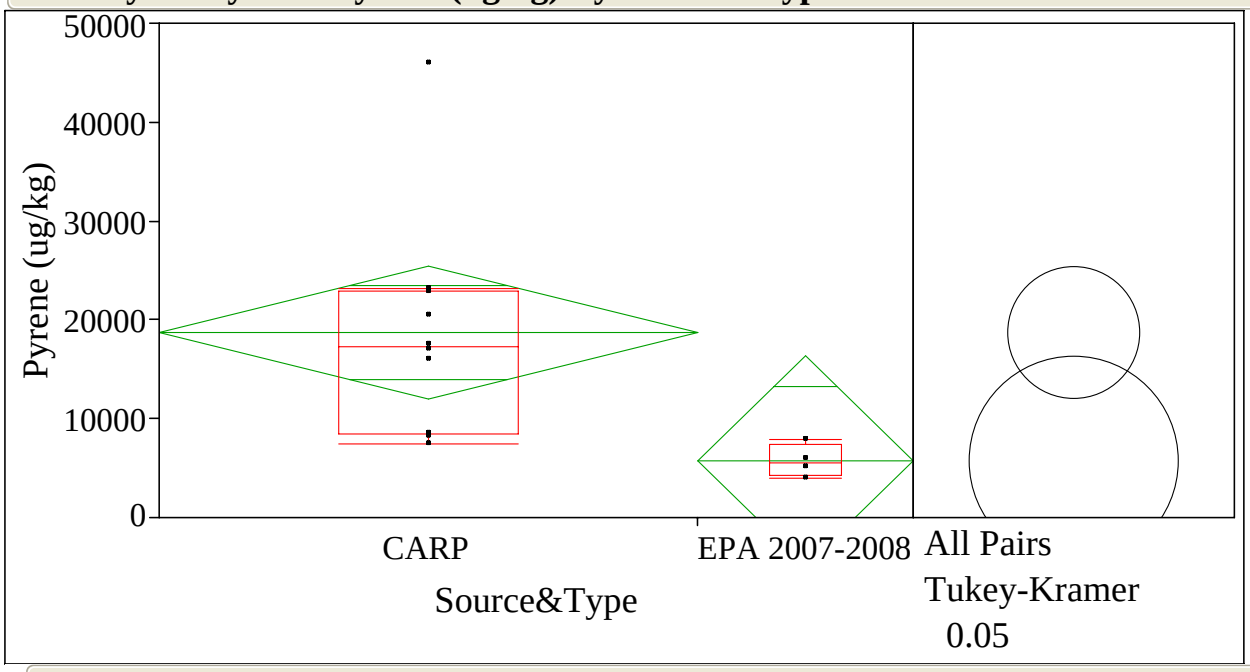
Positive values show pairs of means that are significantly different.

Level		Mean
CARP	A	8053.0525
EPA 2007-2008	A	2399.5474

Levels not connected by same letter are significantly different.

R2-0027282

Oneway Analysis of Pyrene (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	7453.165	7529.837	8453.129	17272.31	22913.61	43682.37	45962.91
EPA 2007-2008	3985.149	3985.149	4267.524	5535.347	7407.078	7890.756	7890.756

Oneway Anova

Summary of Fit

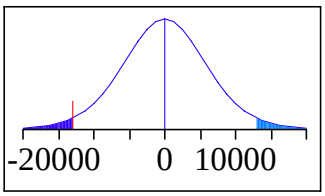
Rsquare	0.296392
Adj Rsquare	0.237758
Root Mean Square Error	9758.06
Mean of Response	15007.67
Observations (or Sum Wgts)	14

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	-12979	t Ratio	-2.24832
Std Err Dif	5773	DF	12
Upper CL Dif	-401	Prob > |t|	0.0441*
Lower CL Dif	-25558	Prob > t	0.9779
Confidence	0.95	Prob < t	0.0221*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	481330491	481330491	5.0549	0.0441*
Error	12	1142636739	95219728		
C. Total	13	1623967230			

Oneway Analysis of Pyrene (ug/kg) By Source&Type

Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	10	18716.1	3085.8	11993	25439
EPA 2007-2008	4	5736.6	4879.0	-4894	16367

Std Error uses a pooled estimate of error variance

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.17880	0.05

Abs(Dif)-LSD

	CARP	EPA 2007-2008
CARP	-9508	401
EPA 2007-2008	401	-15034

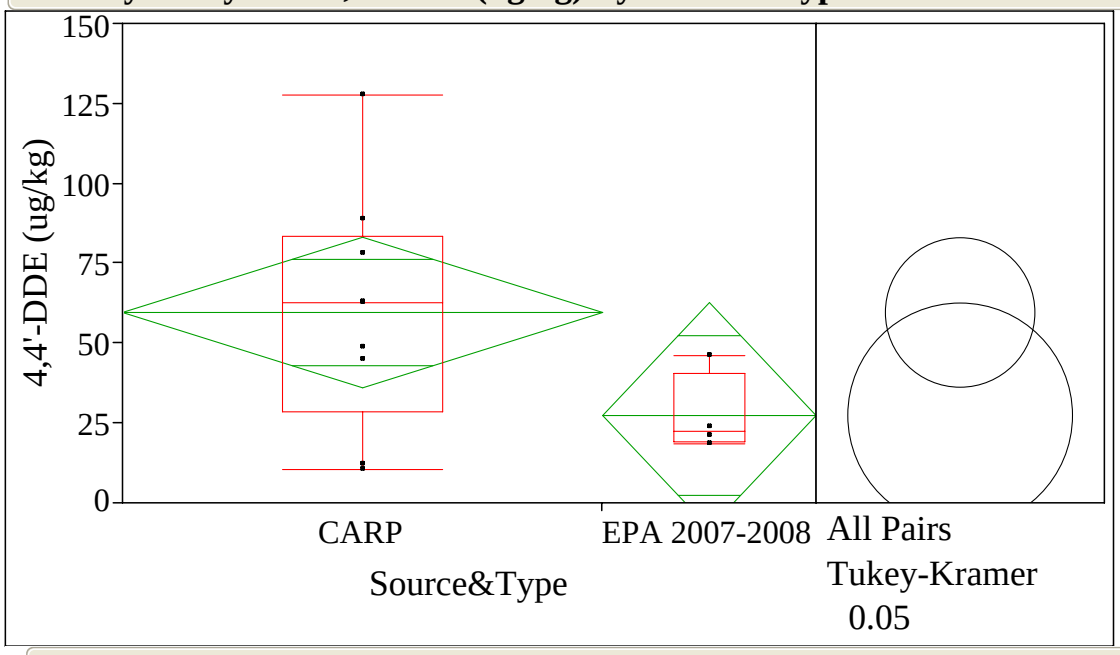
Positive values show pairs of means that are significantly different.

Level		Mean
CARP	A	18716.082
EPA 2007-2008	B	5736.650

Levels not connected by same letter are significantly different.

5/2/2008 12:43PM

Oneway Analysis of 4,4'-DDE (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	10.40581	10.40581	28.46039	62.61018	83.36657	127.6045	127.6045
EPA 2007-2008	18.43956	18.43956	19.08445	22.37837	40.47222	46.05042	46.05042

Oneway Anova

Summary of Fit

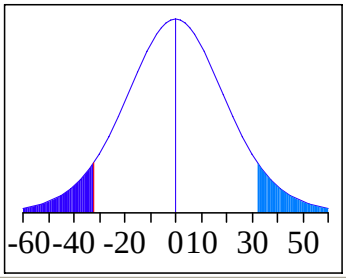
Rsquare	0.202389
Adj Rsquare	0.129879
Root Mean Square Error	32.09461
Mean of Response	49.61891
Observations (or Sum Wgts)	13

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	-32.222	t Ratio	-1.67068
Std Err Dif	19.286	DF	11
Upper CL Dif	10.228	Prob > |t|	0.1230
Lower CL Dif	-74.671	Prob > t	0.9385
Confidence	0.95	Prob < t	0.0615



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	2875.096	2875.10	2.7912	0.1230
Error	11	11330.707	1030.06		
C. Total	12	14205.803			

Oneway Analysis of 4,4'-DDE (ug/kg) By Source&Type

Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	9	59.5332	10.698	35.99	83.080
EPA 2007-2008	4	27.3117	16.047	-8.01	62.632

Std Error uses a pooled estimate of error variance

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.20097	0.05

Abs(Dif)-LSD

	CARP	EPA 2007-2008
CARP	-33.300	-10.227
EPA 2007-2008	-10.227	-49.950

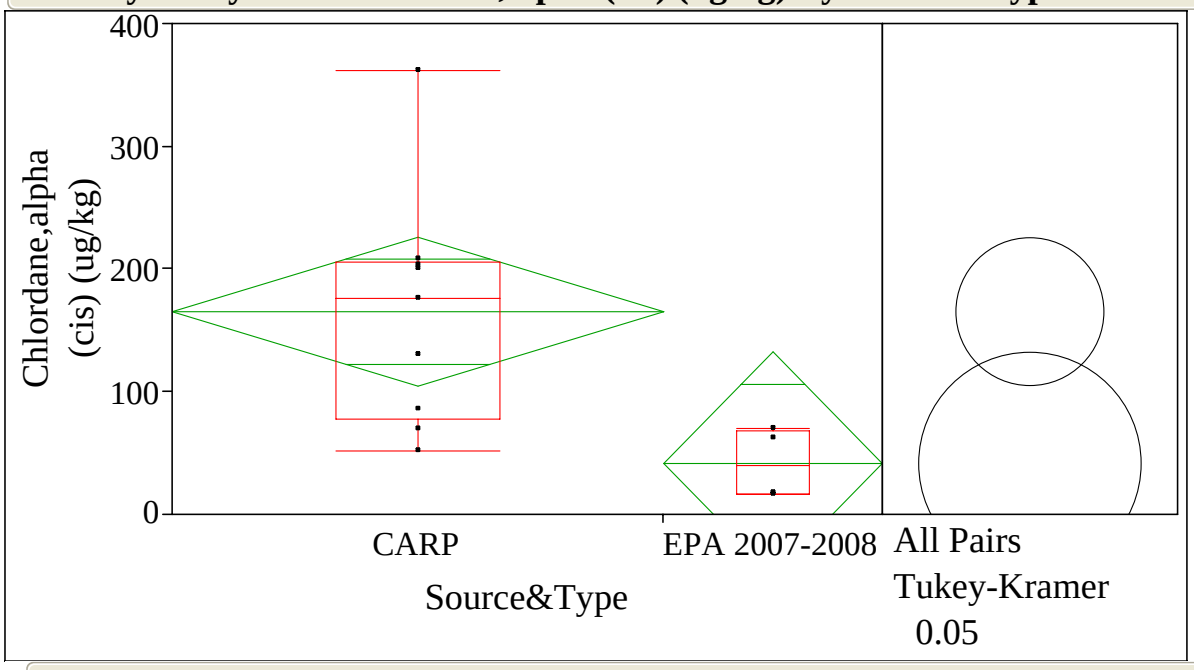
Positive values show pairs of means that are significantly different.

Level		Mean
CARP	A	59.533241
EPA 2007-2008	A	27.311678

Levels not connected by same letter are significantly different.

R2-0027286

Oneway Analysis of Chlordane,alpha (cis) (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	51.69861	51.69861	77.57327	175.979	205.5917	361.6798	361.6798
EPA 2007-2008	16.24204	16.24204	16.54417	39.78963	68.03218	70	70

Oneway Anova

Summary of Fit

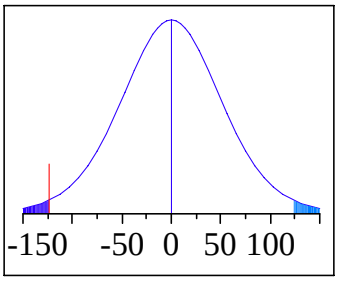
Rsquare	0.359981
Adj Rsquare	0.301798
Root Mean Square Error	82.72505
Mean of Response	127.0598
Observations (or Sum Wgts)	13

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	-123.65	t Ratio	-2.48737
Std Err Dif	49.71	DF	11
Upper CL Dif	-14.24	Prob > |t|	0.0302*
Lower CL Dif	-233.07	Prob > t	0.9849
Confidence	0.95	Prob < t	0.0151*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	42340.30	42340.3	6.1870	0.0302*
Error	11	75277.78	6843.4		
C. Total	12	117618.08			

Oneway Analysis of Chlordane,alpha (cis) (ug/kg) By Source&Type

Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	9	165.106	27.575	104.4	225.80
EPA 2007-2008	4	41.455	41.363	-49.6	132.49

Std Error uses a pooled estimate of error variance

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.20097	0.05

Abs(Dif)-LSD

	CARP	EPA 2007-2008
CARP	-85.83	14.24
EPA 2007-2008	14.24	-128.75

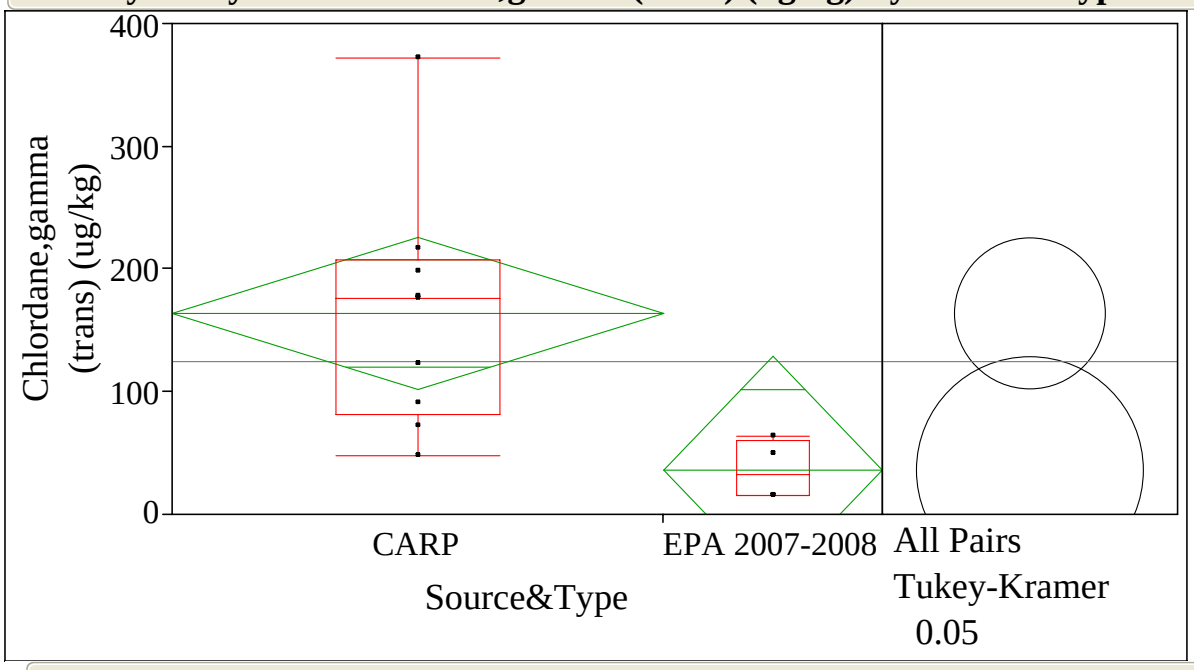
Positive values show pairs of means that are significantly different.

Level		Mean
CARP	A	165.10626
EPA 2007-2008	B	41.45533

Levels not connected by same letter are significantly different.

R2-0027288

Oneway Analysis of Chlordane,gamma (trans) (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	47.73093	47.73093	81.36116	176.0238	207.4211	371.8322	371.8322
EPA 2007-2008	15.36264	15.36264	15.37548	32.45948	60.14935	63.69748	63.69748

Oneway Anova

Summary of Fit

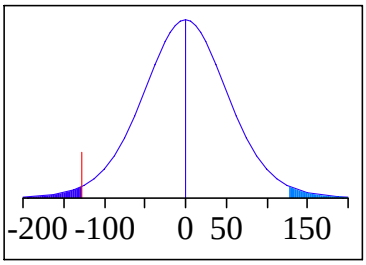
Rsquare	0.365752
Adj Rsquare	0.308093
Root Mean Square Error	84.38668
Mean of Response	124.4154
Observations (or Sum Wgts)	13

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	-127.72	t Ratio	-2.5186
Std Err Dif	50.71	DF	11
Upper CL Dif	-16.11	Prob > |t|	0.0285*
Lower CL Dif	-239.33	Prob > t	0.9857
Confidence	0.95	Prob < t	0.0143*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	45171.84	45171.8	6.3434	0.0285*
Error	11	78332.23	7121.1		
C. Total	12	123504.07			

Oneway Analysis of Chlordane,gamma (trans) (ug/kg) By Source&Type

Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	9	163.713	28.129	101.8	225.62
EPA 2007-2008	4	35.995	42.193	-56.9	128.86

Std Error uses a pooled estimate of error variance

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.20097	0.05

Abs(Dif)-LSD

	CARP	EPA 2007-2008
CARP	-87.56	16.11
EPA 2007-2008	16.11	-131.33

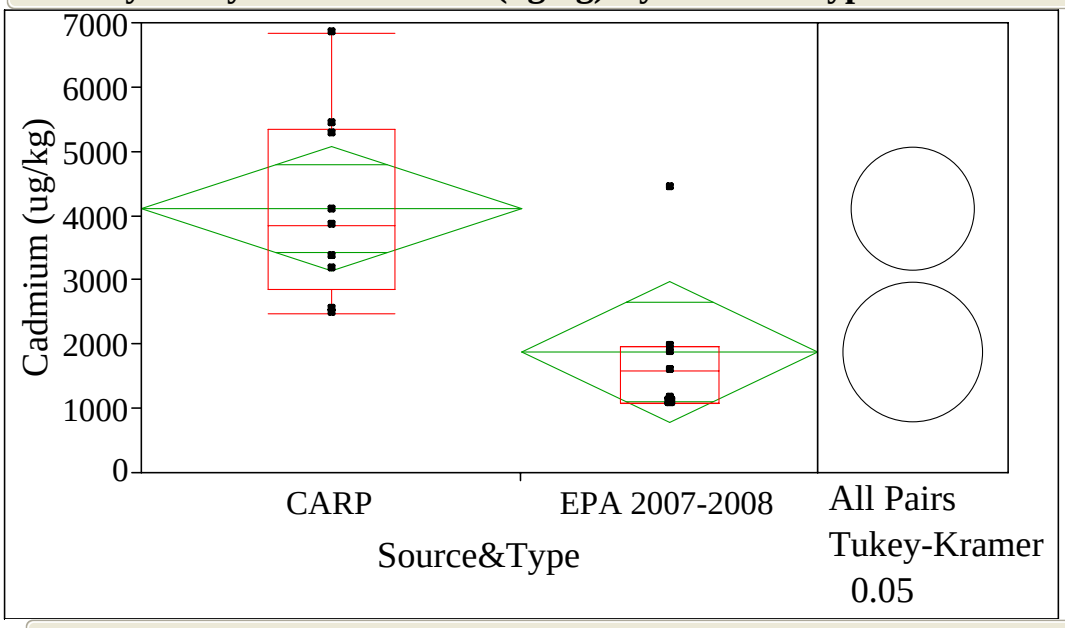
Positive values show pairs of means that are significantly different.

Level		Mean
CARP	A	163.71342
EPA 2007-2008	B	35.99477

Levels not connected by same letter are significantly different.

5/2/2008 3:35PM

Oneway Analysis of Cadmium (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	2471.17	2471.17	2849.144	3843.844	5342.001	6835.017	6835.017
EPA 2007-2008	1076.605	1076.605	1079.944	1583.333	1959.596	4425	4425

Oneway Anova

Summary of Fit

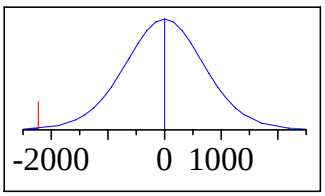
Rsquare	0.433883
Adj Rsquare	0.393446
Root Mean Square Error	1351.269
Mean of Response	3131.437
Observations (or Sum Wgts)	16

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	-2230.6	t Ratio	-3.27565
Std Err Dif	681.0	DF	14
Upper CL Dif	-770.1	Prob > |t|	0.0055*
Lower CL Dif	-3691.2	Prob > t	0.9972
Confidence	0.95	Prob < t	0.0028*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	19591961	19591961	10.7299	0.0055*
Error	14	25563004	1825928.8		
C. Total	15	45154964			

Oneway Analysis of Cadmium (ug/kg) By Source&Type

Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	9	4107.34	450.42	3141.3	5073.4
EPA 2007-2008	7	1876.70	510.73	781.3	2972.1

Std Error uses a pooled estimate of error variance

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.14478	0.05

Abs(Dif)-LSD

	CARP	EPA 2007-2008
CARP	-1366.2	770.1
EPA 2007-2008	770.1	-1549.1

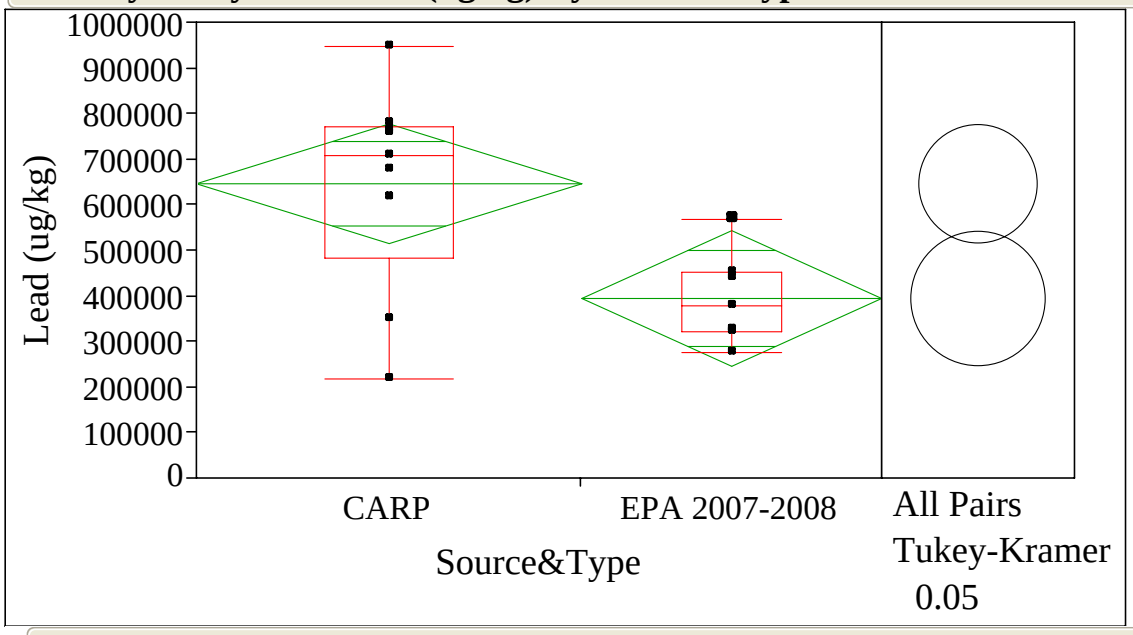
Positive values show pairs of means that are significantly different.

Level		Mean
CARP	A	4107.3398
EPA 2007-2008	B	1876.7040

Levels not connected by same letter are significantly different.

R2-0027292

Oneway Analysis of Lead (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	217210.1	217210.1	482100.3	707289.7	770344.4	946546.5	946546.5
EPA 2007-2008	275000	275000	320754.7	377777.8	451247.2	567287.8	567287.8

Oneway Anova

Summary of Fit

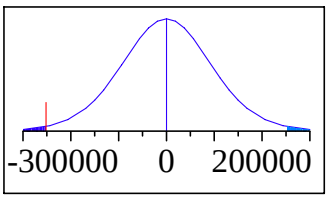
Rsquare	0.346076
Adj Rsquare	0.299367
Root Mean Square Error	183534.9
Mean of Response	535380.5
Observations (or Sum Wgts)	16

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	-251764	t Ratio	-2.72198
Std Err Dif	92493	DF	14
Upper CL Dif	-53387	Prob > |t|	0.0165*
Lower CL Dif	-450142	Prob > t	0.9917
Confidence	0.95	Prob < t	0.0083*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	2.4958e+11	2.496e+11	7.4092	0.0165*
Error	14	4.7159e+11	3.369e+10		
C. Total	15	7.2117e+11			

Oneway Analysis of Lead (ug/kg) By Source&Type

Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	9	645527	61178	514313	776742
EPA 2007-2008	7	393763	69370	244980	542546

Std Error uses a pooled estimate of error variance

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.14478	0.05

Abs(Dif)-LSD

	CARP	EPA 2007-2008
CARP	-185564	53387
EPA 2007-2008	53387	-210410

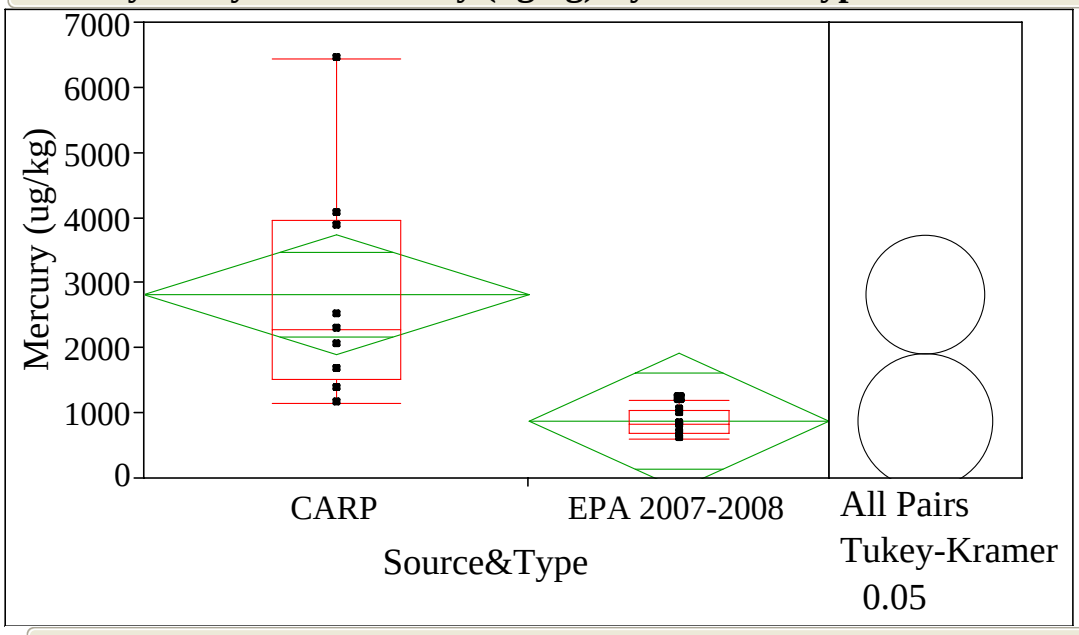
Positive values show pairs of means that are significantly different.

Level		Mean
CARP	A	645527.37
EPA 2007-2008	B	393763.15

Levels not connected by same letter are significantly different.

R2-0027294

Oneway Analysis of Mercury (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	1145.85	1145.85	1512.528	2278.131	3956.531	6433.877	6433.877
EPA 2007-2008	595.9596	595.9596	684.432	825.3968	1037.037	1192.547	1192.547

Oneway Anova

Summary of Fit

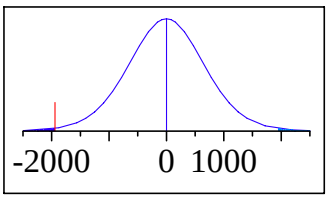
Rsquare	0.390269
Adj Rsquare	0.346717
Root Mean Square Error	1287.184
Mean of Response	1965.116
Observations (or Sum Wgts)	16

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	-1941.8	t Ratio	-2.99349
Std Err Dif	648.7	DF	14
Upper CL Dif	-550.5	Prob > |t|	0.0097*
Lower CL Dif	-3333.1	Prob > t	0.9952
Confidence	0.95	Prob < t	0.0048*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	14846906	14846906	8.9610	0.0097*
Error	14	23195798	1656842.7		
C. Total	15	38042704			

Oneway Analysis of Mercury (ug/kg) By Source&Type

Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	9	2814.66	429.06	1894	3734.9
EPA 2007-2008	7	872.85	486.51	-171	1916.3

Std Error uses a pooled estimate of error variance

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.14478	0.05

Abs(Dif)-LSD

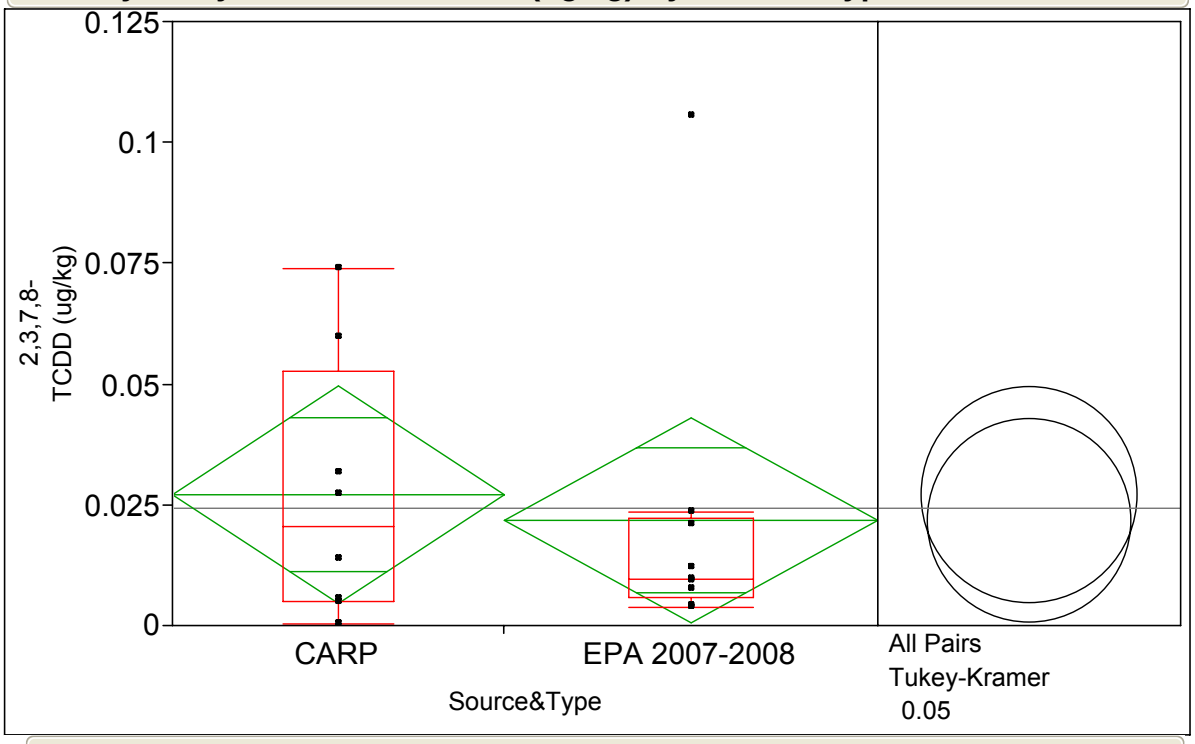
	CARP	EPA 2007-2008
CARP	-1301.4	550.5
EPA 2007-2008	550.5	-1475.7

Positive values show pairs of means that are significantly different.

Level		Mean
CARP	A	2814.6602
EPA 2007-2008	B	872.8459

Levels not connected by same letter are significantly different.

Oneway Analysis of 2,3,7,8-TCDD (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	0.000344	0.000344	0.004959	0.020476	0.052648	0.073886	0.073886
EPA 2007-2008	0.003767	0.003767	0.00579	0.009591	0.022198	0.105455	0.105455

Oneway Anova

Summary of Fit

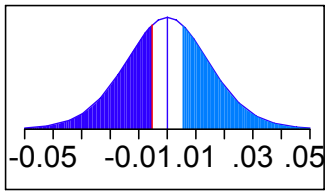
Rsquare	0.008859
Adj Rsquare	-0.05722
Root Mean Square Error	0.029863
Mean of Response	0.024279
Observations (or Sum Wgts)	17

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	-0.00531	t Ratio	-0.36617
Std Err Dif	0.01451	DF	15
Upper CL Dif	0.02562	Prob > |t|	0.7194
Lower CL Dif	-0.03624	Prob > t	0.6403
Confidence	0.95	Prob < t	0.3597



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	0.00011957	0.000120	0.1341	0.7194
Error	15	0.01337659	0.000892		
C. Total	16	0.01349616			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	8	0.027092	0.01056	0.00459	0.04960
EPA 2007-2008	9	0.021779	0.00995	0.00056	0.04300

Std Error uses a pooled estimate of error variance

Oneway Analysis of 2,3,7,8-TCDD (ug/kg) By Source&Type

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.13144	0.05

Abs(Dif)-LSD

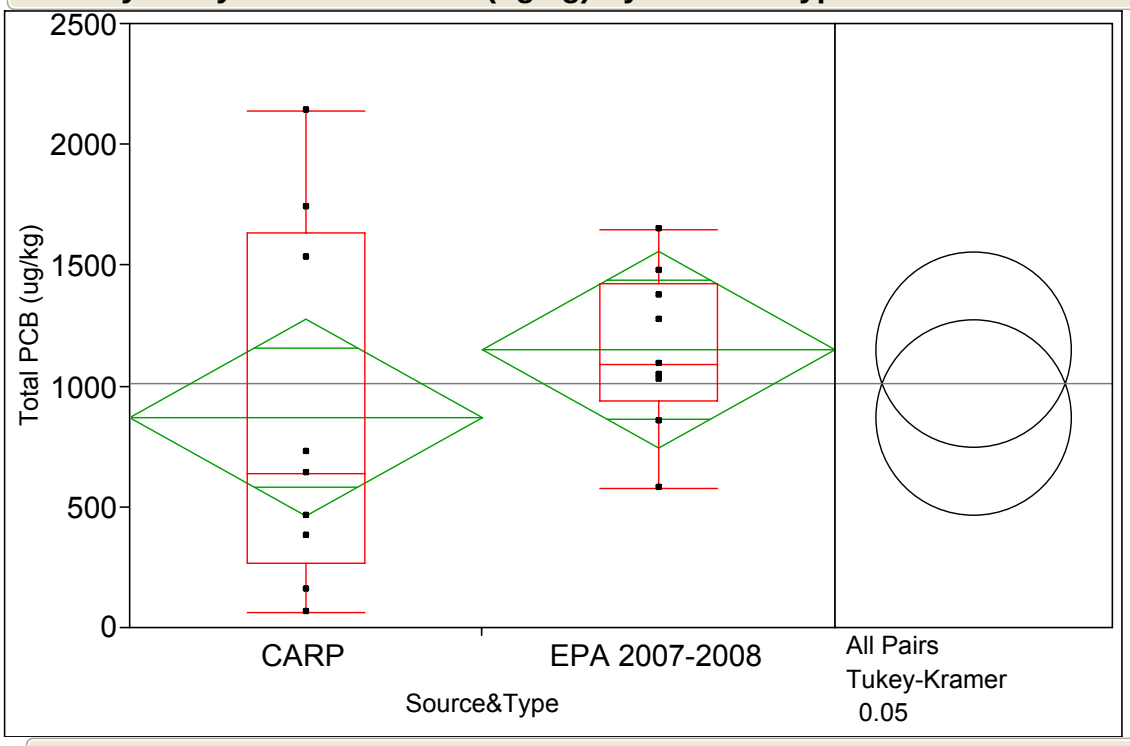
	CARP	EPA 2007-2008
CARP	-0.03183	-0.02562
EPA 2007-2008	-0.02562	-0.03001

Positive values show pairs of means that are significantly different.

Level		Mean
CARP	A	0.02709225
EPA 2007-2008	A	0.02177892

Levels not connected by same letter are significantly different.

Oneway Analysis of Total PCB (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	62.12433	62.12433	266.4628	637.0838	1633.647	2138.653	2138.653
EPA 2007-2008	575.6601	575.6601	938.2486	1089.024	1423.744	1646.734	1646.734

Oneway Anova

Summary of Fit

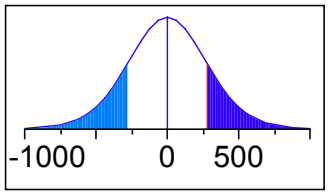
Rsquare	0.062659
Adj Rsquare	0.004075
Root Mean Square Error	576.2587
Mean of Response	1009.61
Observations (or Sum Wgts)	18

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	280.94	t Ratio	1.034196
Std Err Dif	271.65	DF	16
Upper CL Dif	856.81	Prob > |t|	0.3164
Lower CL Dif	-294.93	Prob > t	0.1582
Confidence	0.95	Prob < t	0.8418



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	355173.7	355174	1.0696	0.3164
Error	16	5313185.4	332074		
C. Total	17	5668359.2			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	9	869.14	192.09	461.94	1276.3
EPA 2007-2008	9	1150.08	192.09	742.88	1557.3

Std Error uses a pooled estimate of error variance

Oneway Analysis of Total PCB (ug/kg) By Source&Type

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.11990	0.05

Abs(Dif)-LSD

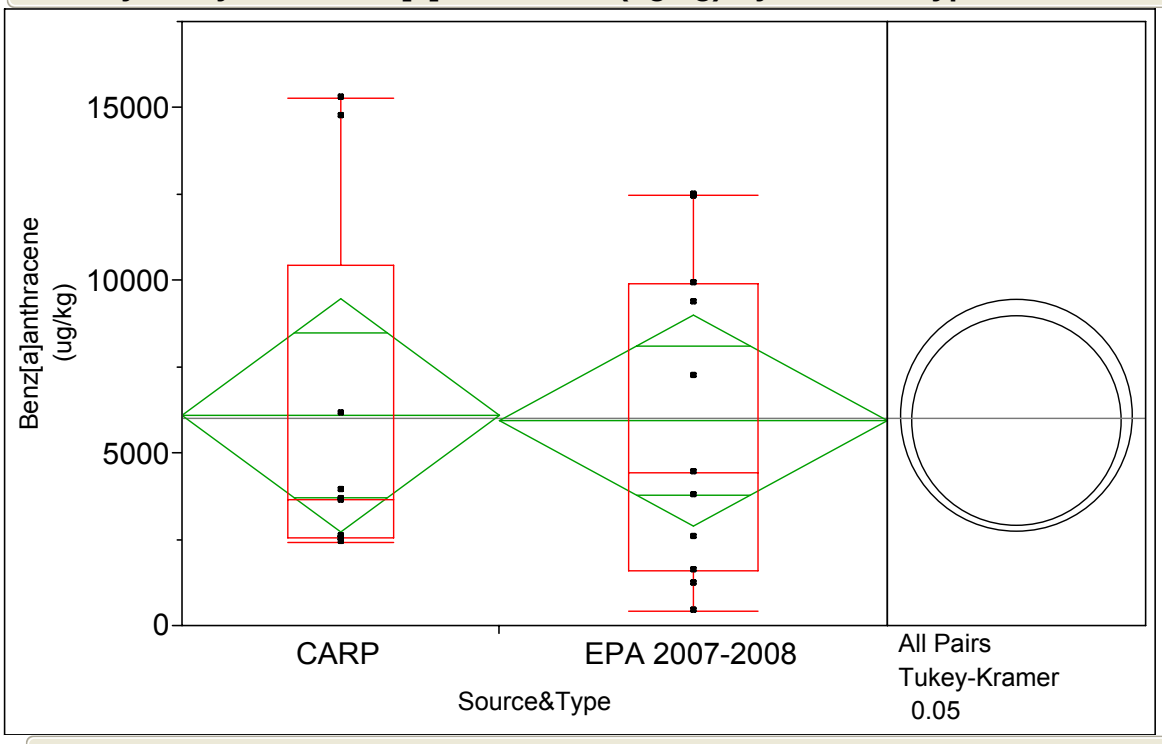
	EPA 2007-2008	CARP
EPA 2007-2008	-575.87	-294.93
CARP	-294.93	-575.87

Positive values show pairs of means that are significantly different.

Level		Mean
EPA 2007-2008	A	1150.0806
CARP	A	869.1402

Levels not connected by same letter are significantly different.

Oneway Analysis of Benz[a]anthracene (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	2406.867	2406.867	2540.651	3646.555	10438.34	15281.91	15281.91
EPA 2007-2008	414.2857	571.9286	1587.517	4427.245	9905.512	12461.09	12471.26

Oneway Anova

Summary of Fit

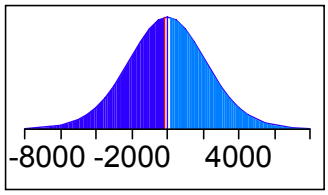
Rsquare	0.000276
Adj Rsquare	-0.05526
Root Mean Square Error	4825.731
Mean of Response	6006.194
Observations (or Sum Wgts)	20

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	-152.9	t Ratio	-0.07048
Std Err Dif	2169.0	DF	18
Upper CL Dif	4404.0	Prob > |t|	0.9446
Lower CL Dif	-4709.8	Prob > t	0.5277
Confidence	0.95	Prob < t	0.4723



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	115671	115671.43	0.0050	0.9446
Error	18	419178299	23287683		
C. Total	19	419293970			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	9	6090.27	1608.6	2710.8	9469.8
EPA 2007-2008	11	5937.40	1455.0	2880.5	8994.3

Std Error uses a pooled estimate of error variance

Oneway Analysis of Benz[a]anthracene (ug/kg) By Source&Type

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.10092	0.05

Abs(Dif)-LSD

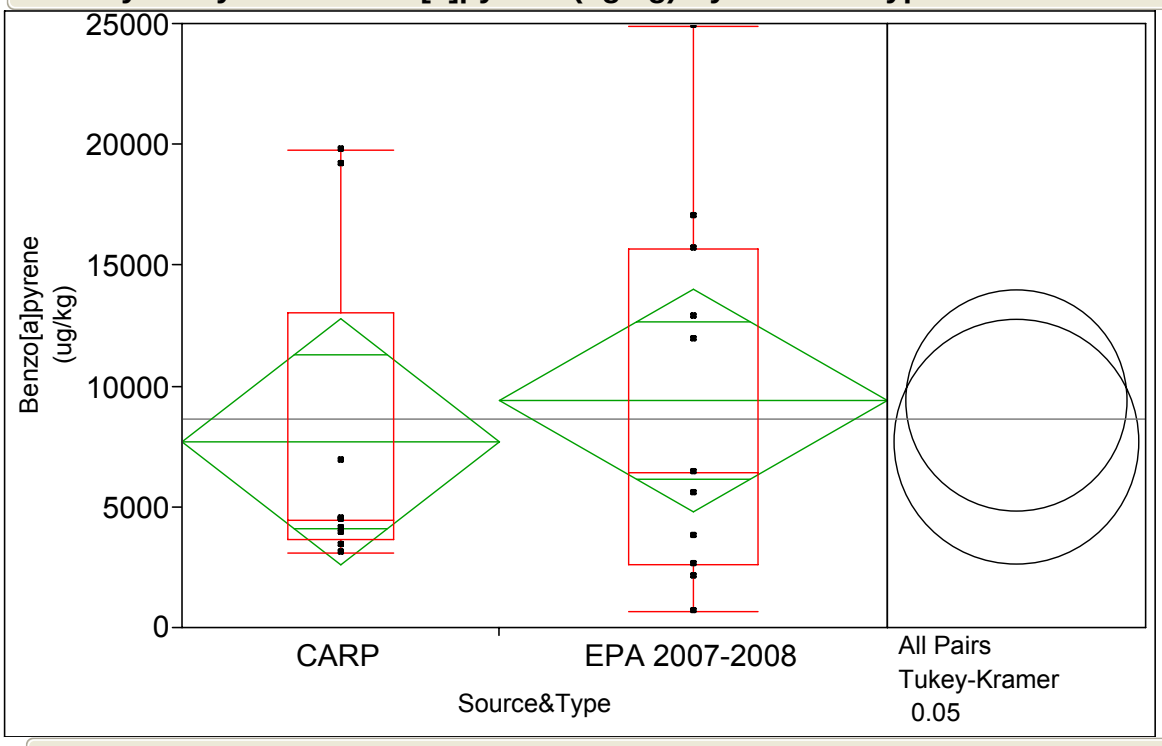
	CARP	EPA 2007-2008
CARP	-4779.3	-4404.0
EPA 2007-2008	-4404.0	-4323.1

Positive values show pairs of means that are significantly different.

Level		Mean
CARP	A	6090.2702
EPA 2007-2008	A	5937.4044

Levels not connected by same letter are significantly different.

Oneway Analysis of Benzo[a]pyrene (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	3083.215	3083.215	3644.925	4442.314	13029.38	19761.13	19761.13
EPA 2007-2008	655.6391	943.5113	2605.156	6408.669	15668.79	23309.62	24885.06

Oneway Anova

Summary of Fit

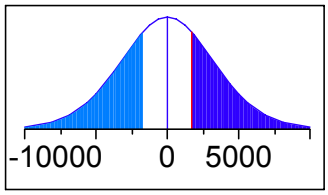
Rsquare	0.014943
Adj Rsquare	-0.03978
Root Mean Square Error	7274.84
Mean of Response	8630.447
Observations (or Sum Wgts)	20

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	1708.6	t Ratio	0.52255
Std Err Dif	3269.8	DF	18
Upper CL Dif	8578.2	Prob > |t|	0.6077
Lower CL Dif	-5161.0	Prob > t	0.3038
Confidence	0.95	Prob < t	0.6962



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	14451136	14451136	0.2731	0.6077
Error	18	952619371	52923298		
C. Total	19	967070508			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	9	7690.70	2424.9	2596.1	12785
EPA 2007-2008	11	9399.33	2193.4	4791.1	14008

Std Error uses a pooled estimate of error variance

Oneway Analysis of Benzo[a]pyrene (ug/kg) By Source&Type

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.10092	0.05

Abs(Dif)-LSD

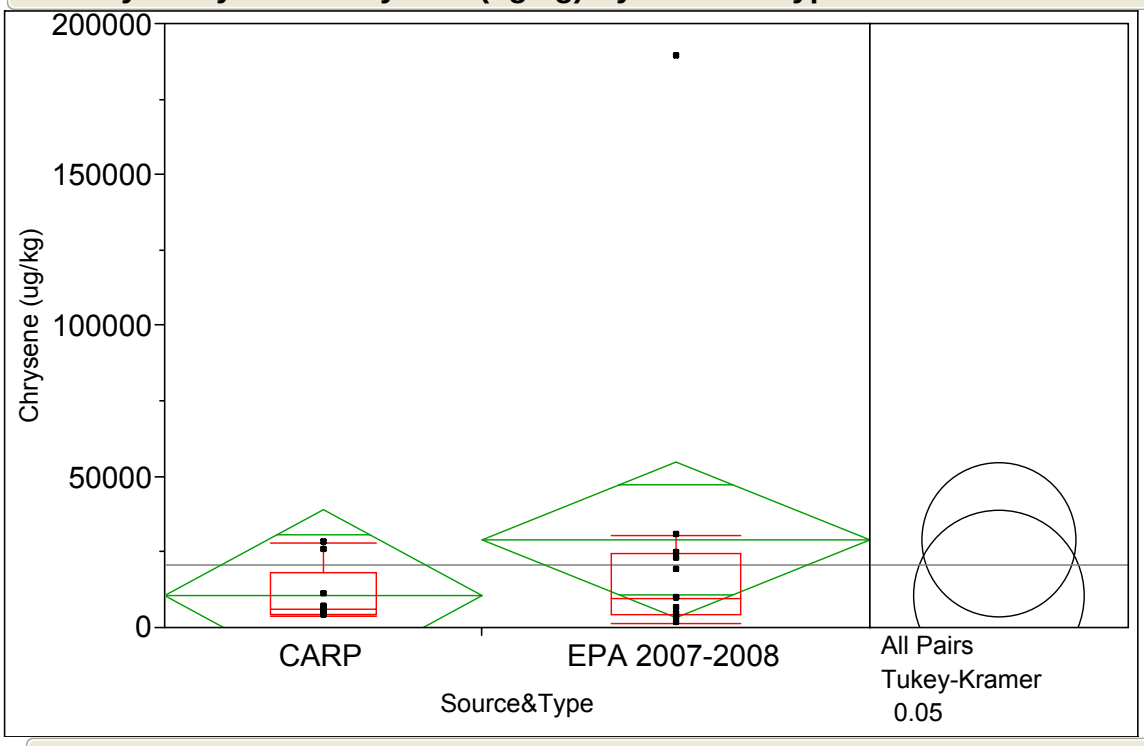
	EPA 2007-2008	CARP
EPA 2007-2008	-6517.1	-5161.0
CARP	-5161.0	-7204.9

Positive values show pairs of means that are significantly different.

Level		Mean
EPA 2007-2008	A	9399.3313
CARP	A	7690.6998

Levels not connected by same letter are significantly different.

Oneway Analysis of Chrysene (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	3739.407	3739.407	4331.79	6080.005	18195.43	27970.78	27970.78
EPA 2007-2008	1315.789	1627.632	4260.516	9623.932	24522.29	157273.1	188976.4

Oneway Anova

Summary of Fit

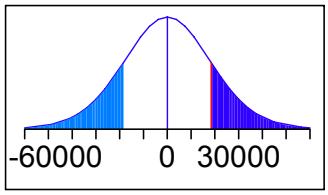
Rsquare	0.053439
Adj Rsquare	0.000853
Root Mean Square Error	40692.5
Mean of Response	20723.79
Observations (or Sum Wgts)	20

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	18438	t Ratio	1.008074
Std Err Dif	18290	DF	18
Upper CL Dif	56863	Prob > |t|	0.3268
Lower CL Dif	-19988	Prob > t	0.1634
Confidence	0.95	Prob < t	0.8366



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	1682725523	1.6827e+9	1.0162	0.3268
Error	18	2.9806e+10	1.6559e+9		
C. Total	19	3.1489e+10			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	9	10583.1	13564	-17914	39080
EPA 2007-2008	11	29020.7	12269	3244	54797

Std Error uses a pooled estimate of error variance

Oneway Analysis of Chrysene (ug/kg) By Source&Type

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.10092	0.05

Abs(Dif)-LSD

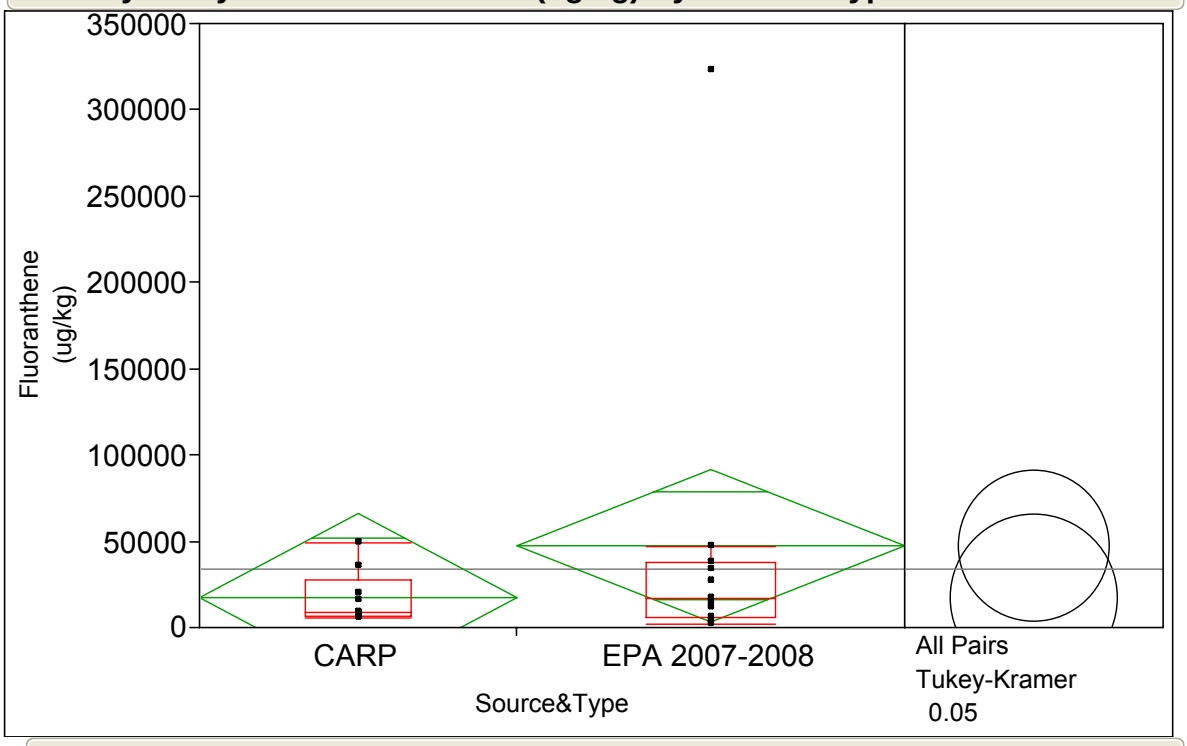
	EPA 2007-2008	CARP
EPA 2007-2008	-36454	-19988
CARP	-19988	-40301

Positive values show pairs of means that are significantly different.

Level		Mean
EPA 2007-2008	A	29020.706
CARP	A	10583.121

Levels not connected by same letter are significantly different.

Oneway Analysis of Fluoranthene (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	5509.952	5509.952	6525.801	8772.832	27597.26	49084.72	49084.72
EPA 2007-2008	1917.293	2178.835	5834.464	16905.98	37756.65	267656.3	322834.6

Oneway Anova

Summary of Fit

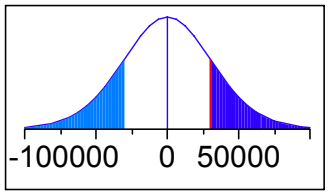
Rsquare	0.048745
Adj Rsquare	-0.0041
Root Mean Square Error	69731.63
Mean of Response	33854.8
Observations (or Sum Wgts)	20

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	30101	t Ratio	0.960397
Std Err Dif	31342	DF	18
Upper CL Dif	95948	Prob > |t|	0.3496
Lower CL Dif	-35746	Prob > t	0.1748
Confidence	0.95	Prob < t	0.8252



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	4484988227	4.485e+9	0.9224	0.3496
Error	18	8.7525e+10	4.8625e+9		
C. Total	19	9.201e+10			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	9	17299.4	23244	-31534	66133
EPA 2007-2008	11	47400.2	21025	3229	91572

Std Error uses a pooled estimate of error variance

Oneway Analysis of Fluoranthene (ug/kg) By Source&Type

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.10092	0.05

Abs(Dif)-LSD

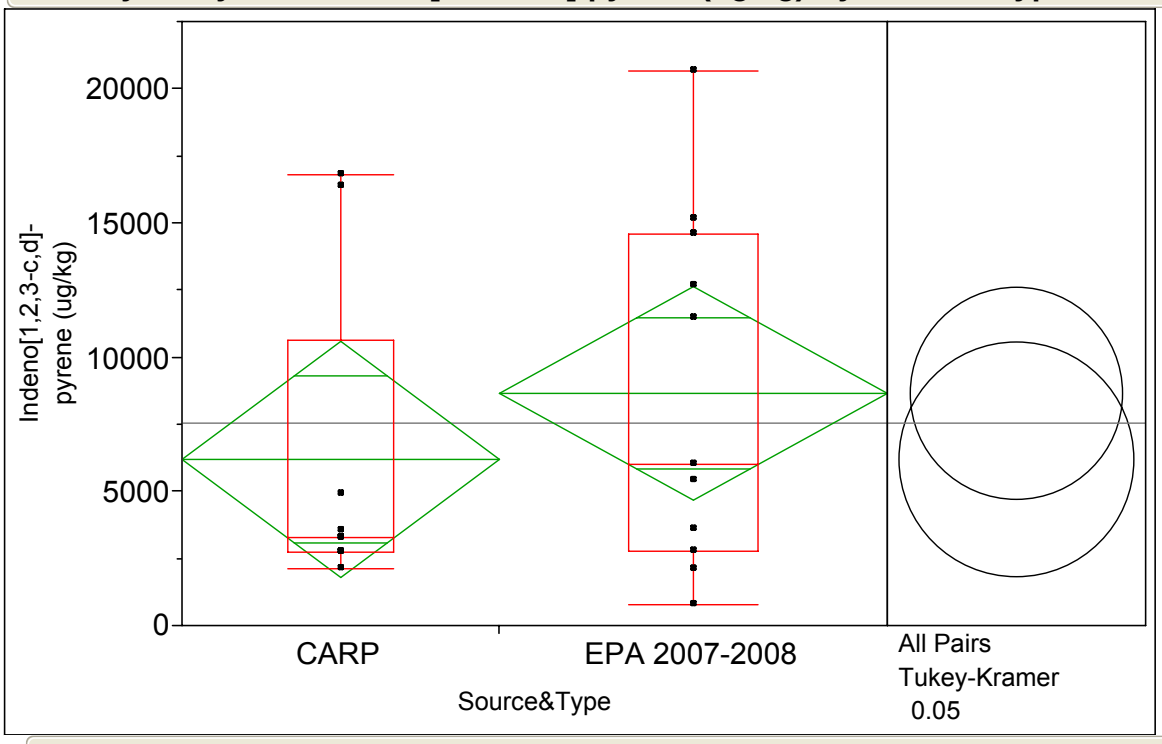
	EPA 2007-2008	CARP
EPA 2007-2008	-62468	-35746
CARP	-35746	-69061

Positive values show pairs of means that are significantly different.

Level		Mean
EPA 2007-2008	A	47400.164
CARP	A	17299.363

Levels not connected by same letter are significantly different.

Oneway Analysis of Indeno[1,2,3-c,d]-pyrene (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	2117.883	2117.883	2736.246	3279.303	10630.15	16796.74	16796.74
EPA 2007-2008	774.4361	1039.049	2767.978	6006.192	14585.99	19558.66	20660.92

Oneway Anova

Summary of Fit

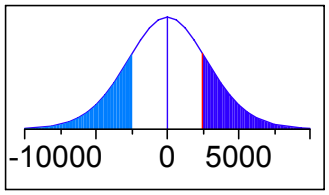
Rsquare	0.040428
Adj Rsquare	-0.01288
Root Mean Square Error	6283.519
Mean of Response	7543.036
Observations (or Sum Wgts)	20

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	2459.5	t Ratio	0.870846
Std Err Dif	2824.2	DF	18
Upper CL Dif	8393.0	Prob > |t|	0.3953
Lower CL Dif	-3474.0	Prob > t	0.1977
Confidence	0.95	Prob < t	0.8023



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	29942539	29942539	0.7584	0.3953
Error	18	710687062	39482615		
C. Total	19	740629601			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	9	6190.33	2094.5	1789.9	10591
EPA 2007-2008	11	8649.80	1894.6	4669.5	12630

Std Error uses a pooled estimate of error variance

Oneway Analysis of Indeno[1,2,3-c,d]-pyrene (ug/kg) By Source&Type

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.10092	0.05

Abs(Dif)-LSD

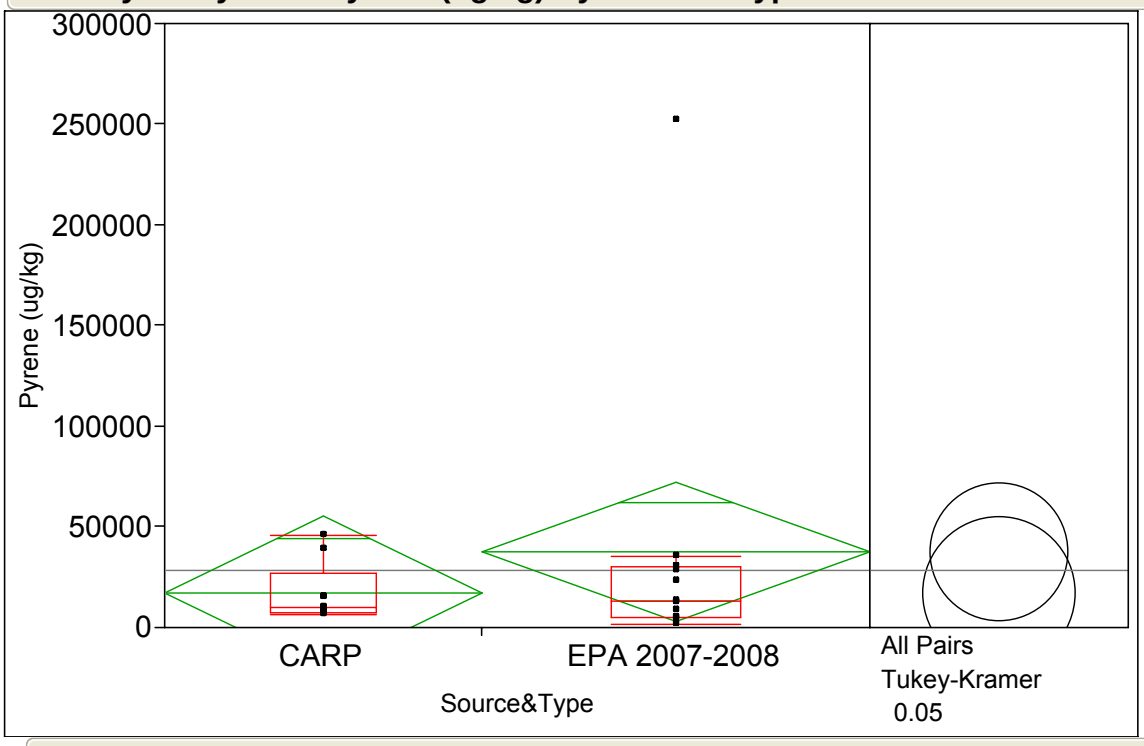
	EPA 2007-2008	CARP
EPA 2007-2008	-5629.0	-3474.0
CARP	-3474.0	-6223.1

Positive values show pairs of means that are significantly different.

Level		Mean
EPA 2007-2008	A	8649.7975
CARP	A	6190.3265

Levels not connected by same letter are significantly different.

Oneway Analysis of Pyrene (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	6393.265	6393.265	7316.302	9992.504	26952.9	45737.88	45737.88
EPA 2007-2008	1601.504	2116.203	4966.079	13126.93	30172.41	208644.9	251968.5

Oneway Anova

Summary of Fit

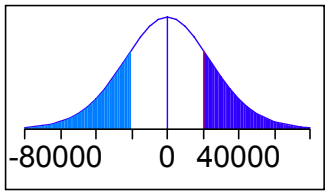
Rsquare	0.037084
Adj Rsquare	-0.01641
Root Mean Square Error	54566.02
Mean of Response	28407.79
Observations (or Sum Wgts)	20

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	20420	t Ratio	0.832594
Std Err Dif	24526	DF	18
Upper CL Dif	71946	Prob > |t|	0.4160
Lower CL Dif	-31107	Prob > t	0.2080
Confidence	0.95	Prob < t	0.7920



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	2064006415	2.064e+9	0.6932	0.4160
Error	18	5.3594e+10	2.9775e+9		
C. Total	19	5.5658e+10			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	9	17176.9	18189	-21036	55390
EPA 2007-2008	11	37596.7	16452	3032	72162

Std Error uses a pooled estimate of error variance

Oneway Analysis of Pyrene (ug/kg) By Source&Type

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.10092	0.05

Abs(Dif)-LSD

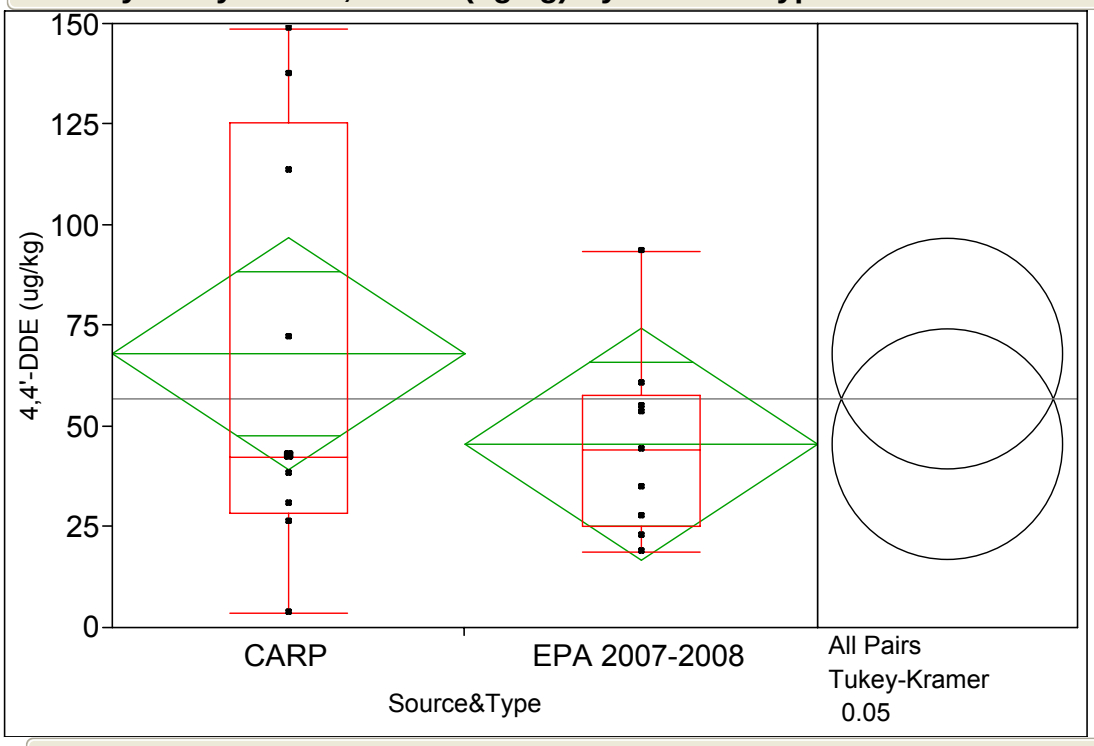
	EPA 2007-2008	CARP
EPA 2007-2008	-48882	-31106
CARP	-31106	-54041

Positive values show pairs of means that are significantly different.

Level		Mean
EPA 2007-2008	A	37596.735
CARP	A	17176.867

Levels not connected by same letter are significantly different.

Oneway Analysis of 4,4'-DDE (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	3.572204	3.572204	28.39605	42.28575	125.3831	148.6614	148.6614
EPA 2007-2008	18.72456	18.72456	25.11764	44.10256	57.67038	93.38583	93.38583

Oneway Anova

Summary of Fit

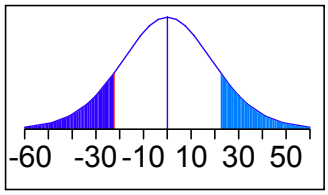
Rsquare	0.078763
Adj Rsquare	0.021186
Root Mean Square Error	40.76771
Mean of Response	56.77889
Observations (or Sum Wgts)	18

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	-22.477	t Ratio	-1.1696
Std Err Dif	19.218	DF	16
Upper CL Dif	18.263	Prob > |t|	0.2593
Lower CL Dif	-63.218	Prob > t	0.8704
Confidence	0.95	Prob < t	0.1296



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	2273.556	2273.56	1.3680	0.2593
Error	16	26592.103	1662.01		
C. Total	17	28865.659			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	9	68.0176	13.589	39.210	96.826
EPA 2007-2008	9	45.5402	13.589	16.732	74.348

Std Error uses a pooled estimate of error variance

Oneway Analysis of 4,4'-DDE (ug/kg) By Source&Type

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.11990	0.05

Abs(Dif)-LSD

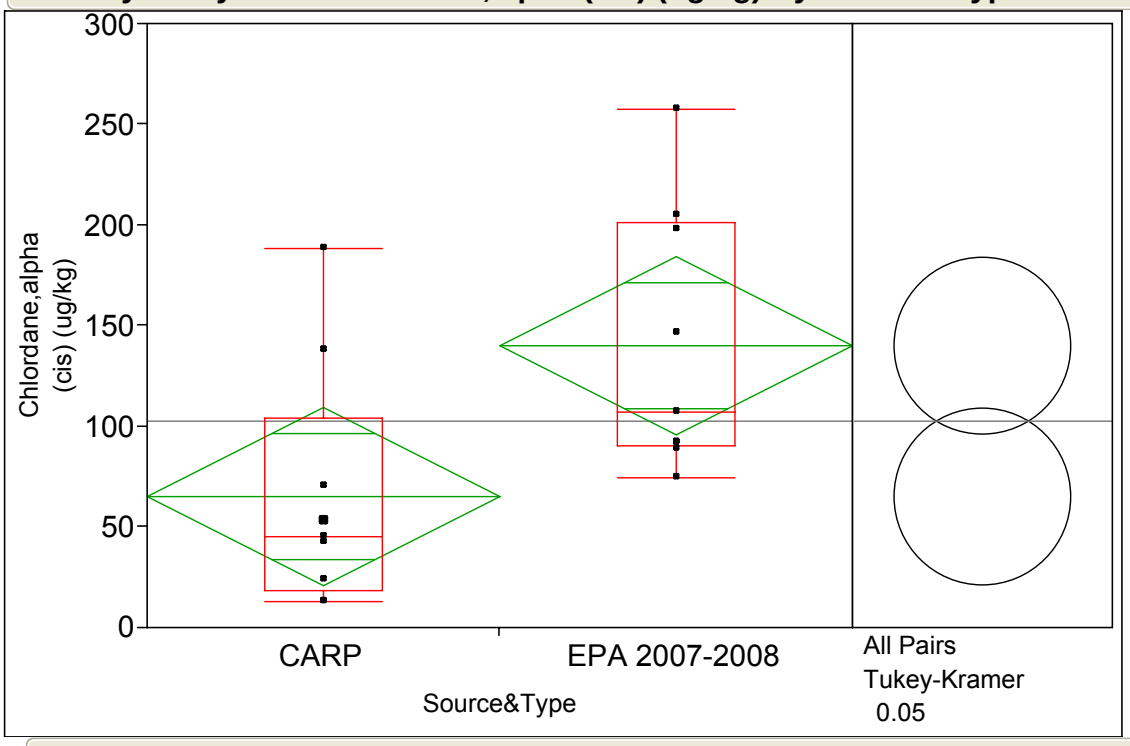
	CARP	EPA 2007-2008
CARP	-40.740	-18.263
EPA 2007-2008	-18.263	-40.740

Positive values show pairs of means that are significantly different.

Level		Mean
CARP	A	68.017608
EPA 2007-2008	A	45.540181

Levels not connected by same letter are significantly different.

Oneway Analysis of Chlordane,alpha (cis) (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	12.89288	12.89288	18.32165	45.14948	103.9978	188.3076	188.3076
EPA 2007-2008	74.39153	74.39153	90.25834	107.0064	201.2215	257.5	257.5

Oneway Anova

Summary of Fit

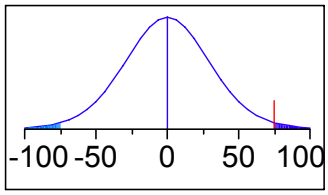
Rsquare	0.287163
Adj Rsquare	0.242611
Root Mean Square Error	62.62287
Mean of Response	102.5503
Observations (or Sum Wgts)	18

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	74.947	t Ratio	2.538803
Std Err Dif	29.521	DF	16
Upper CL Dif	137.528	Prob > |t|	0.0219*
Lower CL Dif	12.366	Prob > t	0.0109*
Confidence	0.95	Prob < t	0.9891



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	25276.917	25276.9	6.4455	0.0219*
Error	16	62745.988	3921.6		
C. Total	17	88022.905			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	9	65.077	20.874	20.825	109.33
EPA 2007-2008	9	140.024	20.874	95.772	184.28

Std Error uses a pooled estimate of error variance

Oneway Analysis of Chlordane,alpha (cis) (ug/kg) By Source&Type

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.11990	0.05

Abs(Dif)-LSD

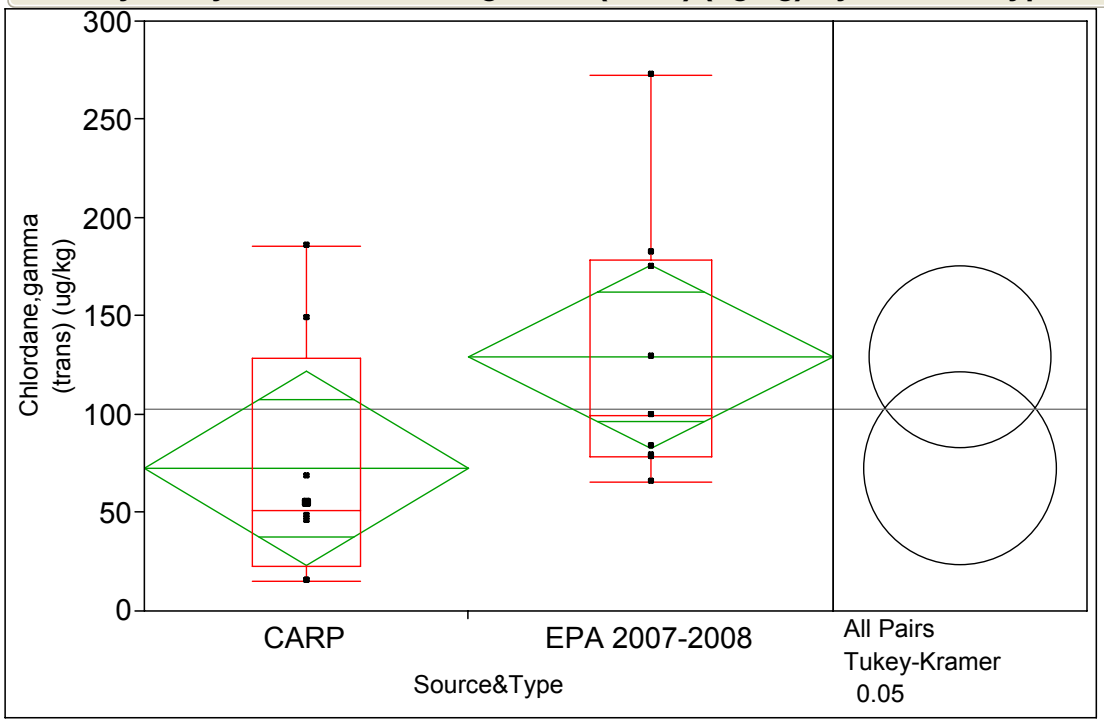
	EPA 2007-2008	CARP
EPA 2007-2008	-62.581	12.366
CARP	12.366	-62.581

Positive values show pairs of means that are significantly different.

Level		Mean
EPA 2007-2008	A	140.02398
CARP	B	65.07672

Levels not connected by same letter are significantly different.

Oneway Analysis of Chlordane,gamma (trans) (ug/kg) By Source&Type



Missing Rows 1

Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	15.06613	15.06613	22.72576	51.10425	128.5565	185.5586	185.5586
EPA 2007-2008	65.50265	65.50265	78.41121	99.36306	178.4662	272.5	272.5

Oneway Anova

Summary of Fit

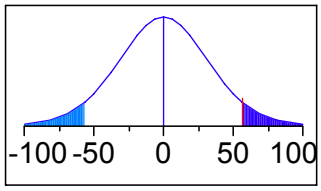
Rsquare	0.174614
Adj Rsquare	0.119588
Root Mean Square Error	65.5589
Mean of Response	102.592
Observations (or Sum Wgts)	17

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	56.75	t Ratio	1.78138
Std Err Dif	31.86	DF	15
Upper CL Dif	124.65	Prob > |t|	0.0951
Lower CL Dif	-11.15	Prob > t	0.0476*
Confidence	0.95	Prob < t	0.9524



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	13638.805	13638.8	3.1733	0.0951
Error	15	64469.539	4298.0		
C. Total	16	78108.343			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	8	72.549	23.179	23.145	121.95
EPA 2007-2008	9	129.297	21.853	82.718	175.88

Std Error uses a pooled estimate of error variance

Oneway Analysis of Chlordane,gamma (trans) (ug/kg) By Source&Type

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.13144	0.05

Abs(Dif)-LSD

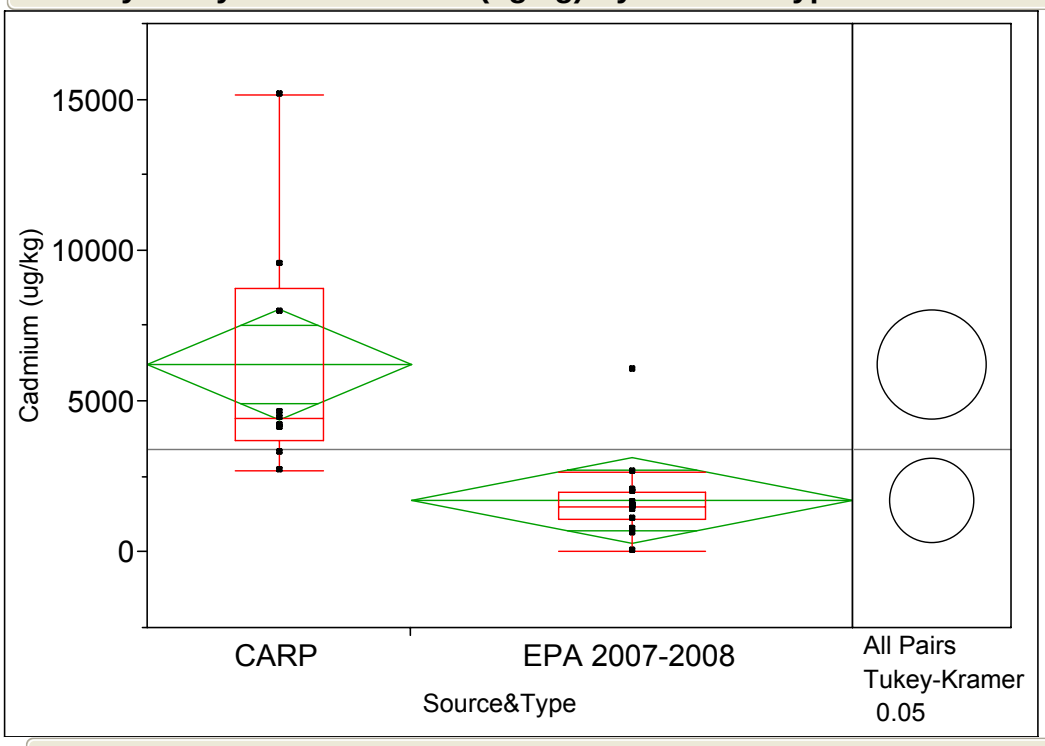
	EPA 2007-2008	CARP
EPA 2007-2008	-65.872	-11.152
CARP	-11.152	-69.868

Positive values show pairs of means that are significantly different.

Level		Mean
EPA 2007-2008	A	129.29668
CARP	A	72.54923

Levels not connected by same letter are significantly different.

Oneway Analysis of Cadmium (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	2690.191	2690.191	3691.604	4427.425	8733.458	15137.1	15137.1
EPA 2007-2008	24.59016	372.1697	1082.803	1493.902	1978.022	3994.844	6024.845

Oneway Anova

Summary of Fit

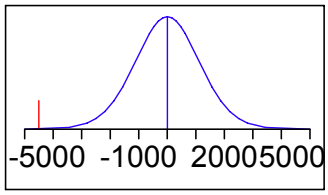
Rsquare	0.424846
Adj Rsquare	0.398703
Root Mean Square Error	2648.602
Mean of Response	3397.211
Observations (or Sum Wgts)	24

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	-4501.8	t Ratio	-4.03121
Std Err Dif	1116.7	DF	22
Upper CL Dif	-2185.9	Prob > |t|	0.0006*
Lower CL Dif	-6817.8	Prob > t	0.9997
Confidence	0.95	Prob < t	0.0003*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	113999739	113999739	16.2506	0.0006*
Error	22	154332094	7015095.2		
C. Total	23	268331832			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	9	6210.87	882.87	4379.9	8041.8
EPA 2007-2008	15	1709.02	683.87	290.8	3127.3

Std Error uses a pooled estimate of error variance

Oneway Analysis of Cadmium (ug/kg) By Source&Type

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.07387	0.05

Abs(Dif)-LSD

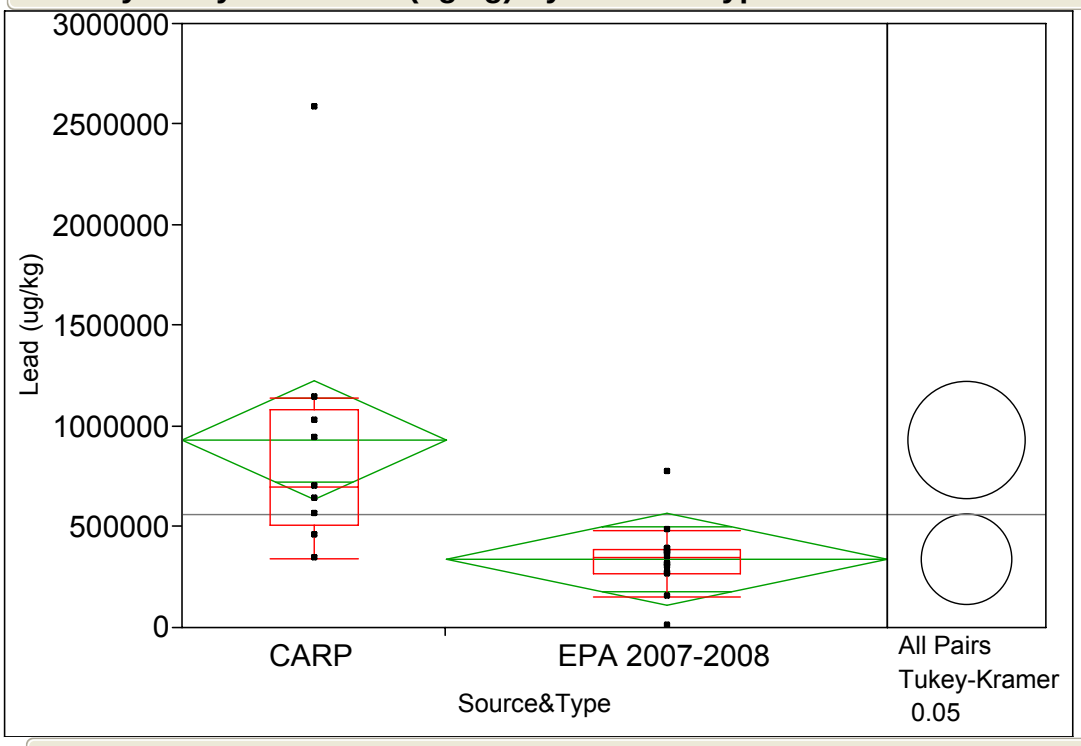
	CARP	EPA 2007-2008
CARP	-2589.4	2185.8
EPA 2007-2008	2185.8	-2005.7

Positive values show pairs of means that are significantly different.

Level		Mean
CARP	A	6210.8654
EPA 2007-2008	B	1709.0191

Levels not connected by same letter are significantly different.

Oneway Analysis of Lead (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	341721.4	341721.4	508399	697739.2	1082125	2581955	2581955
EPA 2007-2008	6475.41	93480.64	267500	348113.2	387500	597098.9	770186.3

Oneway Anova

Summary of Fit

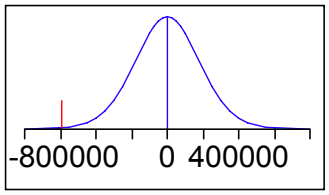
Rsquare	0.329804
Adj Rsquare	0.299341
Root Mean Square Error	426545.2
Mean of Response	561163.2
Observations (or Sum Wgts)	24

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	-591756	t Ratio	-3.29032
Std Err Dif	179847	DF	22
Upper CL Dif	-218775	Prob > |t|	0.0033*
Lower CL Dif	-964736	Prob > t	0.9983
Confidence	0.95	Prob < t	0.0017*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	1.9697e+12	1.97e+12	10.8262	0.0033*
Error	22	4.0027e+12	1.819e+11		
C. Total	23	5.9724e+12			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	9	931011	142182	636144	1225877.4
EPA 2007-2008	15	339255	110134	110852	567657.65

Std Error uses a pooled estimate of error variance

Oneway Analysis of Lead (ug/kg) By Source&Type

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.07387	0.05

Abs(Dif)-LSD

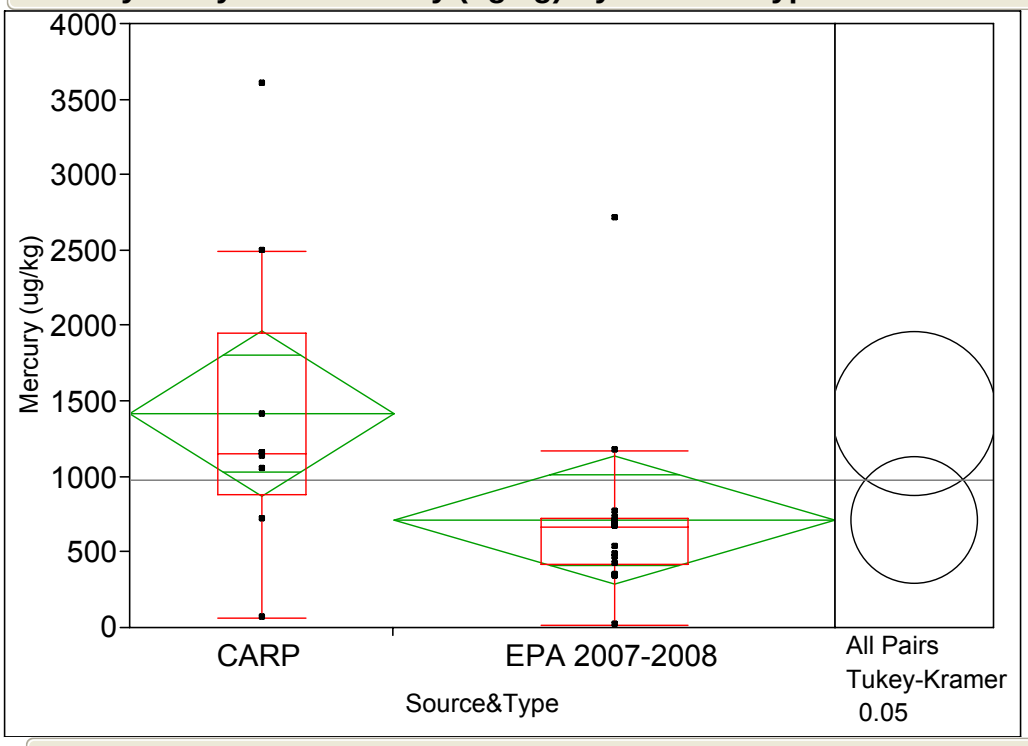
	CARP	EPA 2007-2008
CARP	-417005	218775
EPA 2007-2008	218775	-323011

Positive values show pairs of means that are significantly different.

Level		Mean
CARP	A	931010.55
EPA 2007-2008	B	339254.74

Levels not connected by same letter are significantly different.

Oneway Analysis of Mercury (ug/kg) By Source&Type



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
CARP	62.72794	62.72794	880.2361	1150.714	1949.4	3598.997	3598.997
EPA 2007-2008	14.83607	206.5714	418.0139	664.8352	723.4043	1785.117	2708.075

Oneway Anova

Summary of Fit

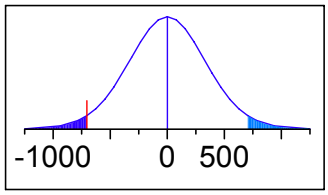
Rsquare	0.16848
Adj Rsquare	0.130684
Root Mean Square Error	792.1843
Mean of Response	976.0946
Observations (or Sum Wgts)	24

t Test

EPA 2007-2008-CARP

Assuming equal variances

Difference	-705.2	t Ratio	-2.1113
Std Err Dif	334.0	DF	22
Upper CL Dif	-12.5	Prob > |t|	0.0463*
Lower CL Dif	-1397.9	Prob > t	0.9768
Confidence	0.95	Prob < t	0.0232*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source&Type	1	2797379	2797379	4.4576	0.0463*
Error	22	13806230	627556		
C. Total	23	16603610			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARP	9	1416.85	264.06	869.22	1964.5
EPA 2007-2008	15	711.64	204.54	287.45	1135.8

Std Error uses a pooled estimate of error variance

Oneway Analysis of Mercury (ug/kg) By Source&Type

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.07387	0.05

Abs(Dif)-LSD

	CARP	EPA 2007-2008
CARP	-774.47	12.50
EPA 2007-2008	12.50	-599.90

Positive values show pairs of means that are significantly different.

Level		Mean
CARP	A	1416.8467
EPA 2007-2008	B	711.6433

Levels not connected by same letter are significantly different.

Data Evaluation Report No. 5:

“Contaminant Inventory Analysis”

LOWER EIGHT MILES OF THE LOWER PASSAIC RIVER
DATA EVALUATION REPORT NO. 5: CONTAMINANT INVENTORY ANALYSIS

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LOWER EIGHT MILES OF THE LOWER PASSAIC RIVER
DATA EVALUATION REPORT NO. 5: CONTAMINANT INVENTORY ANALYSIS

LIST OF ATTACHMENTS

Attachment A Determination of Depth of Contamination

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1 INTRODUCTION

This document is part of a series of data evaluation reports describing different aspects of the Lower Passaic River, which were prepared to support the Remedial Investigation (RI) and Focused Feasibility Study (FFS). Where necessary, data evaluation reports are cross-referenced to direct the reader to another report that contains further explanation. Topics discussed in this series include major sediment and water investigations conducted in the river, boundary conditions on the river, historical sediment contamination, surface sediment contamination, contaminant inventory calculations, and biota analysis. This data evaluation report examines the contaminant inventory for the sum of 4,4'-dichlorodiphenyltrichloroethane (4,4'-DDT), 4,4'-dichlorodiphenyldichloroethane (4,4'-DDE), and 4,4'-dichlorodiphenyldichloroethylene (4,4'-DDE) [Total DDx], 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD), Total polychlorinated biphenyl (PCB), and mercury for river mile (RM[1])0 to RM8.

1.1 Overview of the Study

The FFS Study Area is located within the Lower Passaic River Study Area (LPRSA), which is the 17-mile, tidal portion of the Passaic River from Dundee Dam [located at RM17.4] to the confluence with Newark Bay at RM0 and the watershed of this river portion, including the Saddle River (RM15.6), Third River (RM11.3) and Second River (RM8.1) [Figure 1-1]. During a comprehensive study of the Lower Passaic River, the sediments of the lower eight miles were found to be a major source of contamination to

[1] The FFS uses the "River Mile" (RM) system developed by the United States Army Corps of Engineers (USACE), which follows the navigation channel of the Lower Passaic River. The Data Evaluation Reports (Appendix A), Empirical Mass Balance (Appendix C) and Lower Passaic River-Newark Bay model (Appendix B) were initially developed at the beginning of the 17-mile Remedial Investigation and Feasibility Study (RI/FS), and thus follow a RM system developed for that RI/FS, which follows the geographic centerline of the river. RM0 is defined by an imaginary line between two marker lighthouses at the confluence of the Lower Passaic River and Newark Bay: one in Essex County just offshore of Newark and the other in Hudson County just offshore of Kearny Point. River miles then continue upriver to the Dundee Dam (RM17.4). The two RM systems are about 0.2 miles apart.

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the rest of the river and Newark Bay. Therefore, the United States Environmental Protection Agency (USEPA) completed the FFS to evaluate alternatives to address those sediments in the lower eight-mile stretch from RM0 to RM8.3, near the border between the City of Newark and Belleville Township. The entire 17-mile Lower Passaic River is the subject of another Remedial Investigation/Feasibility Study (RI/FS) being implemented by the Cooperating Parties Group (CPG; a group of approximately 70 potentially responsible parties who signed an agreement with USEPA in 2007), under USEPA oversight. The Upper Passaic River watershed (the portion of the Passaic River located above the Dundee Dam) contributes solids, water, and contaminants that cross over the head-of-tide, which is represented by the Dundee Dam[2], into the Lower Passaic River.

1.2 Overview of the Contaminant Inventory in the Passaic River

The objectives of this document are: i) to present estimates of the mass of contaminated sediments in the Lower Passaic River, and ii) to evaluate the mass and volume for the active remedial alternatives evaluated in the FFS: Deep Dredging with Backfill (Alternative 2), Capping with Dredging for Flooding and Navigation (Alternative 3) and Focused Capping with Dredging for Flooding (Alternative 4). Data sets from 1990 through 2012 were used in this analysis. This includes the following (see Data Evaluation Report No. 1 for more detailed descriptions of the major sediment data sets):

- 1990 Tierra Solutions, Inc. (TSI) Surface Sediment Investigation,
- 1991 to 1993 TSI Sediment Core Investigation,
- 1993 USEPA Surface Sediment Program,
- 1993 National Oceanic and Atmospheric Administration (NOAA) National Status and Trends (NS&T) Hudson-Raritan Phase 2,

[2] The Dundee Dam represents a hydraulic boundary. The head-of-tide actual location is downstream of the dam because even though the tides can influence the water level near the dam, the upper-most extent of saltwater (*i.e.*, the salt front) typically stops several miles below the Dundee Dam (refer to Lower Passaic River System Understanding of Sediment Transport [HQI and Sea Engineering Inc, 2011] for further details on the salt front migration).

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- 1994 TSI Surface sediment Investigation,
- 1995 TSI Remedial Investigation,
- 1995 TSI Sediment Grab Sampling Program,
- 1999 TSI Late Summer/Early Fall Ecological Sampling Plan (ESP) Sampling Program,
- 1999 USACE Sediment Sampling Program,
- 1999/2000 USACE Minish Park Monitoring Program,
- 2000 TSI Spring ESP Sampling Program,
- 2005-2007 USEPA High Resolution Sediment Coring,
- 2006 USEPA Low Resolution Sediment Coring,
- 2007-2008 USEPA Supplemental Sediment Programs,
- 2008 Cooperating Parties Group (CPG) Low Resolution Sediment Coring,
- 2009 CPG Benthic and Sediment Program,
- 2010 CPG Benthic Sediment Sampling,
- 2010 TSI Phase 1 Sediment Sampling and
- 2012 CPG Low Resolution Coring Supplemental Sampling Program.

These data were processed to systematically address different analytical techniques through time, variable core segment lengths, dissimilar segmentation or concentrations below the detection limit. No adjustments were made to the elevation of sediment cores to account for bathymetric changes from 1990-2012. The differences in sampling and analysis methods, and the fact that the studies were not originally undertaken to provide data to calculate contaminant inventory, limit the ability to calculate precise and accurate estimates of mass and volume of contaminant inventory on a small scale (less than half a mile). However, when examined together, the extensive number of samples provides sufficient information to create a fairly robust estimate of the overall lower 8 mile inventory.

This report comprised of the following sections in addition to the introduction:

- *Section 2 Contaminant Inventory and Uncertainties: RM0 to RM8.3*: provides the methodology to estimate the contaminant inventory and its associated uncertainties. This section also presents the results of the inventory estimates.
- *Section 3 Assessment of FFS Capping with Dredging for Flooding and Navigation Alternative*: discusses the contaminant inventory for Alternative 3.
- *Section 4 Assessment of Focused Capping with Dredging for Flooding Alternative*: discusses the contaminant inventory for Alternative 4.
- *Section 5 Summary*: provides a summary of total contaminant mass in the sediments and contaminant mass for Alternative 3.
- *Section 6 Acronyms*: defines the acronyms used in this report
- *Section 7 References*: lists the references used in this report

2 CONTAMINANT INVENTORY AND UNCERTAINTIES: RM0 TO RM8.3

Contaminated sediment mass was estimated using an empirical approach with the goal of determining the total mass and associated precision bounds (referred to herein as uncertainties). The area between RM0 and RM8.3 was divided laterally and vertically into large (more than one mile) segments, and the respective mass estimates and uncertainties were integrated to determine the total mass from RM0 to RM8.3 and the associated uncertainties. The volume of sediments over which the integration occurred extended from RM0 to RM8.3 laterally, and down to the depth of contamination (DoC). Attachment A summarizes how the DoC, which varied spatially, was determined.

2.1 Methodology

The methodology used to estimate the mass of select contaminants from RM0 to RM8.3 was an empirical approach with no interpolation or extrapolation of the chemical data laterally or vertically. This methodology was selected as a means to minimize assumptions, to maintain transparency, and to ensure that uncertainty bounds are developed based on a proper accounting of the degrees of freedom available for estimation within each subarea and depth stratum.

In this analysis special consideration was given to contaminated sediments adjacent to the former Diamond Alkali facility at 80 Lister Avenue. In June 2008, EPA, Occidental Chemical Corporation (OCC) and TSI signed an Administrative Order on Consent (AOC) for a non-time critical removal of 200,000 cy ("Tierra Removal") of contaminated sediment in this area to be conducted in two phases. Phase 1 of the Tierra Removal (40,000 cy) was completed in 2012. Phase 2 (160,000 cy) is undergoing a separate engineering study. A Phase 3 area adjacent to Phase 2 was tentatively identified as potentially containing high concentrations of COPCs, but not included in the AOC governing the Tierra Removal. As shown in this report the contaminant inventory in Phase 3 is significantly lower than that in Phases 1 and 2, and therefore Phase 3 was not

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targeted for removal in any special way, but was addressed within each active remedial alternative in the same manner as all of the other contaminated fine-grained sediment in the FFS Study Area.

2.1.1 Chemical Data Pre-Processing

In this analysis, all the data sets from 1990 through 2012 that fall between RM0 and RM8.3 were used in the estimation of contaminant mass for 2,3,7,8-TCDD, Total PCB, Total 4,4'-DDx, and mercury. These contaminants were selected based on the following factors:

- **Risk contribution**: As reported in Appendix D, dioxins, PCBs, DDx and mercury are significant risk contributors to human health from ingestion of both fish and crab, and for ecological receptors including benthic invertebrates, fish, and wildlife.
- **Contaminant distribution**: The spatial distribution of 2,3,7,8-TCDD and Total 4,4'-DDx differs from that of other contaminants. As will be seen in the results of contaminant mass, 2,3,7,8-TCDD and Total 4,4'-DDx contain local maxima at depth around the Phase 1 and 2 areas, while Total PCB and mercury do not. The local variability in contaminant distribution is a function of the sources of these contaminants, the proximity to these sources, and the overall sedimentation processes in the river over time.
- **Depth of Contamination**: The contaminant with the greatest depth of contamination is mercury. Mercury was used to delineate the depth of full dredging as part of Alternative 2.

No adjustments were made to the elevation of sediment cores to account for bathymetric changes in this time period during the pre-processing of the chemical data. However, adjustments to the data were needed to account for bias and differences in analytical techniques employed to obtain the results for each different data set, and these adjustments were implemented for 2,3,7,8-TCDD, Total PCB and Total 4,4'-DDx. No

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adjustments were made to the mercury data. Adjustments made to the different data sets included the following:

- The CPG 2008 2,3,7,8-TCDD data were multiplied by a correction factor of 1.89. This factor was applied to account for the bias observed in the CPG 2008 2,3,7,8-TCDD data (CSC and Interface, Inc., 2010, 2011).
- The Total PCB concentration was estimated as the sum of congeners for the 2005 to 2010 data sets. Prior to 2005, only a subset of the PCB congeners were reported as part of the data sets, and therefore the Total PCB concentration was calculated as the sum of detected Aroclors. A correction factor of 1.25 was applied to the Total PCB concentrations calculated using detected Aroclors. This correction factor was derived from a regression between Aroclor- and congener- based Total PCB estimates available in the post-2005 data (Figure 2-1a). This correction factor was also used in other data evaluations presented in Data Evaluation Reports No. 4 and No 6.
- Total 4,4'-DDx was calculated as the sum of 4,4'-DDx isomers. The 2,4'-DDx isomers were not included because the 1991 to 1995 sediment samples were analyzed for only the 4,4'-DDx isomers. The analytical methodology used in the historical data sets was based on a gas chromatography/electron capture detector (GC/ECD) system [USEPA Method 8081A]. The ECD is very sensitive to detecting the halogenated compounds such as the 4,4'-DDx isomers, but it is also vulnerable to matrix interferences. Other co-extracted halogenated compounds directly interfere with target analytes. In addition, the use of ECD can lead to false positives or high biases in the results generated by this method. Since then, a new method using high resolution gas chromatography/high resolution mass spectrometry (HRGC/HRMS) [USEPA Methods 1699 and NYSDEC HRMS] was developed. The HRGC/HRMS method was developed to have better selectivity and similar or lower detection limits using a gas chromatography–mass spectrometry (GC-MS). In 2008, the CPG analyzed a total of 130 samples for pesticides using both GC/ECD and HRGC/HRMS methods. A scatter plot between the two methods shows an order of magnitude variability and an average of about 10 percent difference (Figure 2-1b) between the results obtained using

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the two methods. This correction to the historical low resolution results was deemed trivial and was not applied in this analysis.

2.1.2 Spatial and Vertical Segmentation

Segmentation of the domain between RM0 and RM8.3 was necessary to ensure that concentrations were not applied beyond their region of influence (*i.e.*, the volume of sediments most likely to have the concentration found in a core sample), horizontally or vertically. The domain between RM0 and RM8.3 was spatially divided into three broad areas including: the left bank descending (LB), right bank descending (RB), and navigational channel (NC). Within the RB area, contaminant inventories in the Phase 1, 2, and 3 removal areas were separately calculated from the rest of the RB. This separation was necessary because the areas contain the highest observed concentrations of 2,3,7,8-TCDD concentrations at depth. These high concentrations could skew estimates of statistical average and uncertainty if they are extrapolated beyond their local influence. Figure 2-2 shows the observed concentrations of 2,3,7,8-TCDD from 1990 to 2012 in the NC, LB and RB area by river mile. Note that the vertical axis is exaggerated and each point is plotted at the midpoint of the sediment core depth interval. In addition, cores with identical RM assignments were offset by 0.02 miles to maximize the number of points depicted. Each point is colored according to its concentration range as defined in the legend. It is clear from this figure that:

- The NC contains greater density of data than the RB and LB, especially above RM 4.
- Higher concentrations of 2,3,7,8-TCDD are observed at depth in the NC. High concentrations in the RB between RM2.5 and 3.5 are within and proximal to the Phase 1 and 2 areas.
- In the LB, high concentrations of 2,3,7,8-TCDD within the top 2.5 feet of sediments were observed between RM7 to 8.

In the calculation of the total mass present between RM0 and RM8.3, the individual Phase 1, 2 and 3 areas, the LB, and the RB were all treated as individual segments. The

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NC was divided into large segments approximately 2 miles in length. Figure 2-3 depicts the spatial extent of each segment used in the calculation of the total mass. The mass and uncertainties estimated for each of these individual segments were then used to calculate the total estimate for the full study area (RM0 to RM8.3).

The vertical DoC was divided into five strata to account for the segmentation in the sediment cores as well as to meet the objectives of the entire inventory analysis as follows:

- Surface sediments 0 to 0.5 feet: This stratum was delineated because several of the programs involved the sampling of surface sediments, only.
- 0.5 to 2.5 feet: This interval was selected to support assessment of Alternative 3 (see Section 3) where, with the exception of the navigation channel between RM0 and RM2.2, the dredging depth of the alternative was 2.5 feet followed by capping.
- 2.5 feet to 3.5 feet: This interval was selected to investigate the additional mass removed if the Alternative 3 depth were increased from 2.5 to 3.5 feet, as described in Section 4.
- 3.5 to 5.5 feet: The majority of the TSI 1995 data, which was the largest data set, penetrated to a depth of 5.5 feet, creating a logical depth horizon to which data would be applicable.
- 5.5 feet to the Alternative 2 DoC: This interval provided the mass at deeper depths where core penetration was less common and uncertainties were expected to be larger.

This approach to segmentation maximized the ease of application of sample data to proper depth horizons, as well as minimized the negative influence of larger uncertainties in estimates of contaminant inventory in sediments deeper than 5.5 feet.

2.1.3 Estimating Mass and Uncertainty

At each sediment core location, a length-weighted average concentration was estimated for each vertical interval where data were available. For each block or river section and

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for each horizon, the mass was calculated as the product of mean concentration, bulk density and sediment volume. Variances and standard errors were also estimated. For total mass estimates for RM0 to RM8.3, mass estimates from the various strata and sections were summed to determine the total mass estimates. The uncertainties were also combined to determine the uncertainties in the total mass estimates.

The mass is estimated by the product of average sediment contaminant concentration ($\bar{C_s}$) and bulk density ($\bar{B}$) and volume V

$$M = \bar{C_s} \times \bar{B} \times V$$

The variance of the mass is given by

$$var(M) = V^2 \times \{(\bar{C_s})^2 \times var(\bar{B}) + (\bar{B})^2 \times var(\bar{C_s})\}$$

where $var(\bar{B})$ is the sample variance of the bulk density measurements divided by the number of samples, and $var(\bar{C_s})$ is the sample variance of the concentration measurements divided by the number of samples. The standard error of the mass estimate $SE(M)$ is given by the square root of the variance.

The ratio of mass removed M_R to the total mass M_T was also calculated. The variance of this ratio is given by

$$var\left(\frac{M_R}{M_T}\right) = \left(\frac{M_R}{M_T}\right)^2 \times \left\{\frac{var(M_R)}{{M_R}^2} + \frac{var(M_T)}{{M_T}^2} - 2 \times \frac{cov(M_R, M_T)}{M_R \times M_T}\right\}$$

The standard error is once again given by the square root of the variance.

2.1.4 Estimation of Dry Bulk Density by Core Segment

The dry bulk density parameter ($\bar{B}$) in the mass calculation converts contaminant concentration from units of contaminant mass per sediment mass to units of contaminant

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mass per sediment volume. Data collected in 2005 during a geophysical survey (Aqua Survey, Inc. [ASI], 2005) were used to estimate the dry bulk density for this analysis[3]. These values were applied based on the premise that Lower Passaic River sediment density has not changed significantly from 1990 to 2010, when the data were collected.

The 2005 side scan sonar survey defined four discrete surficial sediment texture zones: silt, silt/sand, sand, and coarse material. The last category includes both the rock and rock/sand classification zones. Based on the grain size analysis of 40 samples, a dry bulk density value was assigned to each sediment texture zone as follows:

- Silt = 0.73 g/cm^3;
- Silt and Sand = 1.07 g/cm^3;
- Sand = 1.4 g/cm^3;
- Gravel and Sand = 1.6 g/cm^3; and
- Rock and Coarse Gravel = 1.6 g/cm^3.

Dry bulk density values were then applied to the cores based on the sediment texture zone in which they were located.

A key assumption made in this analysis was that the surface sediment textures defined during the side scan sonar surveys accurately represent subsurface textures. To corroborate this assumption, surficial sediment textures, as interpreted from side scan sonar surveys, were compared to subsurface classifications from geotechnical borings. Figure 2-4 presents fence diagrams showing sub-bottom geological units for the geotechnical borings, with three borings collected along cross sections spaced a mile apart. At each boring location, the sediment texture classification from the side scan sonar survey is also presented.

[3] Additional grain size and dry bulk density data was collected in 1995; however this data was not incorporated into the mass analysis because the density values could not be connected to individual sediment core samples.

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At over 80 percent of the locations, the surficial sediment textures matched the textures at depth. In nearly all instances, the surficial texture extended to at least half of the recovered boring core depth. The surface texture for cores in the lower 7 miles typically extended to a depth of 7 feet or more, and occasionally to a depth of 20 feet. These observations indicate that the surface material as classified by the side scan sonar is generally representative of sediment texture at depth.

2.2 Results of Inventories and Uncertainties

Total inventories of the four chemicals from the region RM0 to RM8, including the Phase 1, 2 and 3 areas, are given in Table 2-1 along with their uncertainties expressed as the standard error relative to the mass estimate. The total mass of 2,3,7,8-TCDD is about 38 kilograms (kg), with a standard error of about 43 percent. For Total 4,4'-DDx the mass is 29,000 kg but the uncertainty associated with this estimate is over 100 percent. Total PCB and mercury have respective inventories of 23,500 kg and 42,000 kg, with associated standard errors of 23 percent (Total PCB) and 10 percent (mercury). The spatial and vertical distribution of these inventories and the relationship amongst the chemicals are discussed below.

2.2.1 Spatial and Vertical Distribution of Contaminant Inventory

The detailed breakdown of the total inventory and uncertainties by spatial and vertical depth intervals are provided in Tables 2-2 to 2-5. Note that the mass estimates in these tables are rounded to two significant digits. Figures 2-5 through 2-8 show the spatial distribution of contaminant mass from RM0 to RM8. Figures 2-9 through 2-12 show the vertical distribution of the mass from RM0 to RM8. Uncertainties are expressed as the ratio of the standard error divided by the estimated mass.

For 2,3,7,8-TCDD, nearly half of the overall spatial mass lies in the navigation channel (16 kg out of 38 kg, or approximately 42 percent). The Phase 1, 2 and 3 areas account for a combined 14 kg out of the total inventory of 38 kg, or about 37 percent. The majority of the mass in Phase 1, 2 and 3 areas falls in the Phase 1 (26 percent of the total) and Phase

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2 (11 percent of the total) areas; the Phase 3 area contributes less than 1 percent to the total mass. In the Phase 3 area, there are only three historical cores to characterize the mass at depth, and therefore, the mass estimate is highly uncertain. The vertical distribution of mass indicates that about 8 percent of the mass is in the top 2.5 feet and that 29 percent is located between 2.5 feet to 5.5 feet. The majority of the mass (greater than 60 percent) of 2,3,7,8-TCDD lies below 5.5 feet, but this is associated with a higher level of uncertainty, as the number of cores that penetrate to this depth is small.

For Total 4,4'-DDx, almost 86 percent of the mass is contained in the Phase 1, 2 and 3 areas, with the Phase 1 area accounting for approximately 74 percent. The LB and NC contribute about 5 percent each. Similar to the observation for 2,3,7,8-TCDD, the Phase 3 area contributes less than 1 percent to the total mass. In the vertical dimension, the top 3.5 feet contains about 3 percent of the Total 4,4'-DDx mass, about 14 percent is located between 3.5 to 5.5 feet, and 83 percent is present below 5.5 feet. Uncertainties associated with Total 4,4'-DDx are higher both at depth and within the Phase 1 area, largely because of highly variable concentrations at depth in this area.

For Total PCBs, spatially, 39 percent of the mass is in NC, 36 percent in the LB, and 22 percent in the RB. The Phase 1, 2 and 3 areas only account for 3 percent. In the vertical dimension, the top 2.5 feet contain about 18 percent of the Total PCB mass, the 2.5-3.5-foot horizon contains about 13 percent, the 3.5-5.5-foot layer about 27 percent, and the material below 5.5 feet accounts for 43 percent of the mass.

For mercury, 48 percent of the spatial mass is in NC, 38 percent is in the LB, and 11 percent in the RB. The Phase 1, 2 and 3 areas only account for 3 percent. About 50 percent of the mercury is estimated to be above the 5.5 feet depth in the vertical dimension, with the other 50 percent below this depth.

The uncertainties estimated for the Total PCB and mercury concentrations are lower as compared to those uncertainties estimated for 2,3,7,8-TCDD and Total 4,4'-DDx. This is

because the concentrations of Total PCB and mercury are less variable compared to 2,3,7,8-TCDD and Total 4,4'-DDx.

This analysis indicates that the contaminant inventories estimated in the Phase 3 area are insignificant compared to the total inventories in the FFS Study Area. Therefore, Phase 3 was not targeted for removal in any special way, but was addressed within each active remedial alternative in the same manner as all of the other contaminated fine-grained sediment in the FFS Study Area.

3 ASSESSMENT OF FFS CAPPING WITH DREDGING FOR FLOODING AND NAVIGATION ALTERNATIVE

The total sediment inventories presented in Section 2 of this Data Evaluation Report represent the contaminant mass targeted under the Tierra Removal Phases 1 and 2 and Alternative 2 (dredging of all of the fine silt areas from RM0 to RM8.3) of the FFS. Another active remedial alternative considered in the FFS is Alternative 3, which would involve placing an engineered cap over the FFS Study Area bank to bank (except in the navigation channel between RM0 and RM1.2, where backfill would be placed). Before placement of the cap and backfill, the following sediment removal actions would be undertaken:

- Dredging to a depth of 2.5 feet in the LB, the RB, and the NC between RM2.2 and RM8.3 followed by capping.
- Dredging of the authorized NC to 20 to 30 feet (depending on RM and determined based on current and reasonably anticipated future use) below RM2.2
- Alternative 3 assumes that dredging of the Phase 1 and 2 areas are completed separately, because that non-time critical removal is governed by a separate legal agreement. Phase 3 is evaluated here for potential inclusion in Alternative 3 as an area needing special treatment (ultimately deemed unnecessary, as explained below). Phase 1 area was dredged down to 12 feet. For Phase 2 and Phase 3 areas, the dredging depths were calculated by dividing the anticipated dredging volumes by the respective surface areas. Using this method, the estimated dredging depths of Phase 2 and Phase 3 areas were 12 and 14 feet, respectively.

An assessment of Alternative 3 in terms of mass targeted for removal was performed to answer the following questions:

1. What is the fraction of the mass targeted for removal in Alternative 3 relative to the total inventory for each contaminant?
2. Are there areas adjacent to the Phase 1, 2 and 3 areas or elsewhere in the river that contain a high mass per volume of sediments and could be targeted for full depth

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dredging to increase the relative percent of mass removed for Alternative 3, while minimizing the need to increase the total volume of sediments dredged?

3. If select smaller scale segments were dredged to an additional foot (to a depth of 3.5 feet), how much additional mass would be removed relative to the Alternative 3 estimate?

To answer these questions, two sets of analyses were performed. The first was to determine the mass of the four contaminants removed under Alternative 3, using the same approach described in Section 2. This involved summing the mass in all depth segments for the NC below RM2.2, but only adding the mass in the top 2.5 feet in the LB, RB, and NC between RM2.2 and RM8.

The second analysis was performed to answer questions 2 and 3, above, and used half-mile segments constructed in the LB, RB, and the NC areas between RM2.2 and RM8 to do so. The nomenclature used to identify the non- Phase 1, 2 and 3 areas half-mile segments is: the spatial location (LB, RB, or NC), followed by the RM designation. For example, NC-RM2.2-2.7 is a navigational channel segment from RM2.2 to RM2.7. The same vertical segmentation described in Section 2 was applied to these half-mile segments. The contaminant mass was estimated in every segment for which data were reported. For this evaluation, if a half mile segment had no data, mass was not calculated and no attempt was made to estimate the mass by interpolating or extrapolating data from adjacent segments, and therefore the sum of these half-mile segment inventories is expected to underestimate the total inventory in the FFS Study Area. This was only done for the half-mile analysis. The half-mile dimension was the smallest dimension identified with sufficient data so as to provide estimates of contaminant inventory and the associated uncertainty. Results of this analysis are described in the following section.

3.1 Contaminant Mass in Alternative 3

Table 3-1 presents the estimated mass and uncertainties for Alternative 3 and the fraction of the Alternative 3 inventory relative to that for Alternative 2 for the four contaminants.

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For 2,3,7,8-TCDD, Alternative 3 mass is estimated at 8 kg, about 30 percent of the inventory for Alternative 2 in the FFS Study Area. For Total DDx, the Alternative 3 mass of 800 kg is about 20 percent of the inventory in the FFS Study Area. For Total PCB and mercury, Alternative 3 accounts for 30 percent and 40 percent of their Alternative 2 inventories in the FFS Study Area, respectively.

3.2 Half-mile Segment Analysis to Assess Full Depth Dredging for Alternative 3

The half-mile segment analysis was performed to determine the potential for increasing the percentage of mass that could be targeted for removal under Alternative 3 while minimizing the need to increase the volume of sediments dredged. Since 90 percent of the Total 4,4'-DDx mass is already targeted under the combined Phase 1, Phase 2 and Alternative 3 remedial option, only 2,3,7,8-TCDD, Total PCB, and mercury were investigated in this analysis. The results are presented as a series of stacked column plots. Figures 3-1 through 3-3 show cumulative percentage mass increases for the spatial segments sorted by mass per unit volume and by mass. These figures reflect the inventory to the full DoC of Alternative 2. They provide information on the additional inventory at various locations and their relative rankings in terms of mass per unit volume or mass. Figure 3-4 shows a map of the 2,3,7,8-TCDD half-mile segments colored by mass per unit volume, and the total mass in selected segments shown in callout boxes. The most important observations from these figures are:

- For 2,3,7,8-TCDD, there is little opportunity for additional mass removal along the RB shoreline up- or downriver of the existing Phase 1, 2 and 3 areas. The NC has the most mass of 2,3,7,8-TCDD per unit volume. For example, based on Figure 3-1a, if the mass of 2,3,7,8-TCDD in NC-RM2.2-2.7 and NC-RM2.7-3.2 were targeted for additional removal in Alternative 3, the mass removed would increase from 60 to 76 percent (see the blue colored bars in Figure 3-1a). However, an additional 583,000 cy in dredged sediments would need to be removed and sent for disposal.
- The highest mass contributor to 2,3,7,8-TCDD mass outside of Phase 1 is segment NC-RM2.7- 3.2, which also has a higher mass per volume. However, an

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examination of the data that led to the mass estimate (Figure 3-5) shows very few sediment cores are located in that segment. The highest concentrations are at depth and are located right on the edge of the NC closer to the Phase 1-3 area.

- For Total PCB, the segment NC-RM2.7-3.2 has the highest mass outside of the mass targeted for Alternative 3. Including the NC from RM 2.7 to RM3.2 would remove an additional 4 percent of Total PCBs, but would increase the volume of sediments dredged by approximately 237,000 cy.
- For mercury, including the NC from NC-RM2.2-2.7 and RM2.7 to RM3.2, identified above for 2,3,78-TCDD, will add about 9 percent to the mercury mass targeted for removal under Alternative 3, but increase the volume of sediments dredged by 237,000 cy.

3.3 Half-mile Segment Analysis to Assess an Additional One-Foot of Dredging for Alternative 3

The increase in mass removed was estimated for a one-foot addition to the Alternative 3 dredging depth (an increase from 2.5 to 3.5 feet). The results are presented as a series of stacked column plots. Figures 3-6 through 3-8 show cumulative mass removal percentages for one-foot increase in depth removal on the basis of half-mile spatial segments sorted by either mass per unit volume or by mass per segment. Figure 3-9 shows a map of the 2,3,7,8-TCDD half-mile segments colored by mass per unit volume, with the mass in selected segments shown in callout boxes. From Figure 3-9, the segment with the most additional mass per unit of volume in the 2.5 to 3.5 foot interval is NC-RM4.2-4.7 and it contains only 0.5 kg of 2,3,7,8-TCDD in 29,000 cy volume of sediments. The results generally show that an additional one-foot of dredging will not significantly increase the mass removed under Alternative 3. The overall increase in contaminant mass removed is limited to 2 percent for 2,3,7,8-TCDD, 6 percent for Total PCB, and 5 percent for mercury.

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4 ASSESSMENT OF FOCUSED CAPPING WITH DREDGING FOR FLOODING ALTERNATIVE

The total sediment inventories presented in this section represent the contaminant mass targeted under Alternative 4. This alternative includes dredging of contaminated fine-grained sediment in selected portions of the FFS Study Area (about one third of the FFS Study Area surface) having the highest gross and net fluxes of COPCs and COPECs, to the targeted depth of 2.5 feet, so that an engineered cap can be placed over the dredged portions without causing additional flooding. Note that this alternative includes the Tierra Phase 1 and 2 Removal but does not include removal of sediments in the authorized navigation channel.

To quantify the mass removed under this alternative, the half mile segment approach developed for Alternative 3 evaluation (see Section 3) was used, with some modifications. For this evaluation, if a half mile segment had no data, mass was calculated using a one mile segment constructed for LB, RB and the NC areas. The one-mile segments were necessary only for quantifying the concentration in the 0.5-2.5 horizon for the RB half mile segment between RM8 to 8.3 and LB half mile segment between RM4.5 to RM5. Mass estimates were developed for 2,3,7,8-TCDD, Total PCB, Total 4,4'-DDx and mercury using this method.

Table 4-1 presents the estimated mass and uncertainties for Alternative 4 and the fraction of the Alternative 4 inventory relative to that for Alternative 2 for the four contaminants. It is estimated that the mass targeted for removal under Alternative 4 is 1.3 kg for 2,3,7,8-TCDD, 1400 kg for Total PCB, 150 kg for Total 4,-4'-DDx and 2400 kg for mercury. These Alternative 4 mass estimates are approximately 5 percent of the mass targeted under Alternative 2 for these four contaminants.

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5 SUMMARY

The analysis of contamination inventory in RM0 to RM8.3 of the Lower Passaic River has provided a series of observations about the spatial and vertical distribution of mass and associated uncertainties. Table 5.1 presents the distribution of the total inventory in the FFS Study Area associated with the Tierra Removal (Phase 1 and 2) and the active remedial alternatives evaluated in the FFS. Section 5.1 provides a summary of the total contaminant mass in the sediments, which represents the contaminant mass targeted under Phase 1, Phase 2 and Alternative 2 (Deep Dredging with Backfill). The analysis performed included an estimation of the mass of 2,3,7,8-TCDD, Total 4,4'-DDx, Total PCB, and mercury from RM0 to RM8.3. Section 5.2 summarizes the contaminant mass associated with Alternative 3 (Capping with Dredging for Flooding and Navigation), and Section 5.3 summarizes the mass estimate associated with Alternative 4 (Focused Capping with Dredging for Flooding).

5.1 Summary of Total Contaminant Mass in the Sediments

- The total mass of 2,3,7,8-TCDD between RM0 and RM8.3 is about 38 kg. The Phase 1 and 2 areas account for 14 kg, with the additional 24 kg targeted as part of Alternative 2. Vertically, more than 60 percent of the 2,3,7,8-TCDD mass lies below 5.5 feet. Approximately 42 percent of the overall 2,3,7,8-TCDD mass lies in the navigation channel.
- The mass of Total 4,4'-DDx between RM0 and RM8 is 29,000 kg, with approximately 86 percent located in the Phase 1 and 2 areas. In the vertical dimension, the top 3.5 feet contains about 3 percent of the Total 4,4'-DDx mass, about 14 percent is present between 3.5 to 5.5 feet, and 83 percent is located below 5.5 feet. Uncertainties are higher at depth and within the Phase 1 area.
- For Total PCB, the total mass is 23,500 kg. The Phase 1 and 2 areas account for only 3 percent of the total mass and are therefore not important for removal of Total PCB mass. The Total PCB mass is not dominated by any particular river segment analyzed. The spatial distribution indicates that 39 percent of the mass is

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in the NC, 36 percent in the LB, and 22 percent in the RB. In the vertical dimension, 57 percent of the mass in above 5.5 feet and the sediments below 5.5 feet account for 43 percent of the mass.

- For mercury, the total mass is 42,000 kg. The distribution of mass for mercury, like Total PCBs, indicates that the Phase 1 and 2 areas are not an important contributor to the overall mercury mass. The NC contains about 48 percent of the mass, followed by the LB, which contains 38 percent. In the vertical direction, about 50 percent of the mercury is estimated to be in the sediments above 5.5 feet and the remaining 50 percent is below 5.5 feet.
- The spatial and vertical distribution of the total contaminant mass estimates show that the Phase 1 and 2 areas are important for 2,3,7,8-TCDD and Total 4,4'-DDx. These two chemicals show a local maximum around RM3, where the Phase 1 and 2 areas are located. A local maximum was not observed for Total PCBs or mercury.
- An important finding in this analysis is that the Phase 3 area contains a very small and uncertain mass of the contaminants evaluated in this analysis. This area contains only 3 sediment data points. Because of its small mass this area was not given special consideration for removal in the FFS.

5.2 Summary of Alternative 3 Evaluation

- For 2,3,7,8-TCDD, the contaminant mass targeted for removal in Alternative 3 is estimated at 8 kg, which accounts for about 30 percent of the Alternative 2 inventory in the FFS Study Area.
- For Total 4,4'-DDx, Alternative 3 mass of 800 kg corresponds to 20 percent of the Alternative 2 mass in the FFS Study Area.
- For Total PCB and mercury, the mass targeted for removal in Alternative 3 accounts for 30 and 40 percent of their Alternative 2 inventories in the FFS Study Area, respectively.
- The half-mile segment analysis for Alternative 3 indicates that there is little opportunity for additional 2,3,7,8-TCDD mass removal along the RB shoreline up

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or down river of the existing Phase 1 and 2 area. If the large inventories of 2,3,7,8-TCDD in segments NC-RM2.2-2.7 and NC-RM2.7-3.2 were also targeted for removal in Alternative 3, the 2,3,7,8-TCDD mass removed would increase by 16 percent. However, removing those segments would also add 583,000 cubic yards to the Alternative 3 dredging volume.

- The single highest contributor to the 2,3,7,8-TCDD mass outside the Phase 1 and 2 areas is segment NC-RM2.7-3.2. It is characterized by the highest mass per volume, and contains high sediment concentrations at depth on the edge of the NC close to the Phase 2 and 3 areas. However, removing that segment would also add 237,000 cubic yards to the Alternative 3 dredging volume.
- The half-mile segment analysis for Alternative 3 indicates that the segment NC-RM2.7-3.2 also has the highest mass per unit volume for Total PCB. Including the segments NC-RM2.2-2.7 and NC-RM2.7-3.2, identified above for 2,3,7,8-TCDD, would add about 6 percent to the Total PCB mass targeted for removal under Alternative 3. However, removing those segments would also add 583,000 cubic yards to the Alternative 3 dredging volume.
- The half-mile segment analysis for Alternative 3 further indicates that there are various mercury candidate locations on a mass per unit volume basis that could increase the overall mass removal. In particular, segments NC-RM2.2-2.7 and NC-RM2.7-3.2, identified above for 2,3,7,8-TCDD, would together add about 9 percent to the mercury mass targeted for removal under Alternative 3 (but would add 583,000 cubic yards to the dredging volume).
- The percentage increase in mass removed if Alternative 3 dredging depth were increase from 2.5 to 3.5 feet was also investigated in the half-mile scale. The results generally show that an additional one foot dredging will not significantly increase the mass removed under Alternative 3. The increase in mass is limited to 2 percent for 2,3,7,8-TCDD, 6 percent for Total PCB, and 5 percent for mercury.

5.3 Summary of Alternative 4 Evaluation

For all four contaminants evaluated, the mass targeted under Alternative 4 is estimated as 5 percent of the corresponding Alternative 2 inventories.

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6 ACRONYMS

2,3,7,8-TCDD	2,3,7,8-Tetrachlorodibenzo-p-dioxin
AOC	Administrative Order on Consent
ASI	Aqua Survey, Inc.
CPG	Cooperating Parties Group
CSM	Conceptual Site Model
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
DDx	Sum of DDD, DDE and DDT
DoC	depth of contamination
GC/ECD	Gas Chromatography/Electron Capture Detector
ESP	Ecological Sampling Plan
FFS	Focused Feasibility Study
FS	Feasibility Study
GC-MS	Gas Chromatography-Mass Spectrometry
HRGC	High Resolution Gas Chromatography
HRMS	High Resolution Mass Spectrometry
kg	kilograms
LB	left bank descending
LPRSA	Lower Passaic River Study Area
NC	navigation channel
NOAA	National Oceanic and Atmospheric Administration
NS&T	National Status and Trends
NYSDEC	New York State Department of Conservation
PCB	Polychlorinated Biphenyl
R	Correlation Coefficients
RB	right bank descending
RI	Remedial Investigation
RM	River Mile

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TSI	Tierra Solutions, Inc.
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency

7 REFERENCES

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CSC and Interface, Inc., 2010. "Report on Suspected Causes of Disparities between the Results Produced by Columbia Analytical Services and AXYS Analytical Services in Analysis of Lower Passaic River Sediment Split Samples for Chlorinated Dibenzo-p-Dioxins and Dibenzofurans, and Development of a Conversion Factor to Adjust Results between the Two Laboratories," March 2010.

TABLES

Table 2-1: Summary of Global Mass and Uncertainty for RM0 to RM8.3

Inventory Estimate (kg)		
Chemical	Total Mass (kg)	Standard Error/Mean
2,3,7,8-TCDD	38	43%
Total 4,4´-DDx	29,000	115%
Total PCB	23,500	23%
Mercury	42,000	10%

Table 2-2: Spatial and Vertical Distribution of 2,3,7,8-TCDD Mass and Uncertainty for RM0 to RM8.3

Depth	0-0.5ft		0.5-2.5ft		2.5-3.5ft		3.5-5.5ft		5.5 ft to Alternative 2 DoC		Grand Total			
	Mass (g)	Uncertainty	Mass (g)	Uncertainty	Mass (g)	Uncertainty	Mass (g)	Uncertainty	Mass (g)	Uncertainty	Area (acres)	Mass (g)	Mass (kg)	Uncertainty
Left Bank Descending	100	20%	1,100	53%	610	23%	2,700	35%	2,200	108%	280	6,700	6.7	39%
Right Bank Descending	17	8%	190	58%	83	33%	130	47%	160	74%	83	590	0.6	30%
Nav Channel	71	13%	1,300	28%	900	39%	4,200	130%	9,600	66%	280	16,000	16	53%
PTW-Phase 1	1.6	28%	19	72%	130	100%	1,700	63%	7,900	168%	2.1	9,800	9.8	137%
PTW-Phase 2	1.4	8%	19	21%	9.1	20%	560	24%	3,600	49%	8.3	4,200	4.2	42%
PTW-Phase 3	2.1	14%	270	88%	40	63%	0.17	20%	0.12	82%	83	320	0.32	77%
Grand Total	200	12%	2,900	25%	1,800	23%	9,300	62%	23,000	64%	740	38,000	38	43%

Note:
Mass estimates are rounded to 2 significant digits

Table 2-3: Spatial and Vertical Distribution of Total 4,4´-DDx Mass and Uncertainty for RM0 to RM8.3

Depth	0-0.5ft		0.5-2.5ft		2.5-3.5ft		3.5-5.5ft		5.5 ft to Alternative 2 DoC		Grand Total		
	Mass (kg)	Uncertainty	Mass (kg)	Uncertainty	Mass (kg)	Uncertainty	Mass (kg)	Uncertainty	Mass (kg)	Uncertainty	Area (acres)	Mass (kg)	Uncertainty
Left Bank Descending	21	18%	200	34%	95	24%	320	51%	830	144%	280	1,500	83%
Right Bank Descending	6.5	10%	34	25%	45	46%	33	42%	620	202%	83	740	170%
Nav Channel	35	26%	150	22%	140	17%	240	24%	900	65%	280	1,500	40%
PTW-Phase 1	1.4	26%	19	64%	6.5	69%	3,400	125%	18,000	183%	2.1	21,000	155%
PTW-Phase 2	0.87	17%	24	24%	1.1	20%	54	25%	3,700	51%	8.3	3,800	50%
PTW-Phase 3	1.0	14%	22	72%	11	182%	0.1	47%	0.85	237%	83	35	73%
Grand Total	66	15%	450	17%	290	15%	4,000	105%	24,000	137%	740	29,000	115%

Note:
Mass estimates are rounded to 2 significant digits

Table 2-4: Spatial and Vertical Distribution of Total PCB Mass and Uncertainty for RM0 to RM8.3

Depth	0-0.5ft		0.5-2.5ft		2.5-3.5ft		3.5-5.5ft		5.5 ft to Alternative 2 DoC		Grand Total		
	Mass (kg)	Uncertainty	Mass (kg)	Uncertainty	Mass (kg)	Uncertainty	Mass (kg)	Uncertainty	Mass (kg)	Uncertainty	Area (acres)	Mass (kg)	Uncertainty
Left Bank Descending	180	13%	1,600	27%	1,400	21%	3,100	31%	2,000	60%	280	8,400	19%
Right Bank Descending	54	10%	400	26%	580	34%	950	49%	3,100	164%	83	5,100	100%
Nav Channel	220	11%	1,500	15%	840	18%	1,700	21%	5,000	28%	280	9,200	16%
PTW-Phase 1	1.4	14%	12	14%	21	12%	62	21%	140	95%	2.1	240	56%
PTW-Phase 2	4.8	9%	55	13%	18	17%	280	30%	12	159%	8.3	370	24%
PTW-Phase 3	5.2	9%	120	29%	76	64%	0.91	101%	1.8	343%	83	200	30%
Grand Total	460	7%	3,700	13%	3,000	13%	6,100	18%	10,000	53%	740	23,000	23%

Note:

Mass Estimates are rounded to 2 significant digits

Table 2-5: Spatial and Vertical Distribution of Mercury Mass and Uncertainty for RM0 to RM8.3

Depth	0-0.5ft		0.5-2.5ft		2.5-3.5ft		3.5-5.5ft		5.5 ft to Alternative 2 DoC		Grand Total		
	Mass (kg)	Uncertainty	Mass (kg)	Uncertainty	Mass (kg)	Uncertainty	Mass (kg)	Uncertainty	Mass (kg)	Uncertainty	Area (acres)	Mass (kg)	Uncertainty
Left Bank Descending	390	8%	3,300	16%	1,800	14%	4,800	19%	5,500	31%	280	16,000	13%
Right Bank Descending	130	6%	740	15%	360	21%	950	23%	2,500	39%	83	4,700	22%
Nav Channel	310	6%	2,200	10%	1,300	11%	3,700	14%	12,000	28%	280	20,000	17%
PTW-Phase 1	4.2	9%	26	18%	22	12%	47	18%	150	23%	2.1	240	14%
PTW-Phase 2	13	9%	150	8%	95	14%	120	22%	340	34%	8.3	720	17%
PTW-Phase 3	12	8%	130	11%	68	18%	190	5%	37	157%	83	440	14%
Grand Total	860	4%	6,600	9%	3,700	8%	9,800	11%	21,000	19%	740	42,000	10%

Note:
Mass estimates are rounded to 2 significant digits

Table 3-1: Summary of Alternative 3 Mass and Uncertainty

Contaminant	Alternative 3		Fraction of Alternative 3 to Alternative 2 Inventory
	Mass (kg)	Standard Error/Mean	
2,3,7,8-TCDD	8	86%	30%
Total 4,4´-DDx	800	60%	20%
Total PCB	7000	20%	30%
Mercury	16000	20%	40%

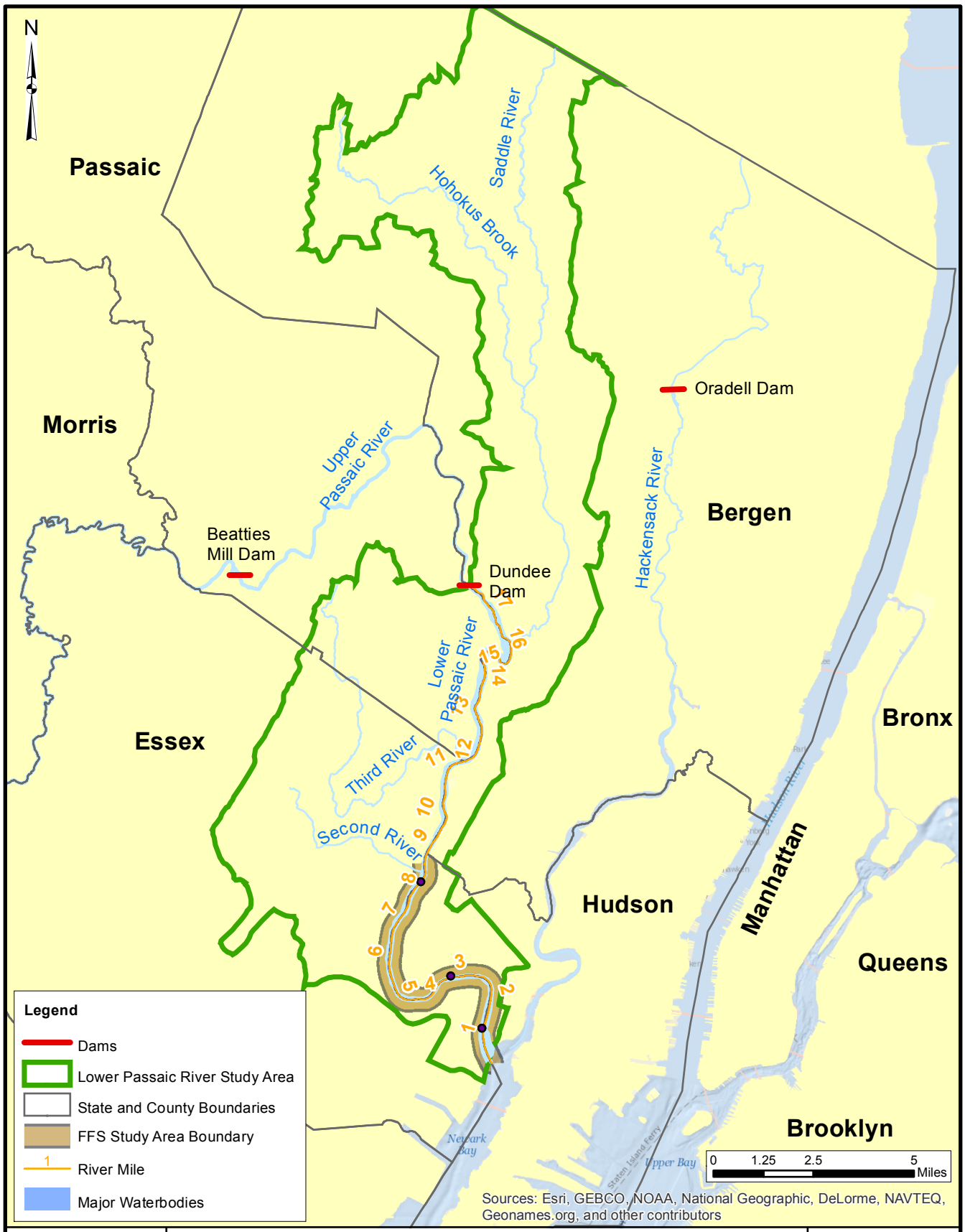
Table 4-1 Summary of Alternative 4 Mass and Uncertainty

Contaminant	Alternative 4		Fraction of Alternative 4 to Alternative 2 Inventory
	Mass (kg)	Standard Error/Mean	
2,3,7,8-TCDD	1.3	40%	5%
Total 4,4´-DDx	150	20%	6%
Total PCB	1400	20%	5%
Mercury	2400	10%	6%

Table 5-1: Summary of Total Inventory for Different Alternatives

Contaminant	Total Mass (kg)	Phase 1 Mass (kg)	Phase 2 Mass (kg)	Alternative 2 Mass (kg)	Alternative 3 Mass (kg)	Alternative 4 Mass (kg)
2,3,7,8-TCDD	38	9.8	4.2	24	8	1.3
Total 4,4´-DDx	29,000	21,000	3,800	4,200	800	150
Total PCB	23,500	240	370	22,890	7,000	1400
Mercury	42,000	240	720	41,040	16,000	2400

FIGURES



FFS Study Area Location Map

Lower Eight Miles of the Lower Passaic River

Figure 1-1

2014

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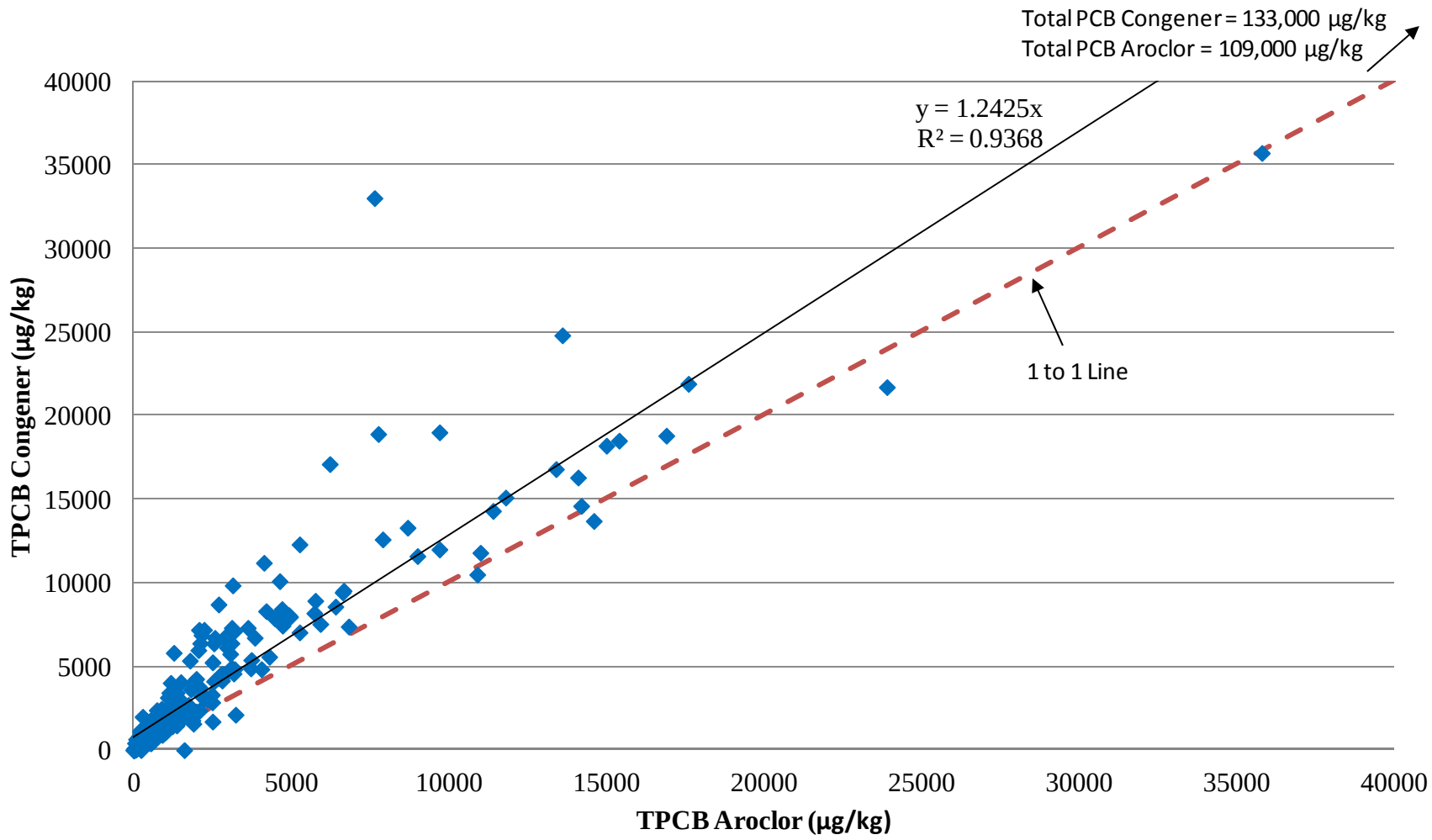
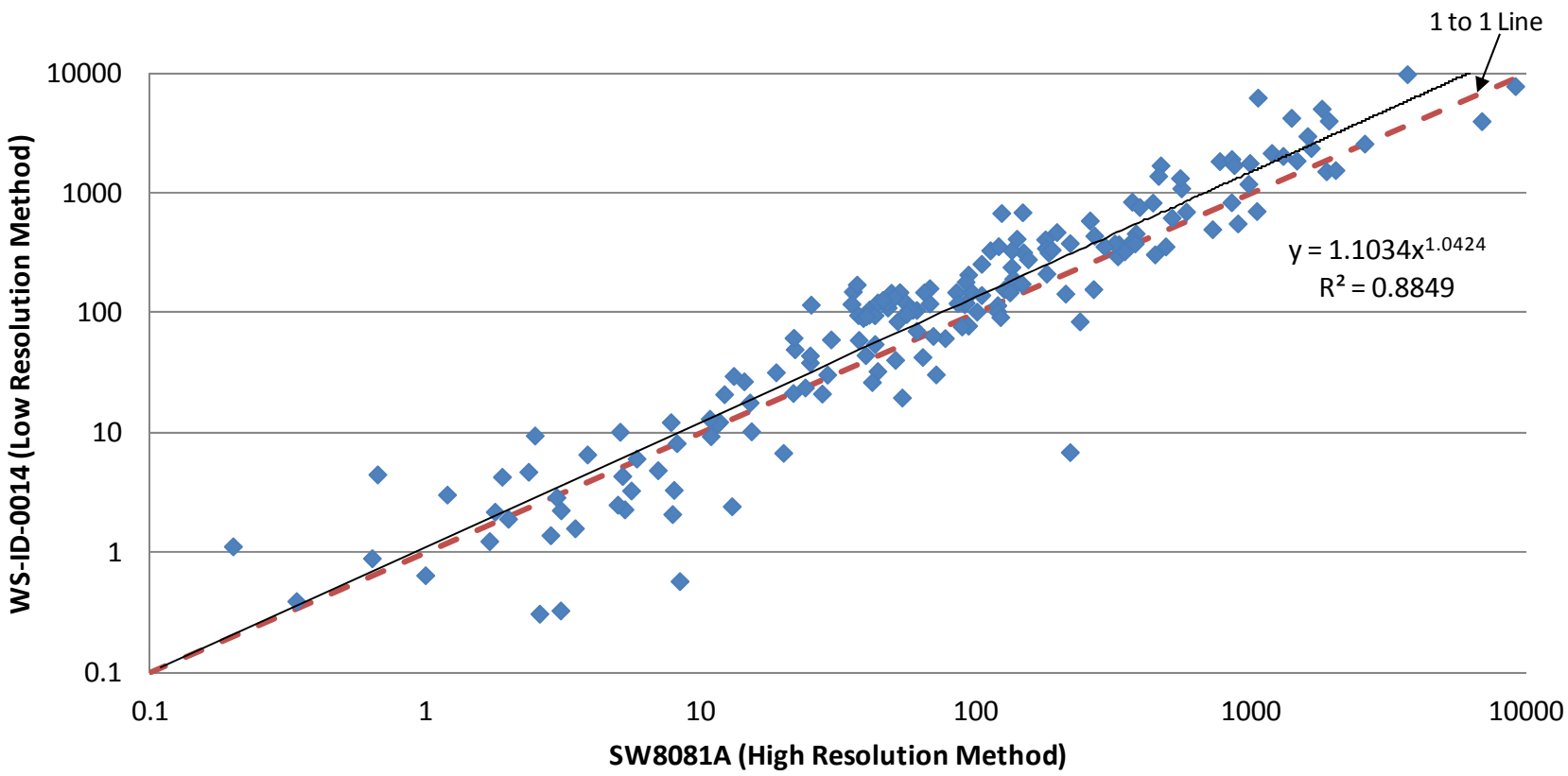
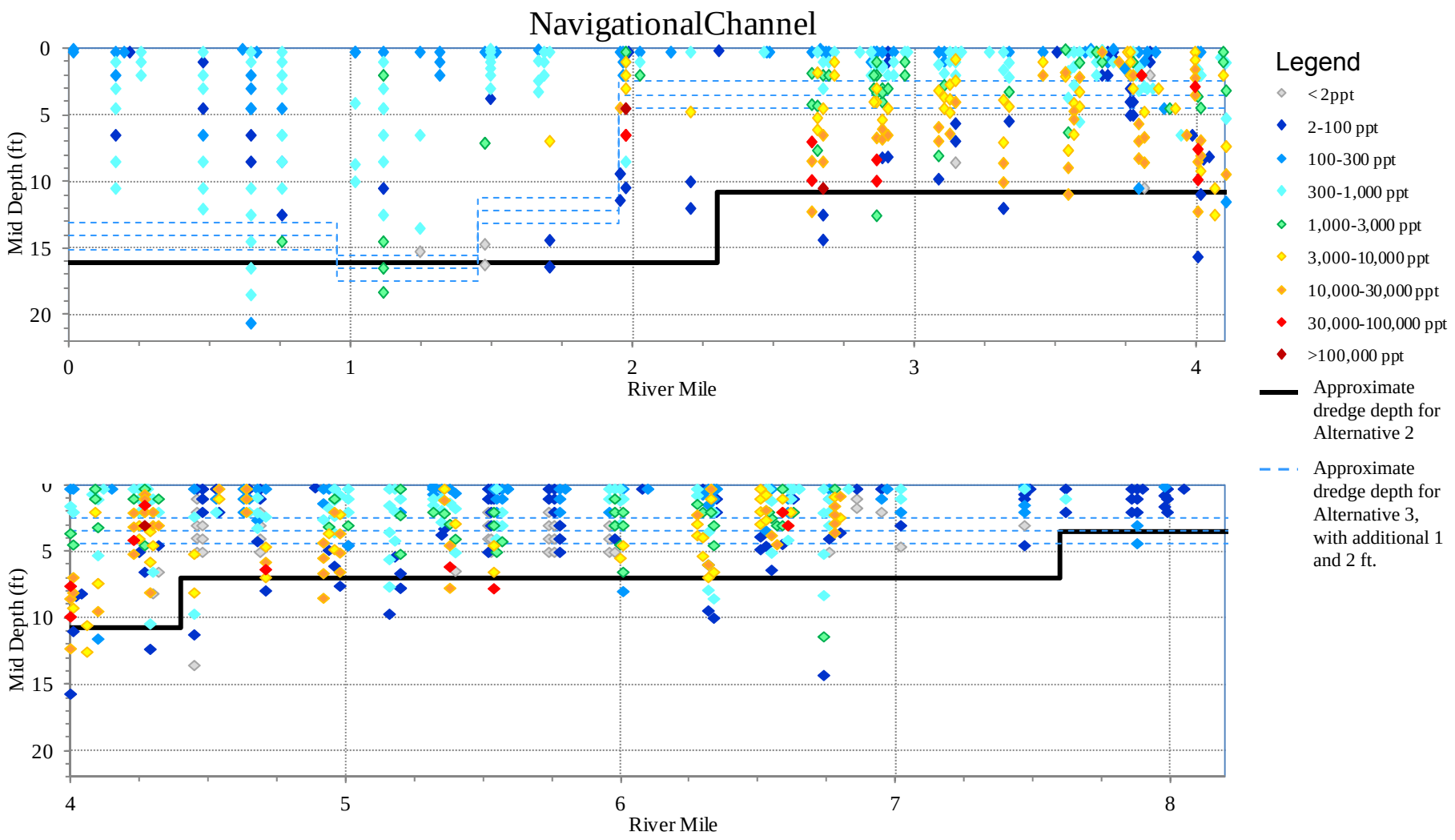


	Comparison of Paired Congener and Aroclor Analytical Results for Total PCBs *Lower Eight Miles of the Lower Passaic River*	Figure 2-1a 2014



	Comparison of Paired Low Resolution and High Resolution Analytical Results for Total 4,4´-DDx *Lower Eight Miles of the Lower Passaic River*	Figure 2-1b 2014



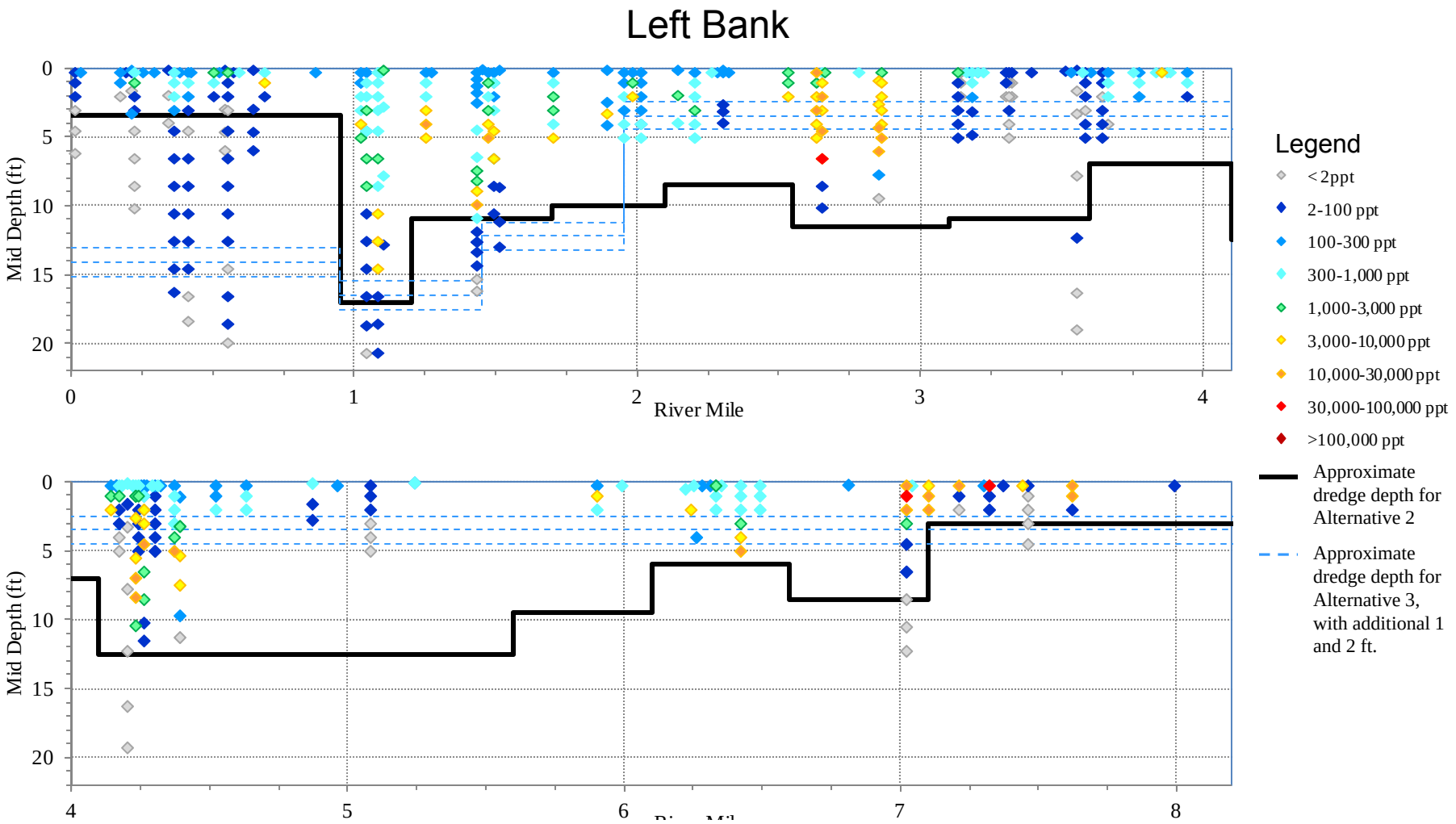
2,3,7,8-TCDD Concentrations in Sediment Data from 1990 to 2012 (Navigational Channel) – RM0 to RM8.3

Lower Eight Miles of the Lower Passaic River

Figure 2-2a

2014

R2-0027371



2,3,7,8-TCDD Concentrations in Sediment Data from 1990 to 2012 (Left Bank) – RM0 to RM8.3

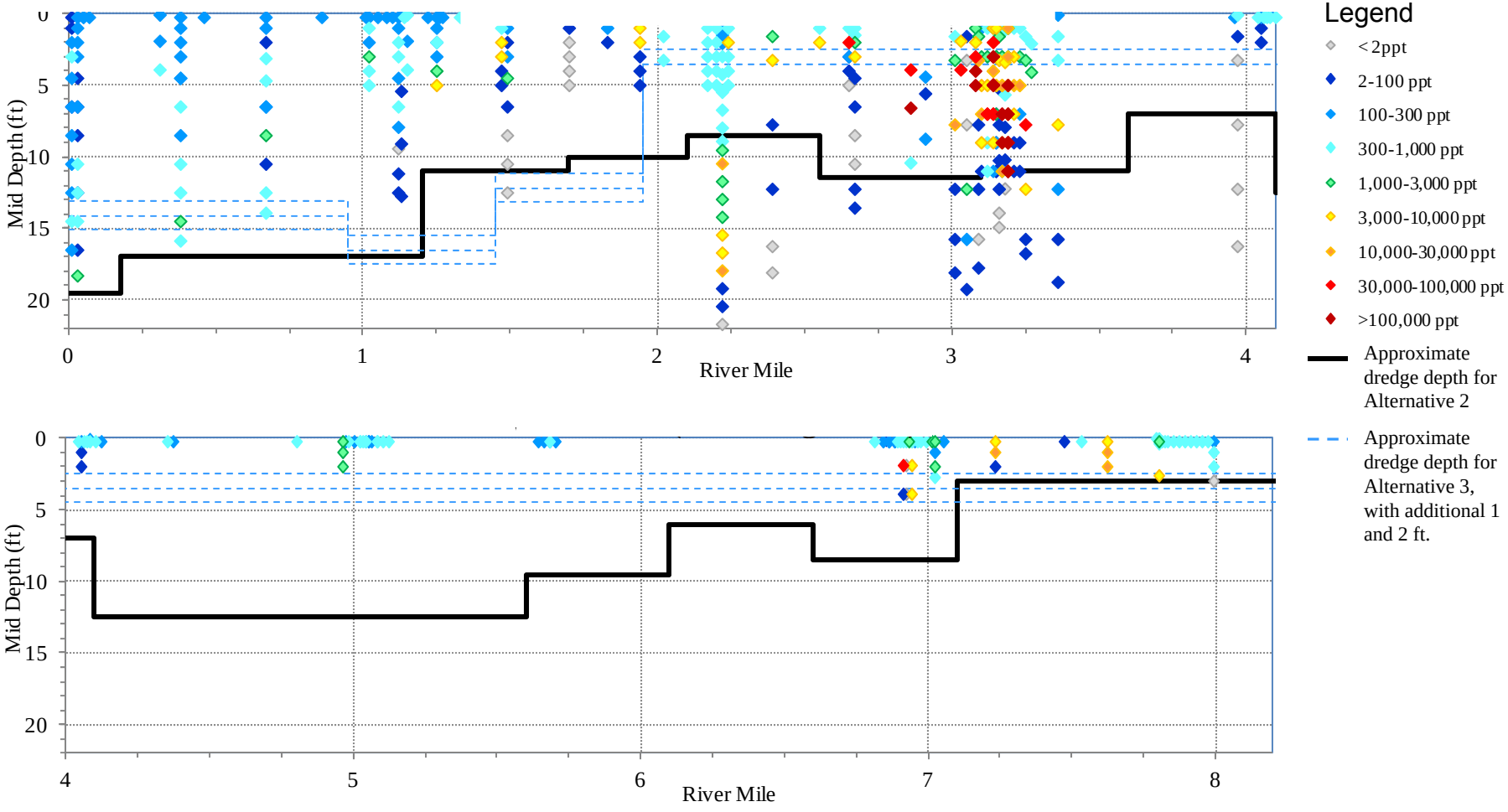
Lower Eight Miles of the Lower Passaic River

Figure 2-2b

2014

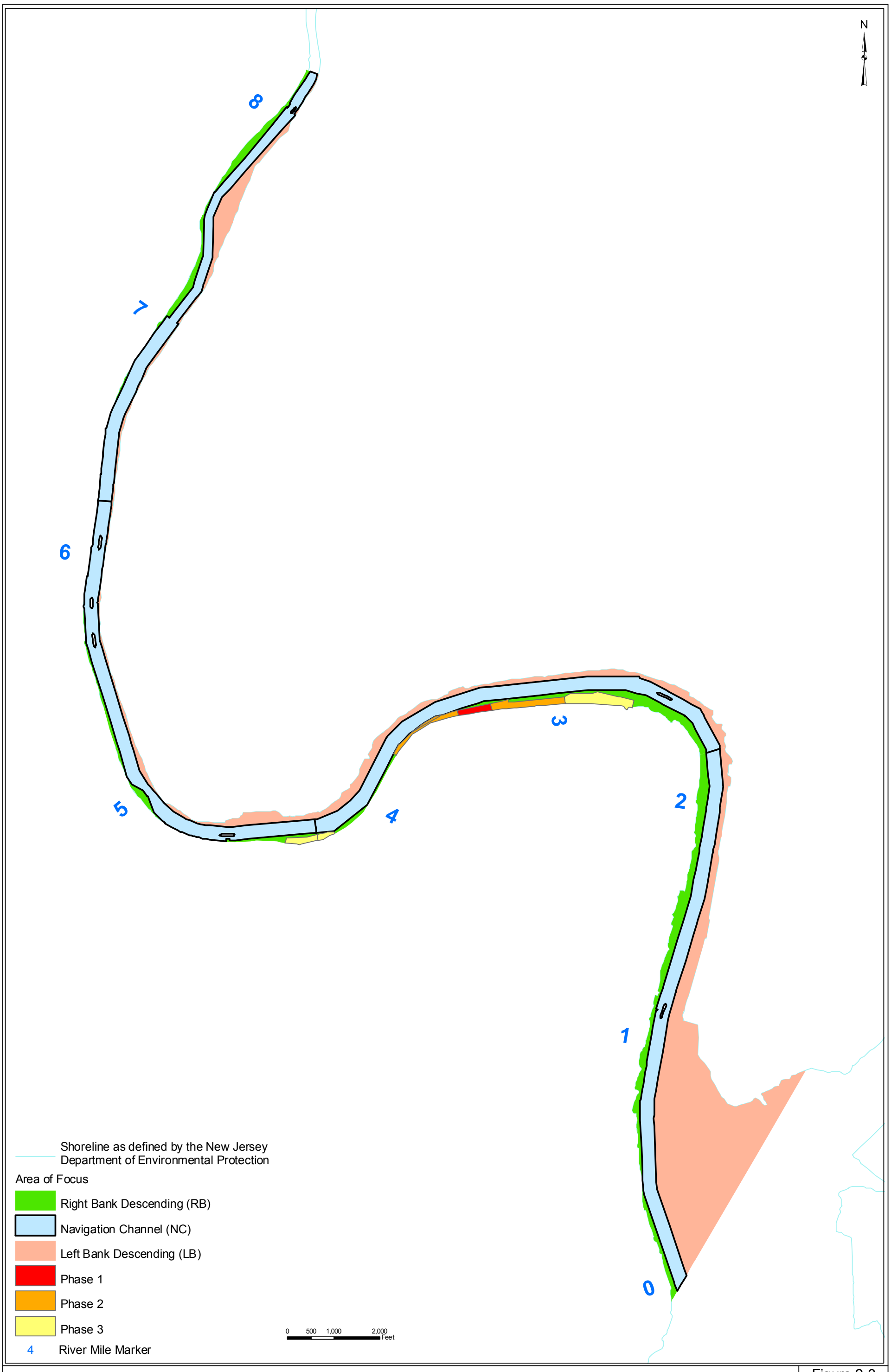
R2-0027372

Right Bank (including Phase 1 and 2)



	2,3,7,8-TCDD Concentrations in Sediment Data from 1990 to 2012 (Right Bank) – RM0 to RM8.3 *Lower Eight Miles of the Lower Passaic River*	Figure 2-2c 2014

R2-0027373



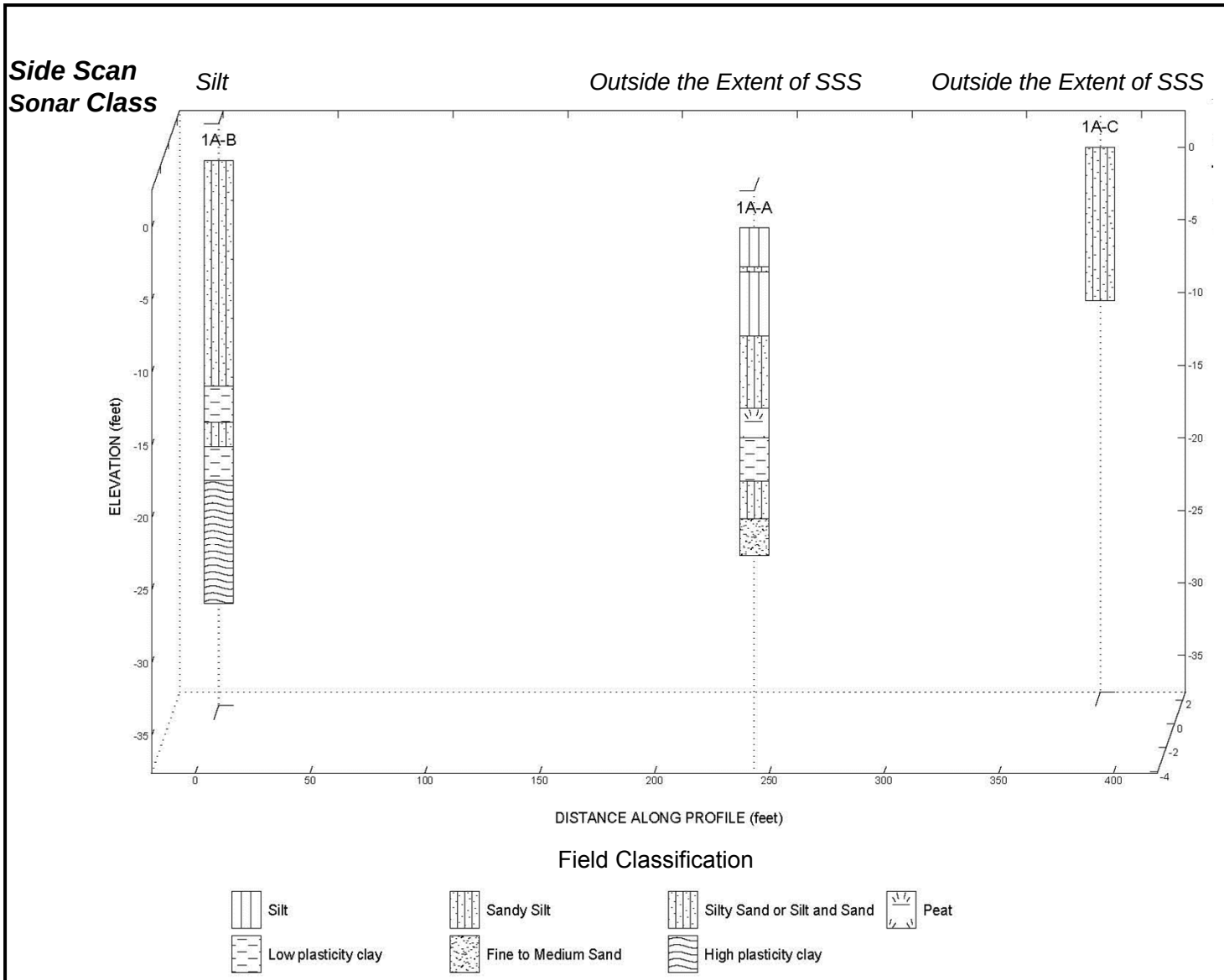
Spatial Extent used for Mass Calculation

Lower Eight Miles of the Lower Passaic River

Figure 2-3

2014

R2-0027374



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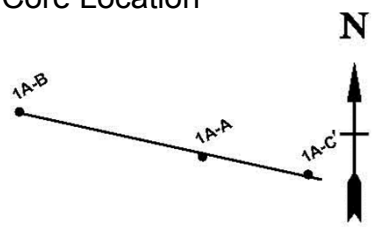


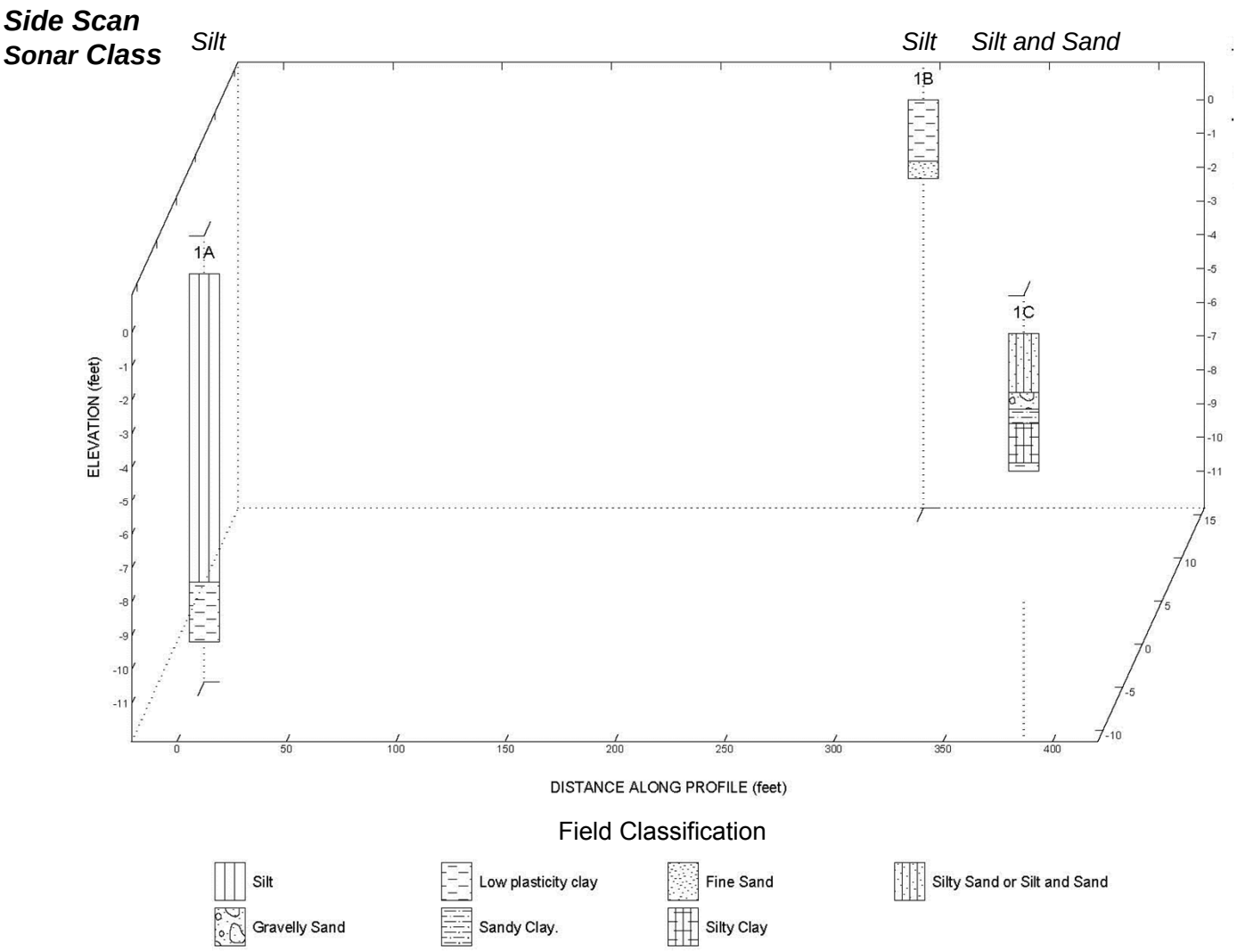
Site Map Scale 1 inch equals 220 feet

Comparison of Side Scan Sonar Sediment Class and Subsurface Sediment Texture by Coring
Location: Mile 0
Lower Eight Miles of the Lower Passaic River

Figure 2-4a

2014

R2-0027375



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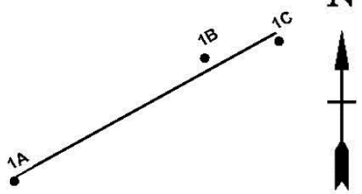


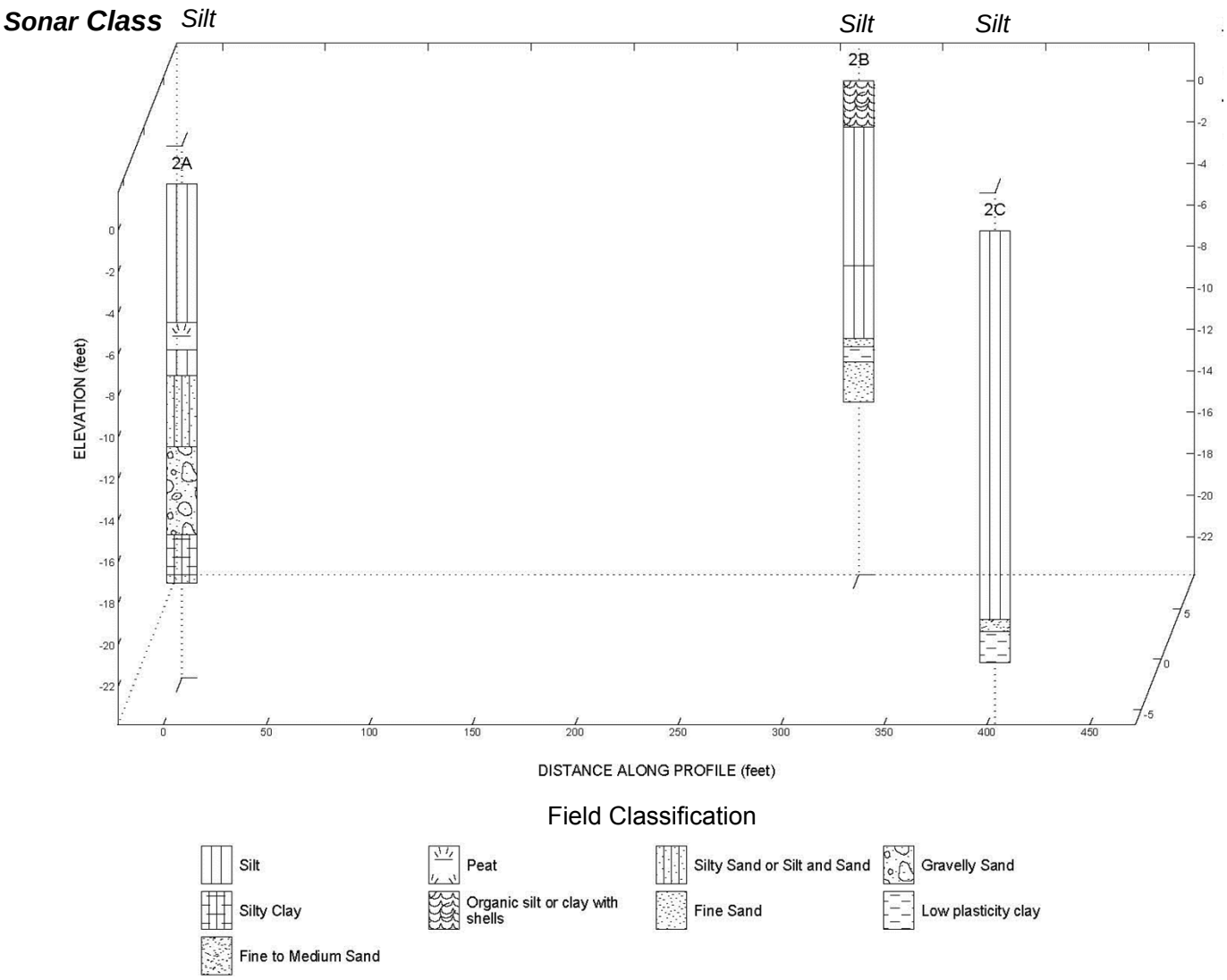
Site Map Scale 1 inch equals 220 feet

Comparison of Side Scan Sonar Sediment Class and Subsurface Sediment Texture by Coring
Location: Mile 1
Lower Eight Miles of the Lower Passaic River

Figure 2-4b

2014

R2-0027376



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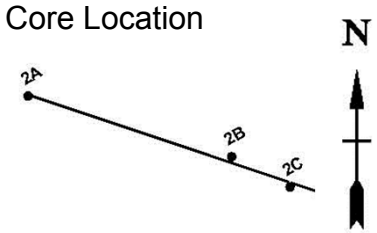


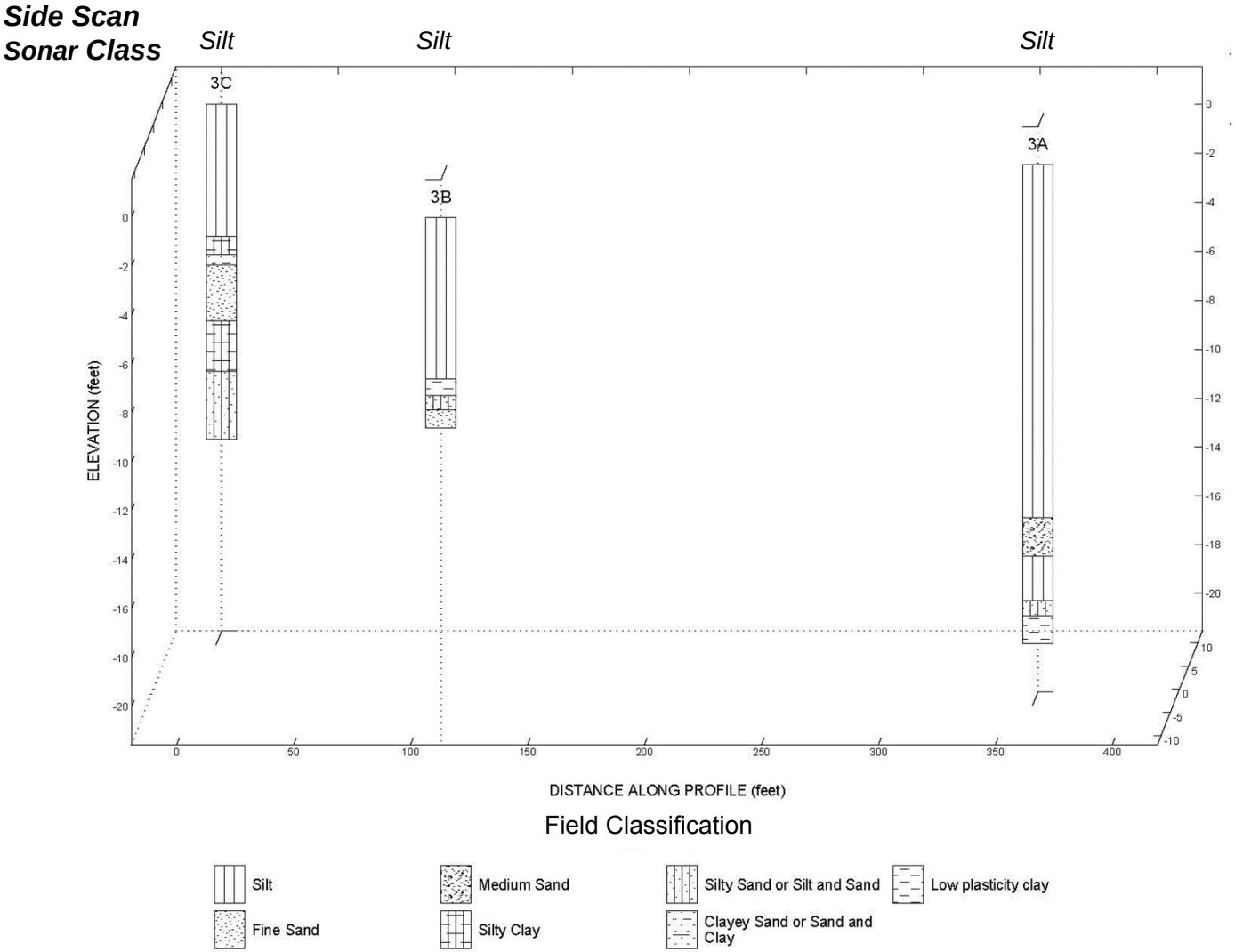
Site Map Scale 1 inch equals 250 feet

Comparison of Side Scan Sonar Sediment Class and Subsurface Sediment Texture by Coring
Location: Mile 2
Lower Eight Miles of the Lower Passaic River

Figure 2-4c

2014

R2-0027377



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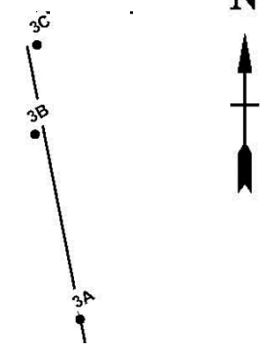


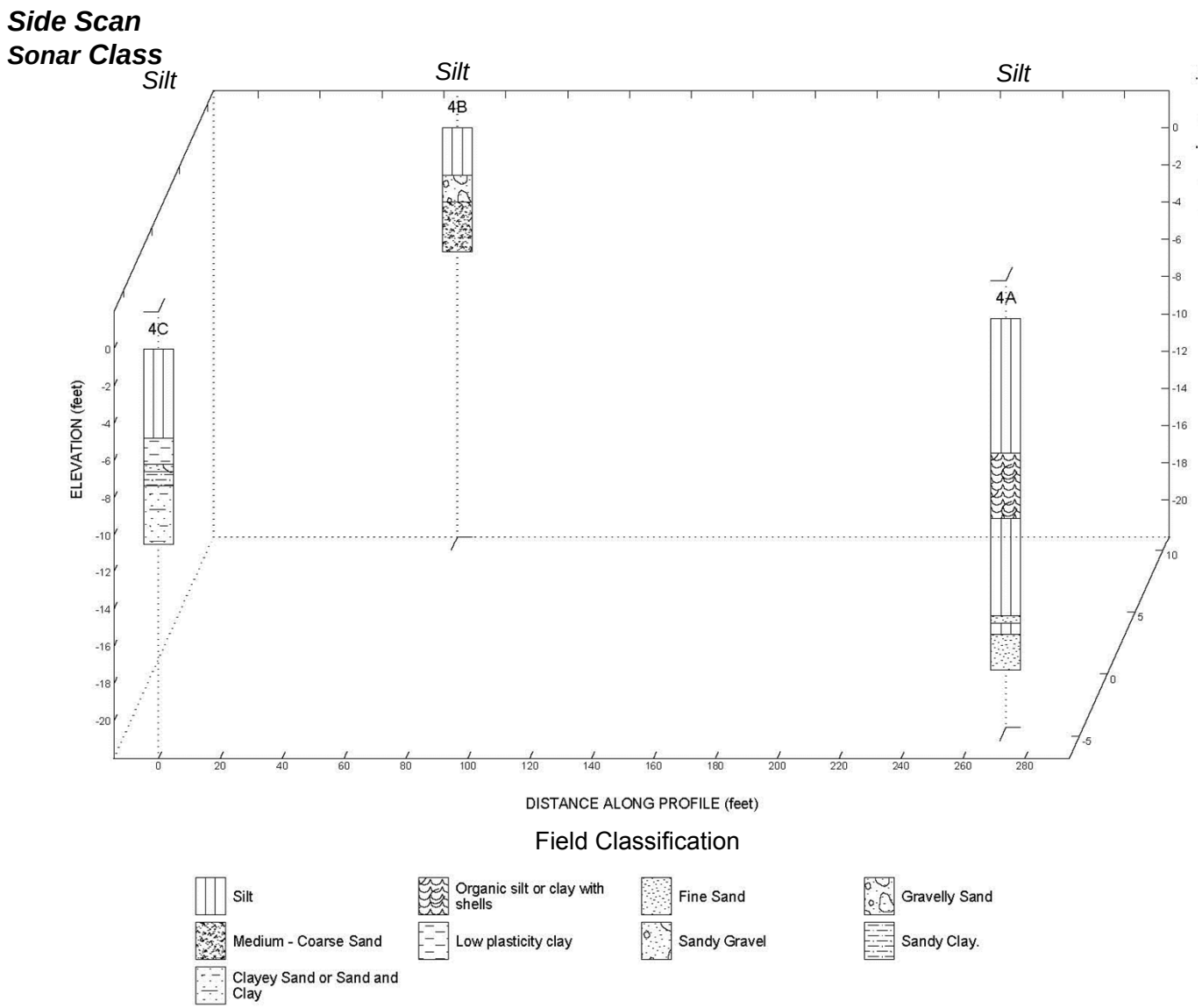
Site Map Scale 1 inch equals 220 feet

Comparison of Side Scan Sonar Sediment Class and Subsurface Sediment Texture by Coring
Location: Mile 3
Lower Eight Miles of the Lower Passaic River

Figure 2-4d

2014

R2-0027378



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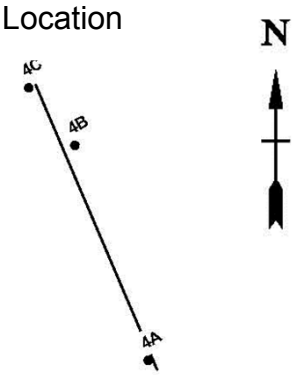


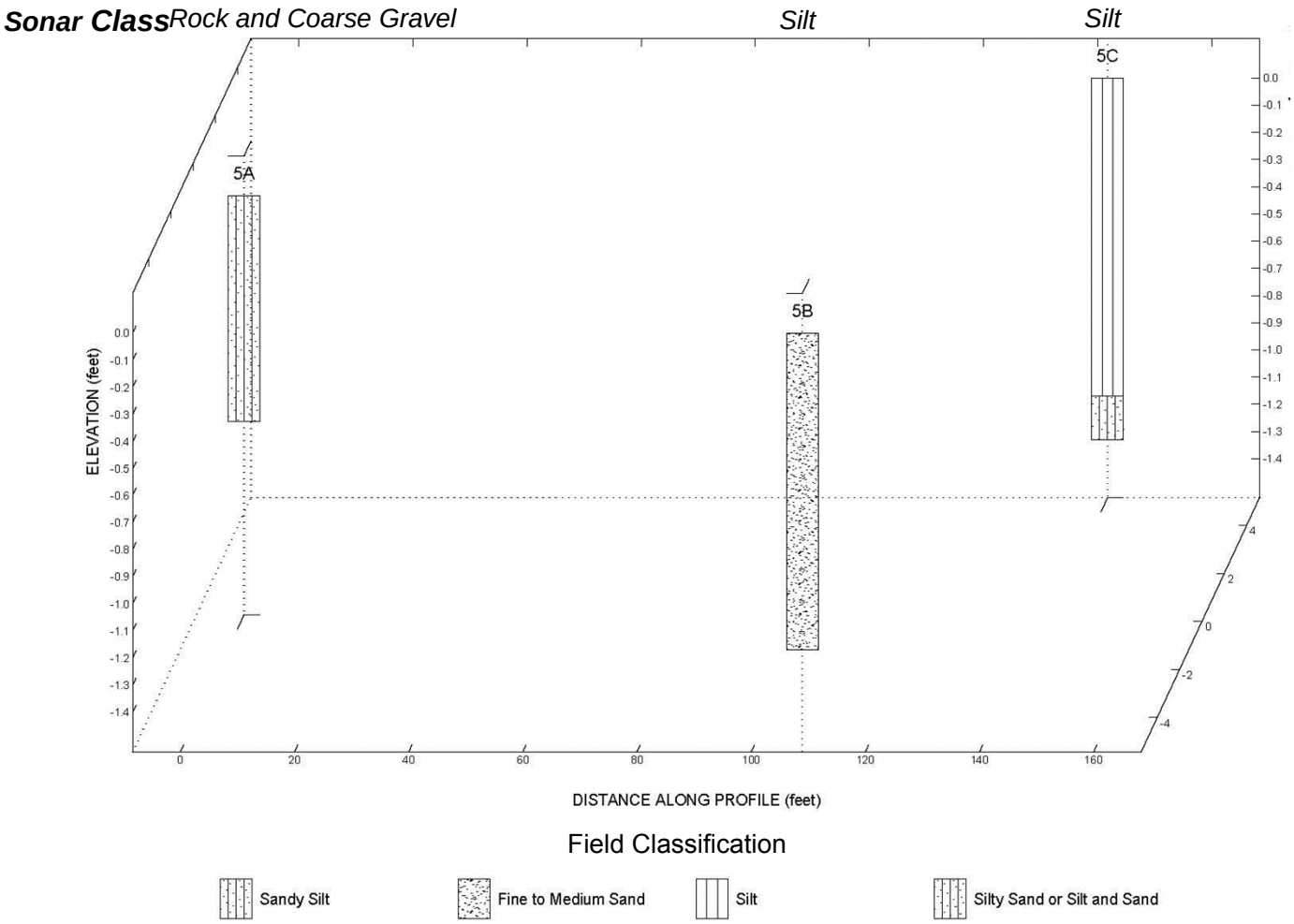
Site Map Scale 1 inch equals 155 feet

Comparison of Side Scan Sonar Sediment Class and Subsurface Sediment Texture by Coring
Location: Mile 4
Lower Eight Miles of the Lower Passaic River

Figure 2-4e

2014

R2-0027379



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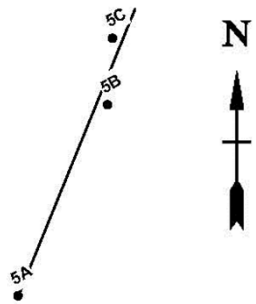


Site Map Scale 1 inch equals 90 feet

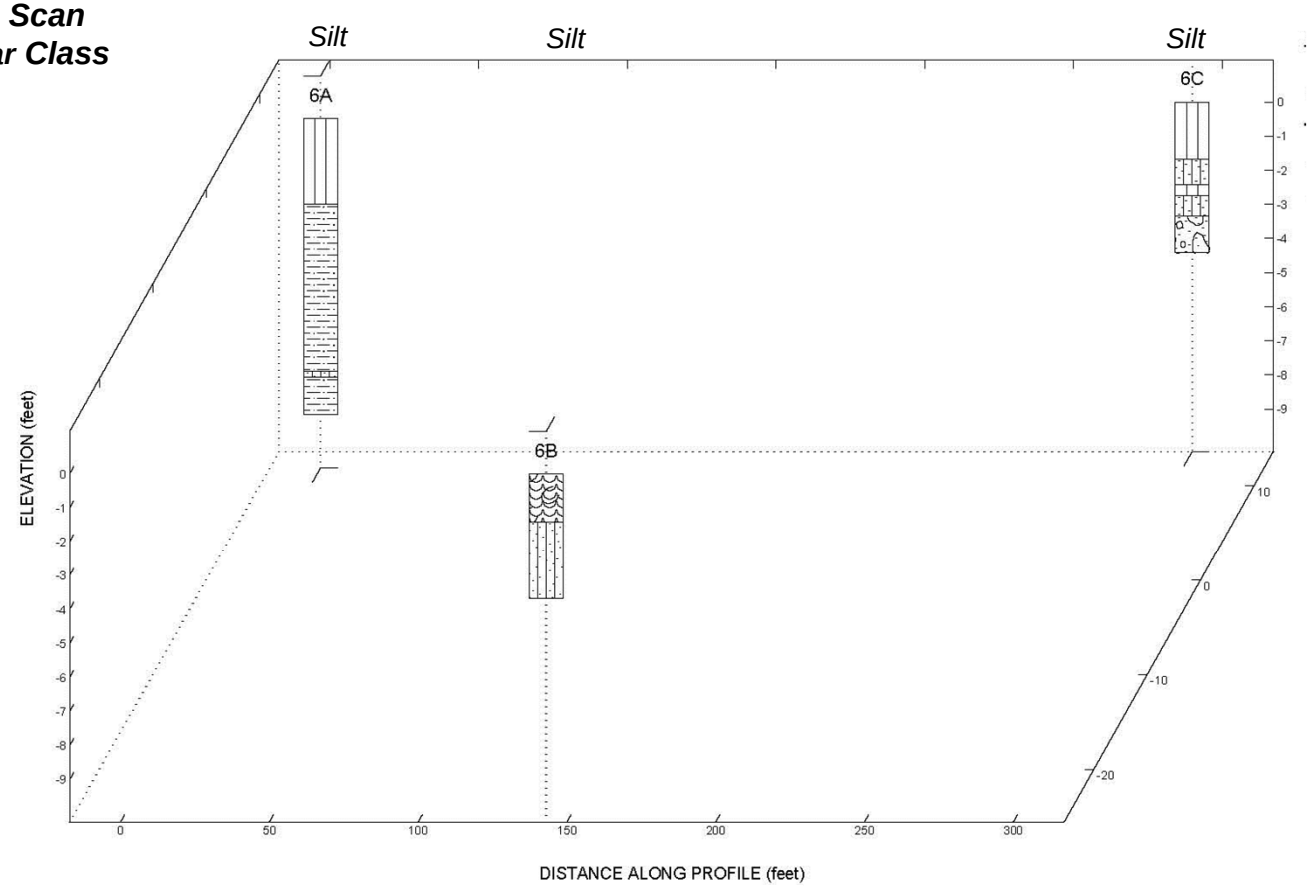
Comparison of Side Scan Sonar Sediment Class and Subsurface Sediment Texture by Coring
Location: Mile 5
Lower Eight Miles of the Lower Passaic River

Figure 2-4f

2014

R2-0027380

Side Scan Sonar Class

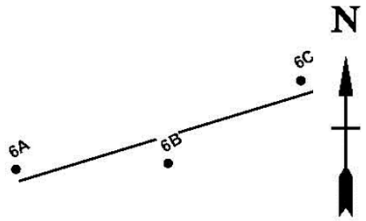


Field Classification

Silt
Sandy Clay.
Sandy Silt
Organic silt or clay with shells
Gravelly Sand

Legend

Core Location

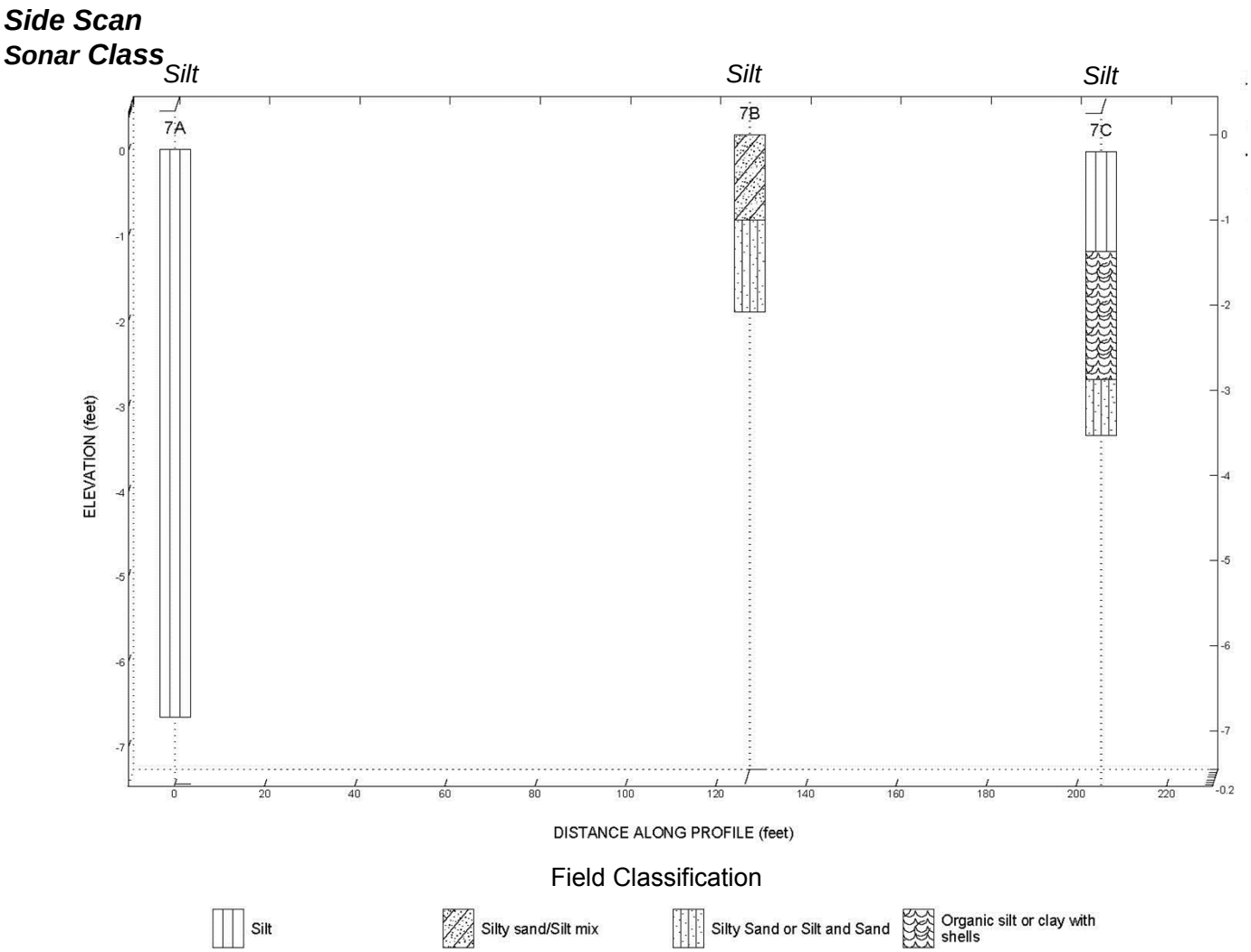


Site Map Scale 1 inch equals 165 feet

Comparison of Side Scan Sonar Sediment Class and Subsurface Sediment Texture by Coring
Location: Mile 6
Lower Eight Miles of the Lower Passaic River

Figure 2-4g

2014



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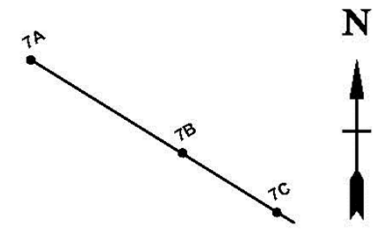
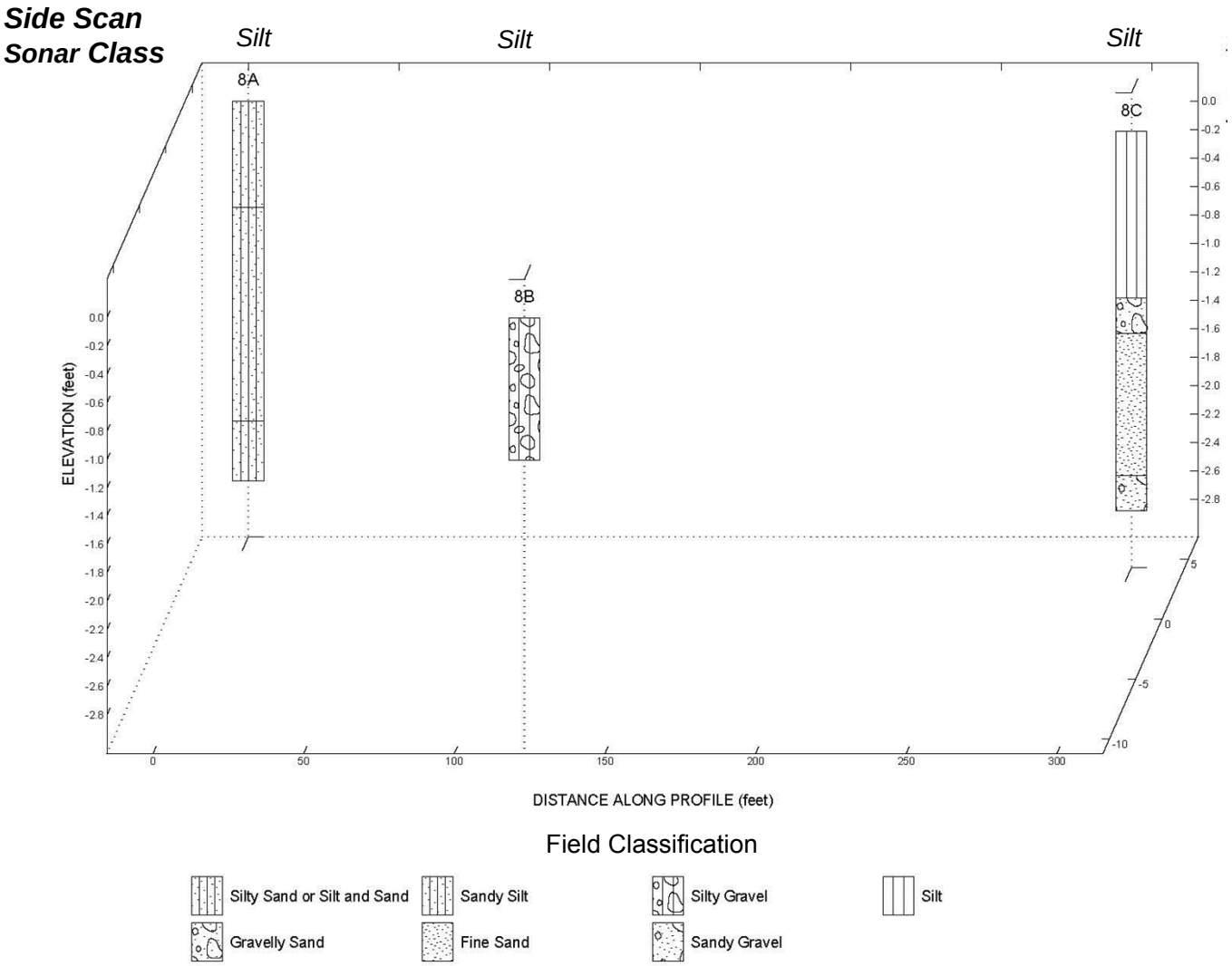


Site Map Scale 1 inch equals 120 feet

Comparison of Side Scan Sonar Sediment Class and Subsurface Sediment Texture by Coring
Location: Mile 7
Lower Eight Miles of the Lower Passaic River

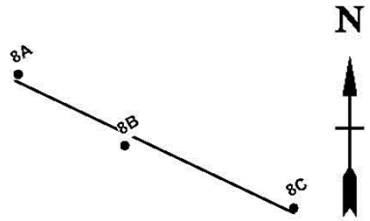
Figure 2-4h

2014



Legend

Core Location



Site Map Scale 1 inch equals 165 feet

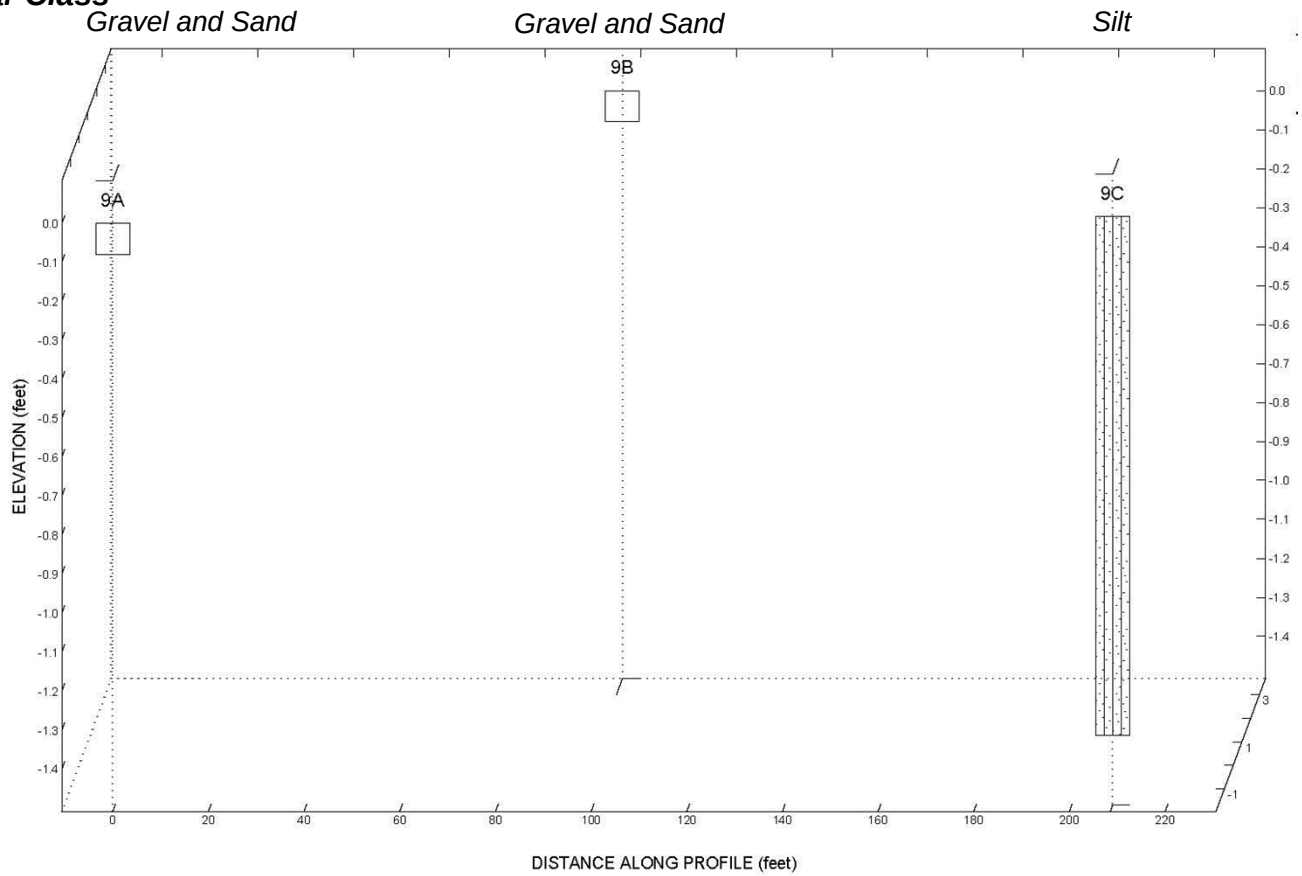
Comparison of Side Scan Sonar Sediment Class and Subsurface Sediment Texture by Coring
Location: Mile 8
Lower Eight Miles of the Lower Passaic River

Figure 2-4i

2014

R2-0027383

Side Scan Sonar Class

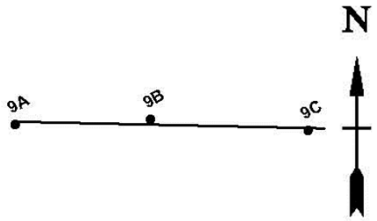


Field Classification

Silty Sand or Silt and Sand

Legend

Core Location



Site Map Scale 1 inch equals 165 feet

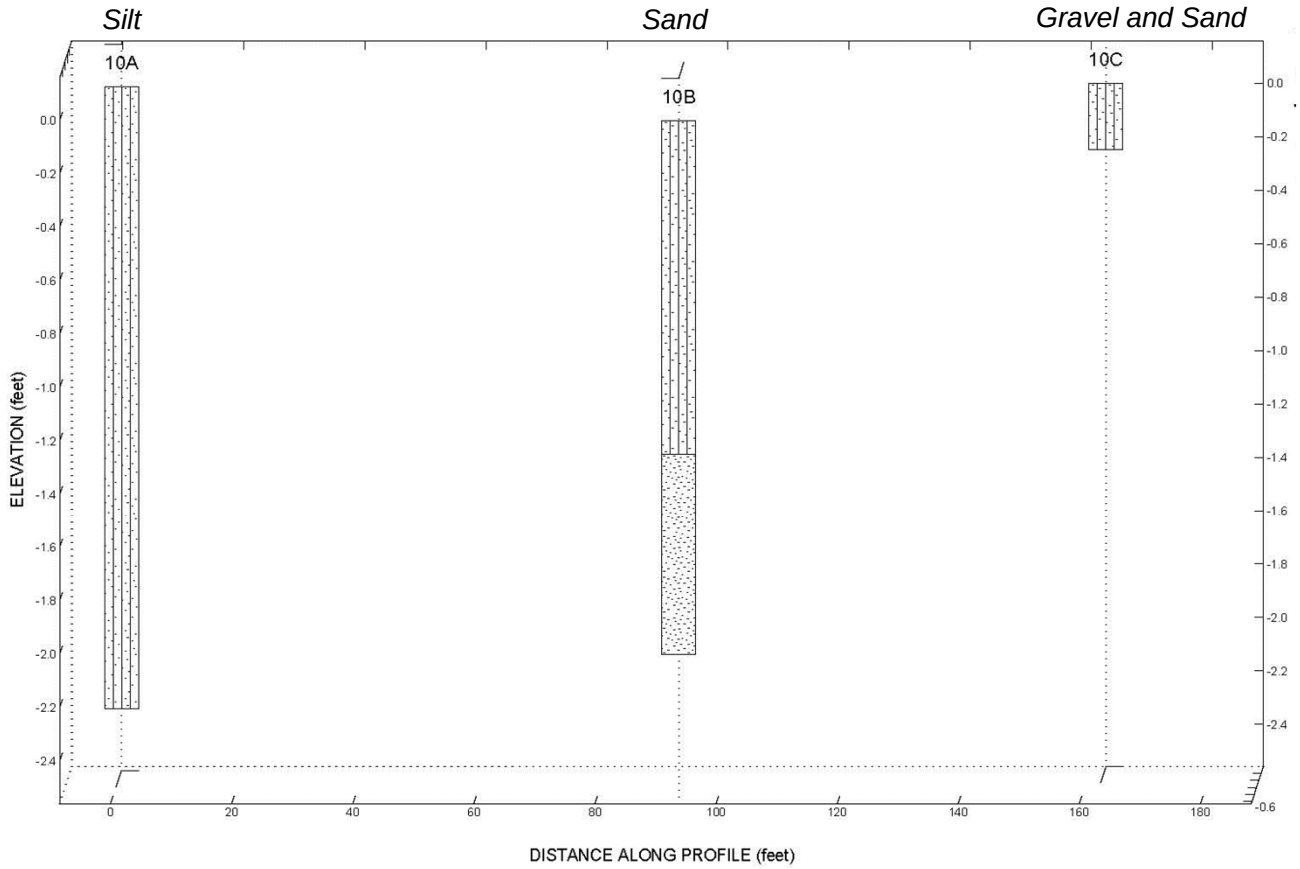
Comparison of Side Scan Sonar Sediment Class and Subsurface Sediment Texture by Coring
Location: Mile 9
Lower Eight Miles of the Lower Passaic River

Figure 2-4j

2014

R2-0027384

Side Scan
Sonar Class

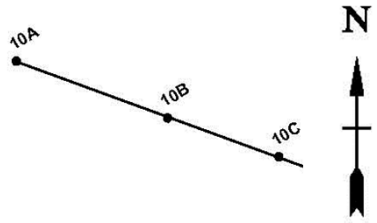


Field Classification

Silty Sand or Silt and Sand Fine Sand

Legend

Core Location



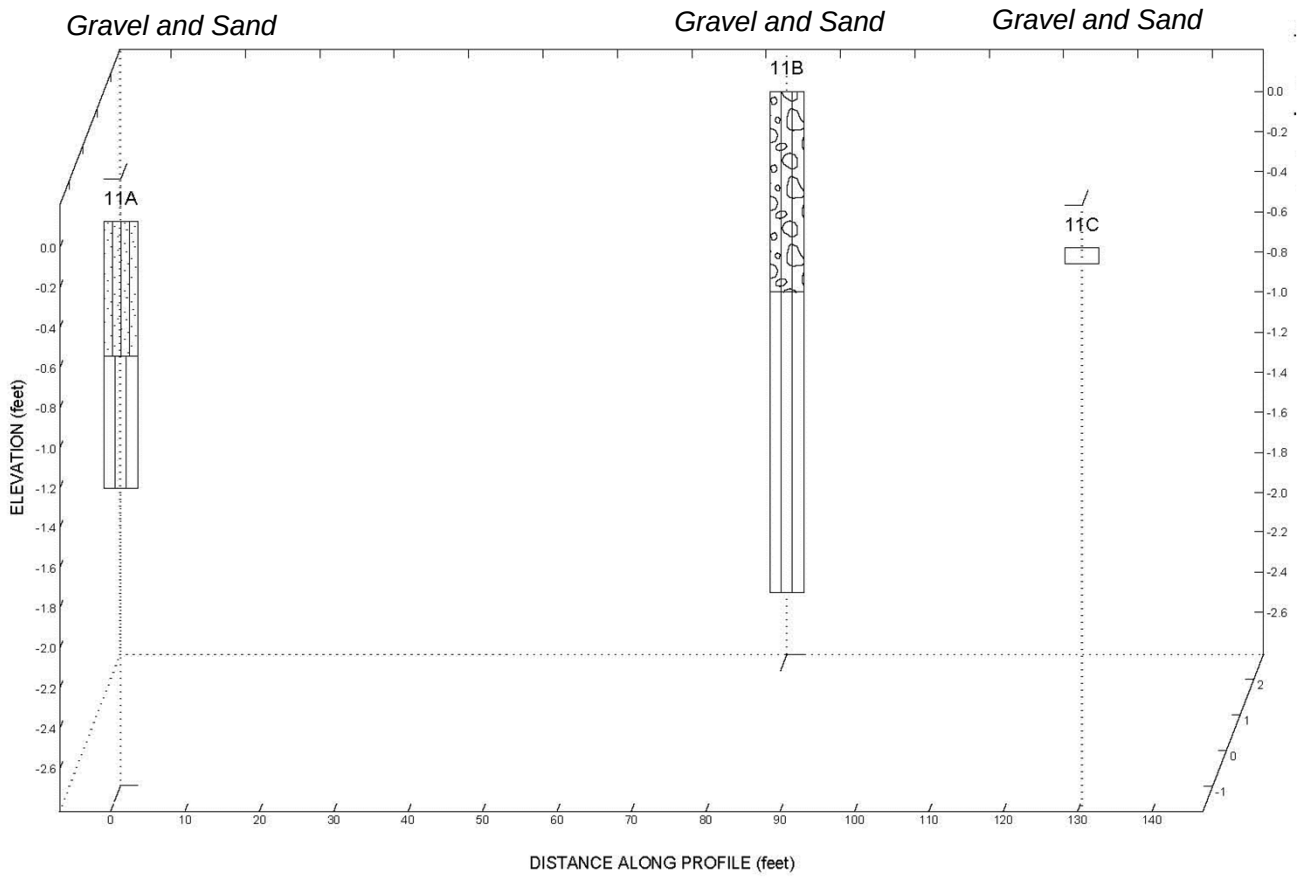
Site Map Scale 1 inch equals 100 feet

Comparison of Side Scan Sonar Sediment Class and Subsurface Sediment Texture by Coring
Location: Mile 10
Lower Eight Miles of the Lower Passaic River

Figure 2-4k

2014

Side Scan
Sonar Class

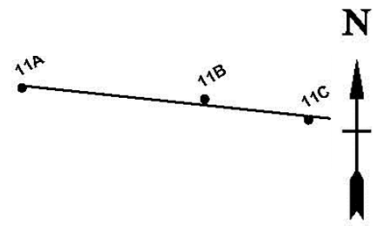


Field Classification

Silty Sand or Silt and Sand | Silt | Silty Gravel

Legend

Core Location



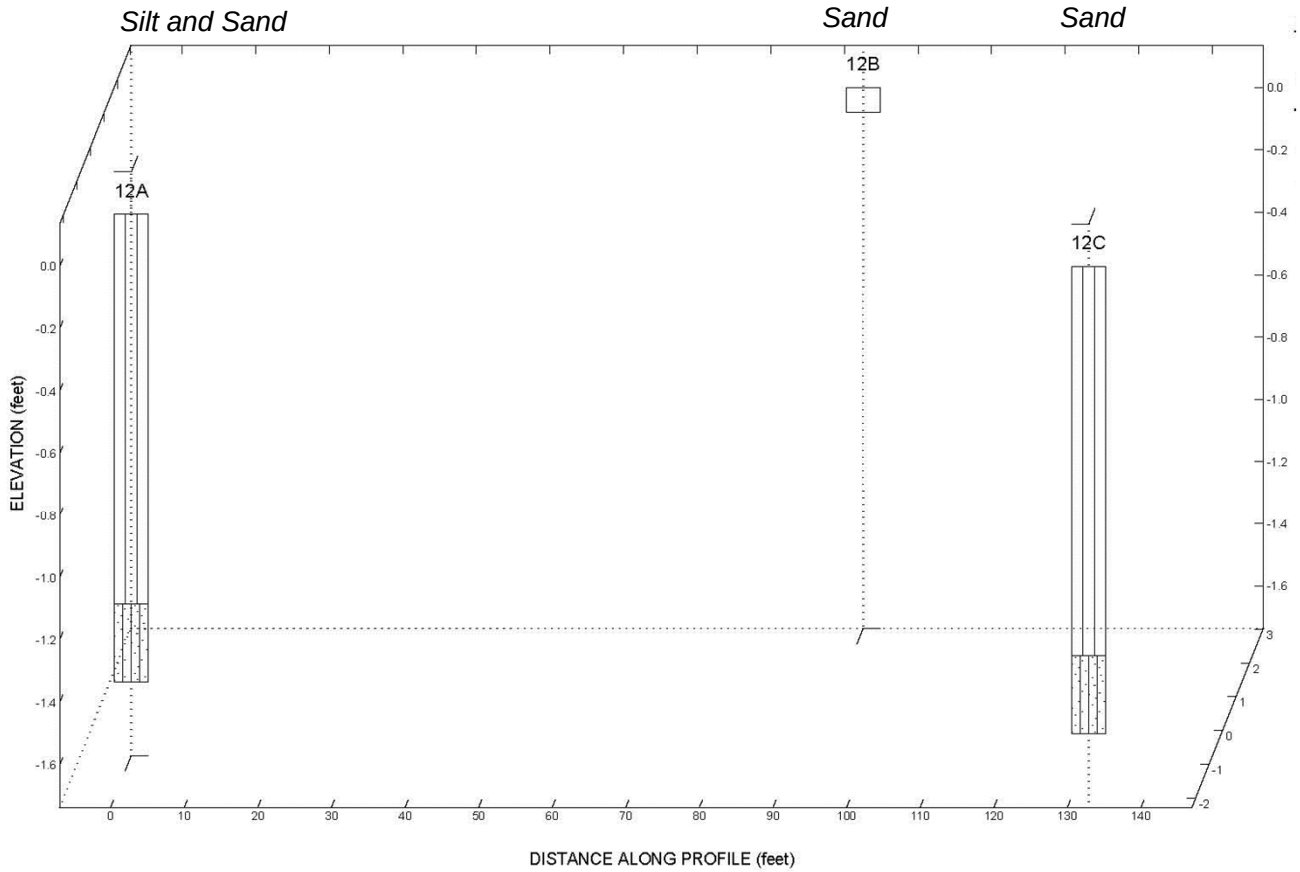
Site Map Scale 1 inch equals 75 feet

Comparison of Side Scan Sonar Sediment Class and Subsurface Sediment Texture by Coring
Location: Mile 11
Lower Eight Miles of the Lower Passaic River

Figure 2-4l

2014

Side Scan Sonar Class



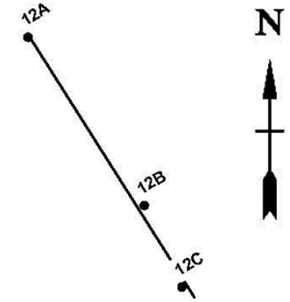
Field Classification

Silt

Silty Sand or Silt and Sand

Legend

Core Location

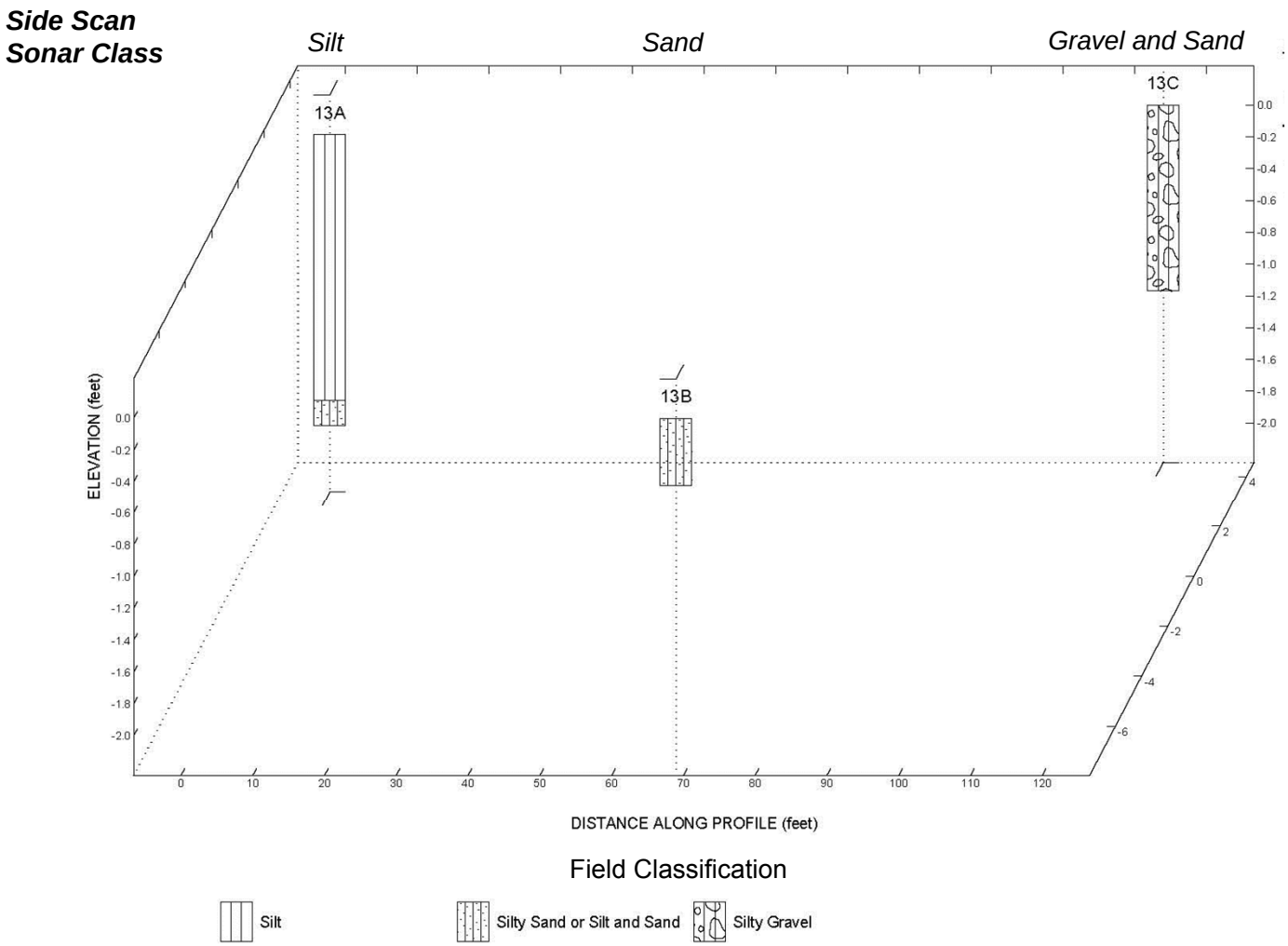


Site Map Scale 1 inch equals 75 feet

Comparison of Side Scan Sonar Sediment Class and Subsurface Sediment Texture by Coring
Location: Mile 12
Lower Eight Miles of the Lower Passaic River

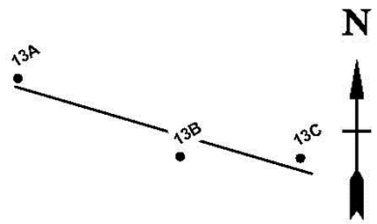
Figure 2-4m

2014



Legend

Core Location



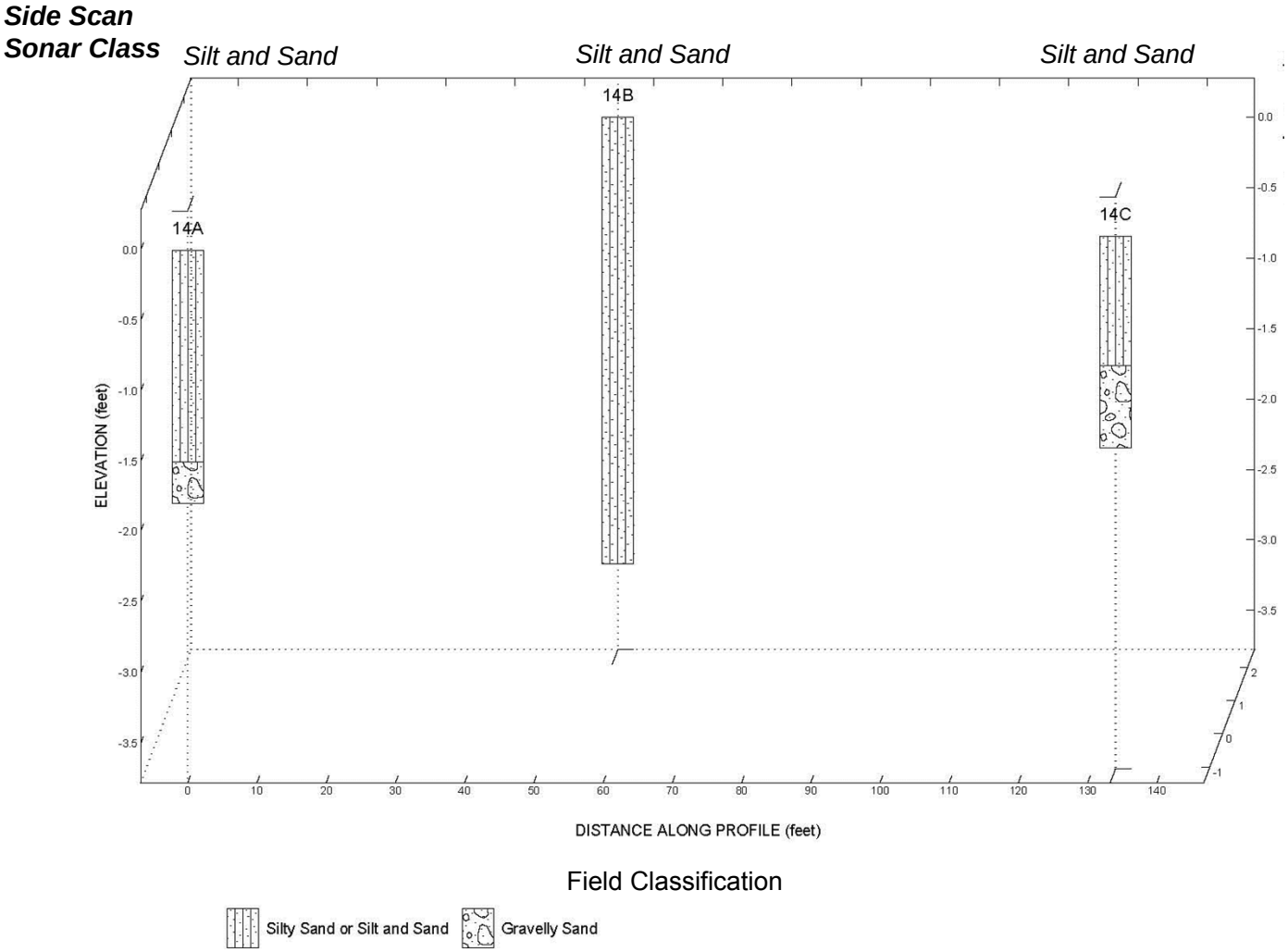
Site Map Scale 1 inch equals 65 feet

Comparison of Side Scan Sonar Sediment Class and Subsurface Sediment Texture by Coring
Location: Mile 13
Lower Eight Miles of the Lower Passaic River

Figure 2-4n

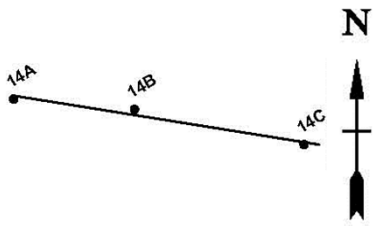
2014

R2-0027388



Legend

Core Location

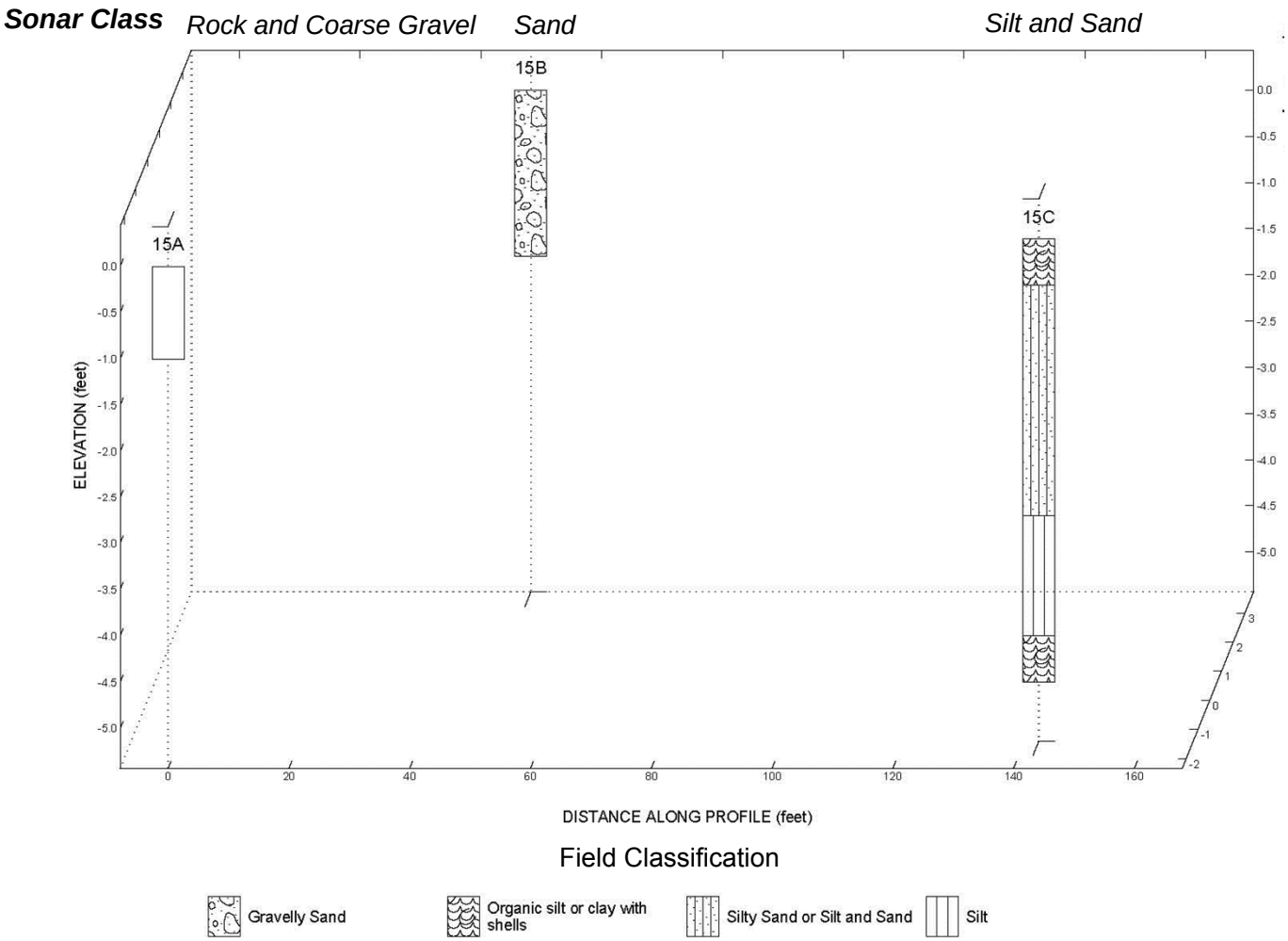


Site Map Scale 1 inch equals 75 feet

Comparison of Side Scan Sonar Sediment Class and Subsurface Sediment Texture by Coring
Location: Mile 14
Lower Eight Miles of the Lower Passaic River

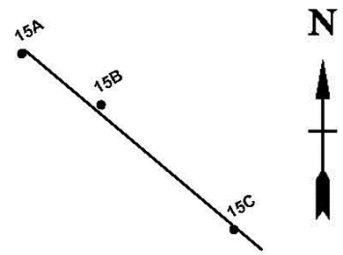
Figure 2-4o

2014



Legend

Core Location

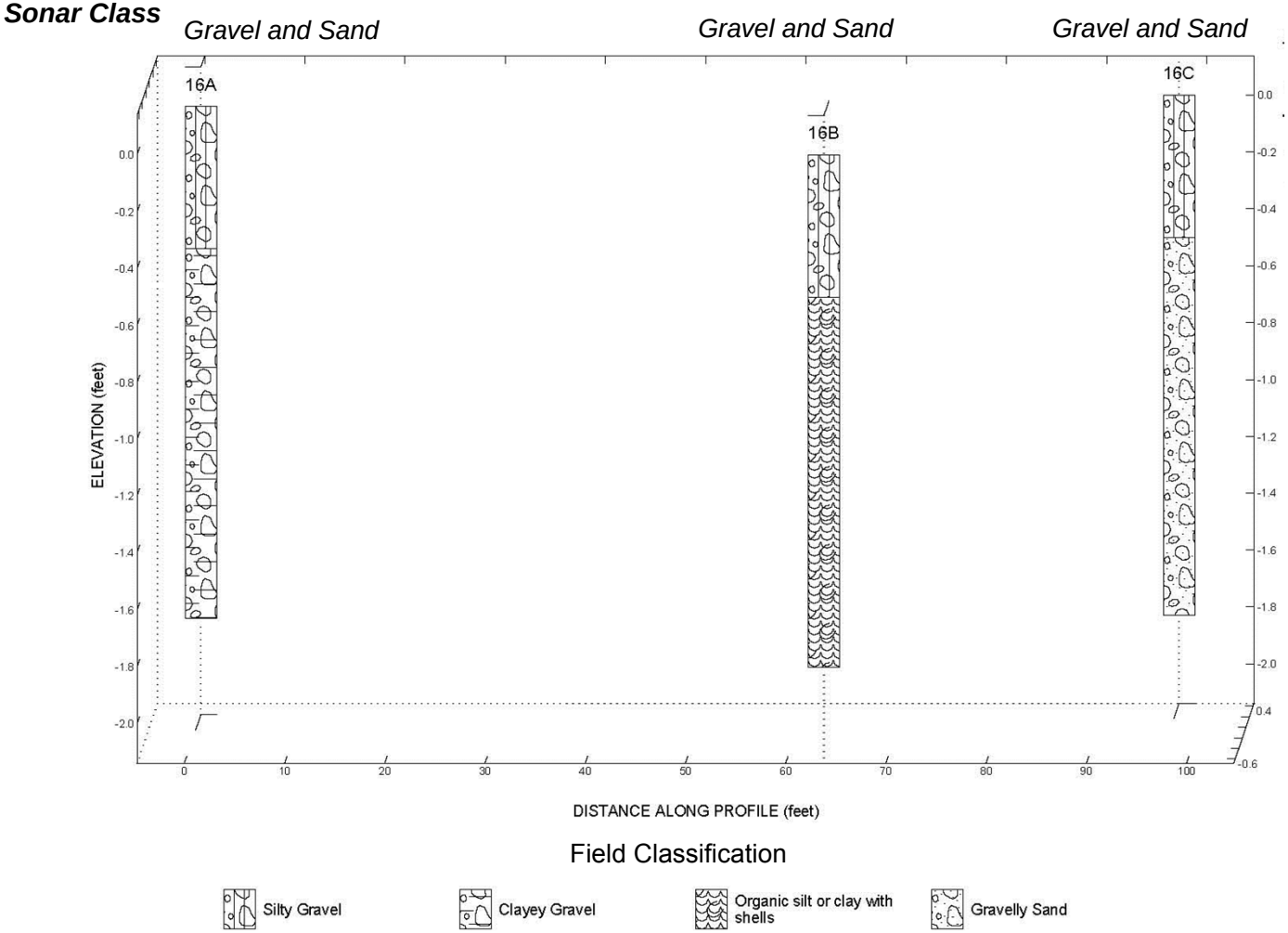


Site Map Scale 1 inch equals 90 feet

Comparison of Side Scan Sonar Sediment Class and Subsurface Sediment Texture by Coring
Location: Mile 15
Lower Eight Miles of the Lower Passaic River

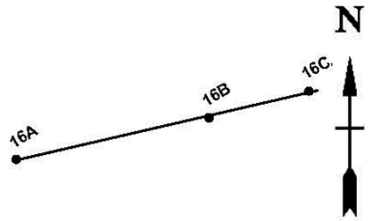
Figure 2-4p

2014



Legend

Core Location

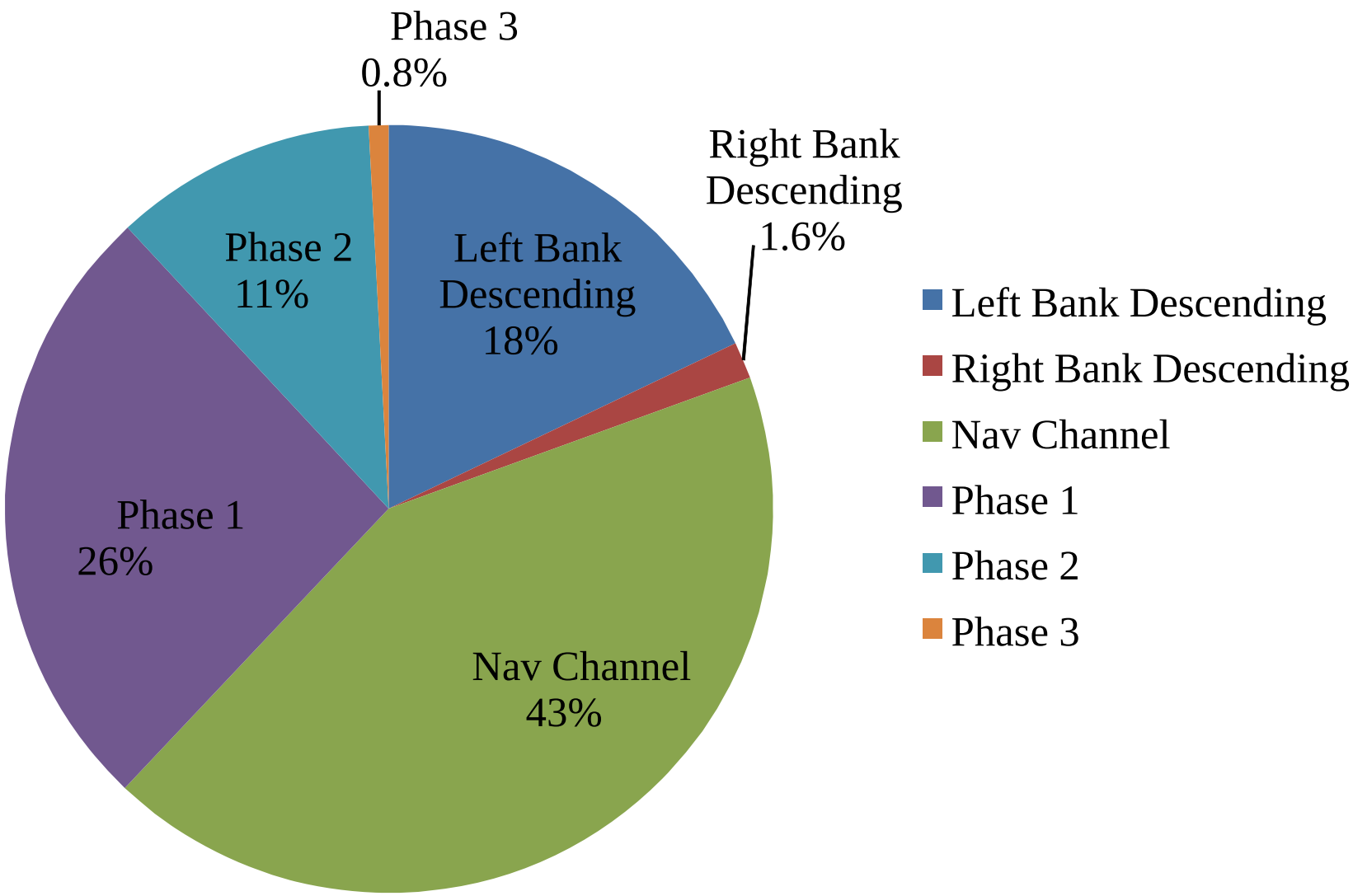


Site Map Scale 1 inch equals 55 feet

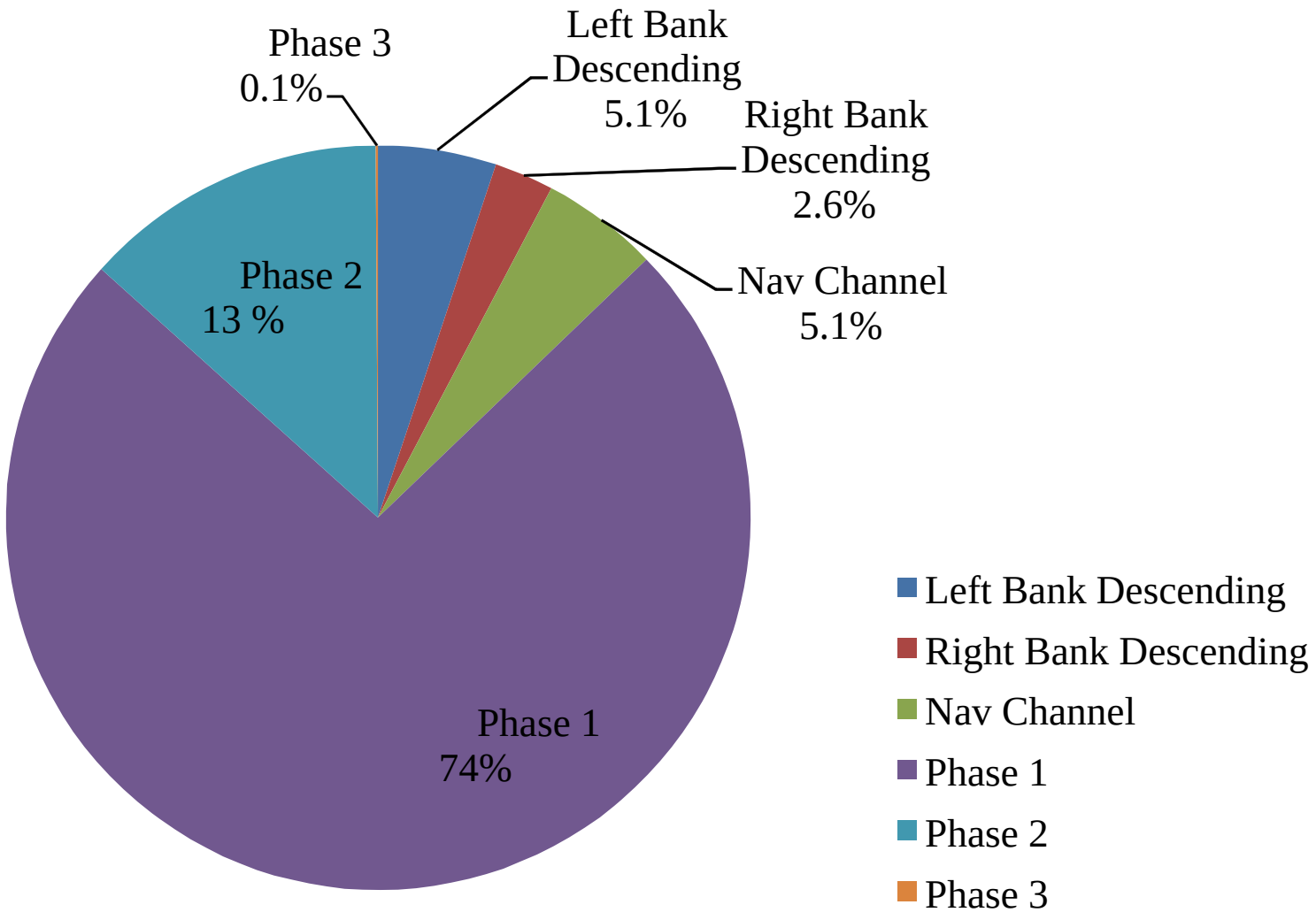
Comparison of Side Scan Sonar Sediment Class and Subsurface Sediment Texture by Coring
Location: Mile 16
Lower Eight Miles of the Lower Passaic River

Figure 2-4q

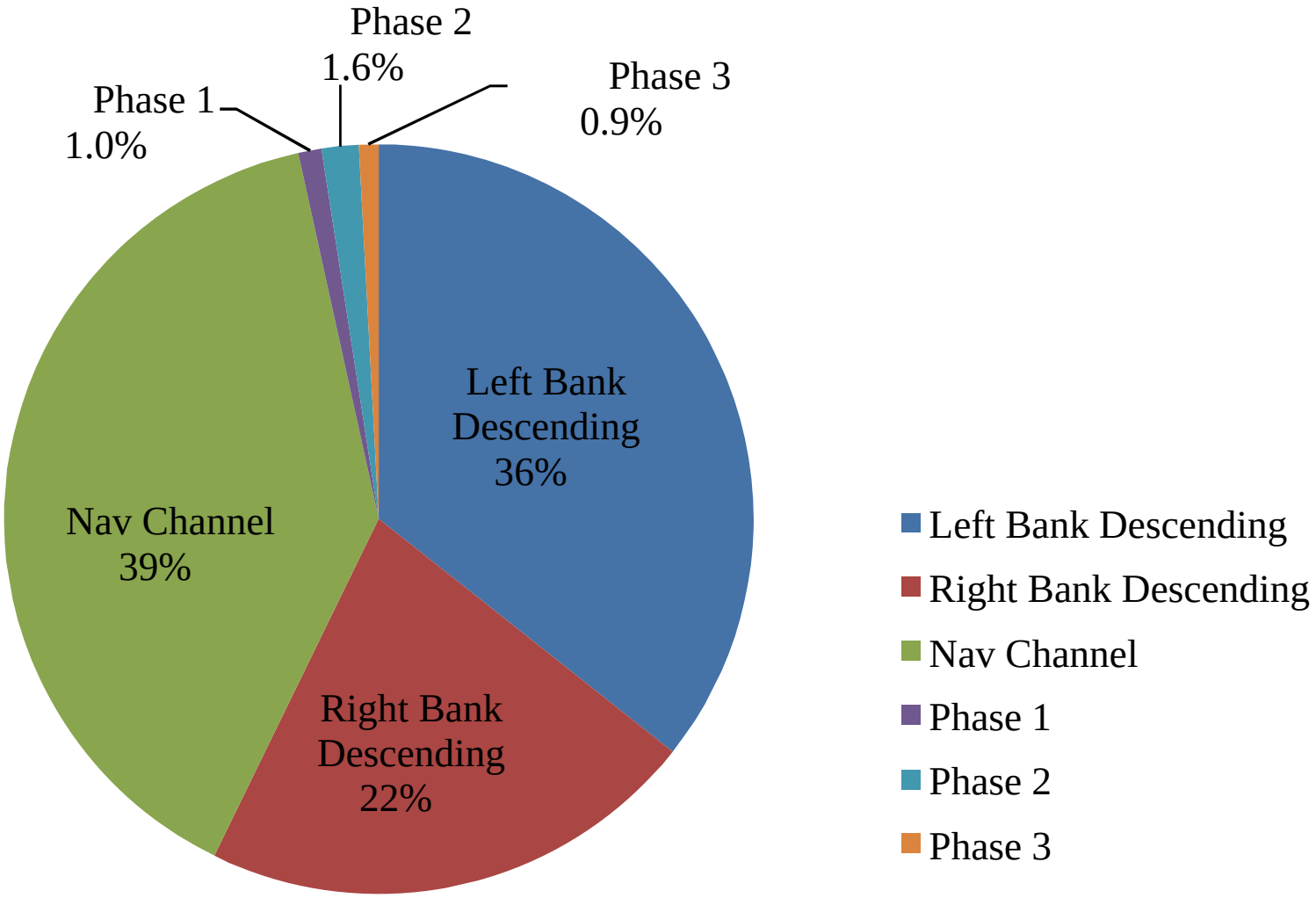
2014



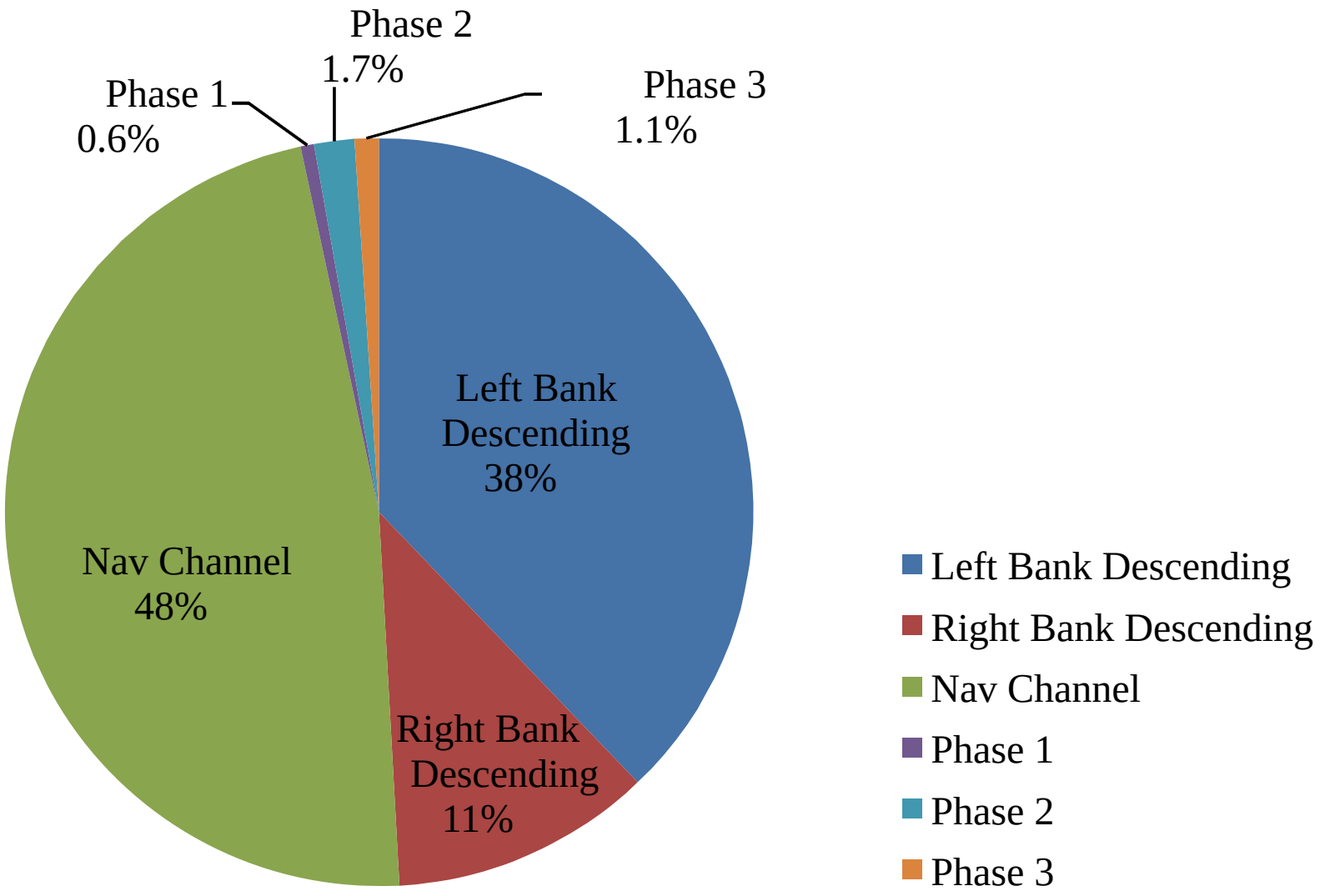
	2,3,7,8-TCDD Mass Distribution by Remedial Area (RM0 to RM8.3) *Lower Eight Miles of the Lower Passaic River*	Figure 2-5 2014



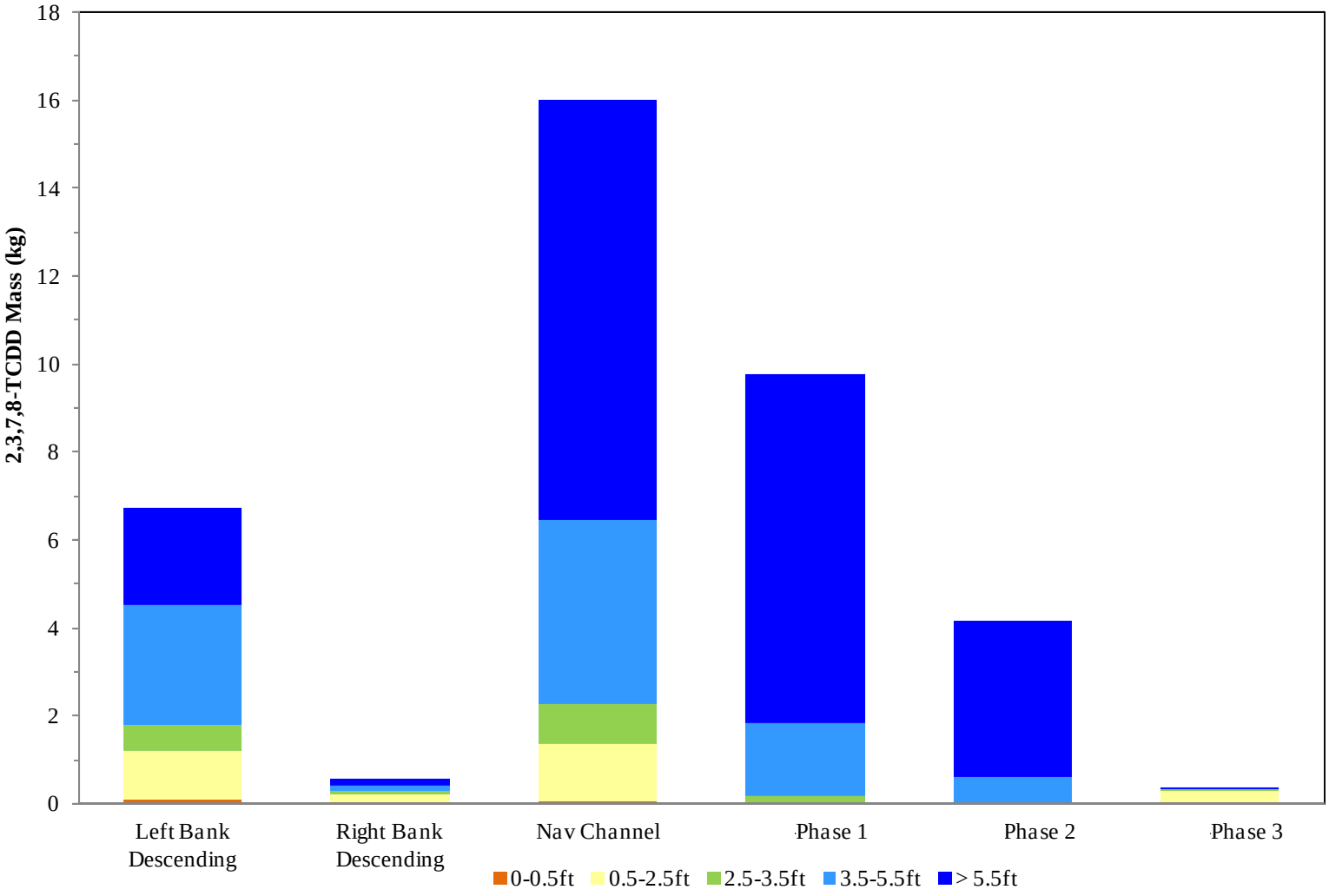
	Total 4,4´-DDx Mass Distribution by Remedial Area (RM0 to RM8.3) *Lower Eight Miles of the Lower Passaic River*	Figure 2-6 2014



	Total PCB Mass Distribution by Remedial Area (RM0 to RM8.3) *Lower Eight Miles of the Lower Passaic River*	Figure 2-7 2014



	Mercury Mass Distribution by Remedial Area (RM0 to RM8.3) *Lower Eight Miles of the Lower Passaic River*	Figure 2-8 2014



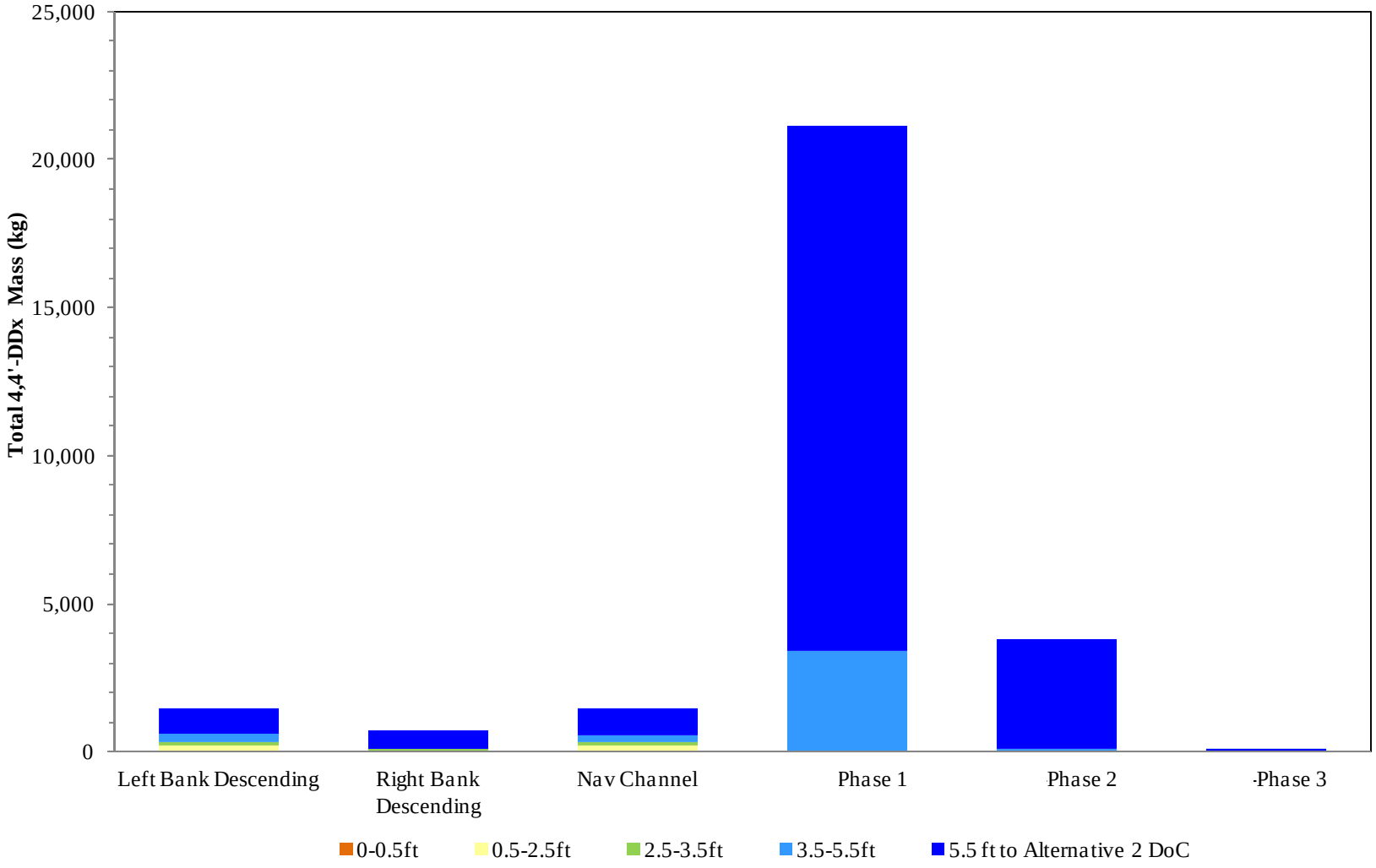
2,3,7,8-TCDD Mass Distribution by Remedial Area and Depth Horizon (RM0 to RM8.3)

Lower Eight Miles of the Lower Passaic River

Figure 2-9

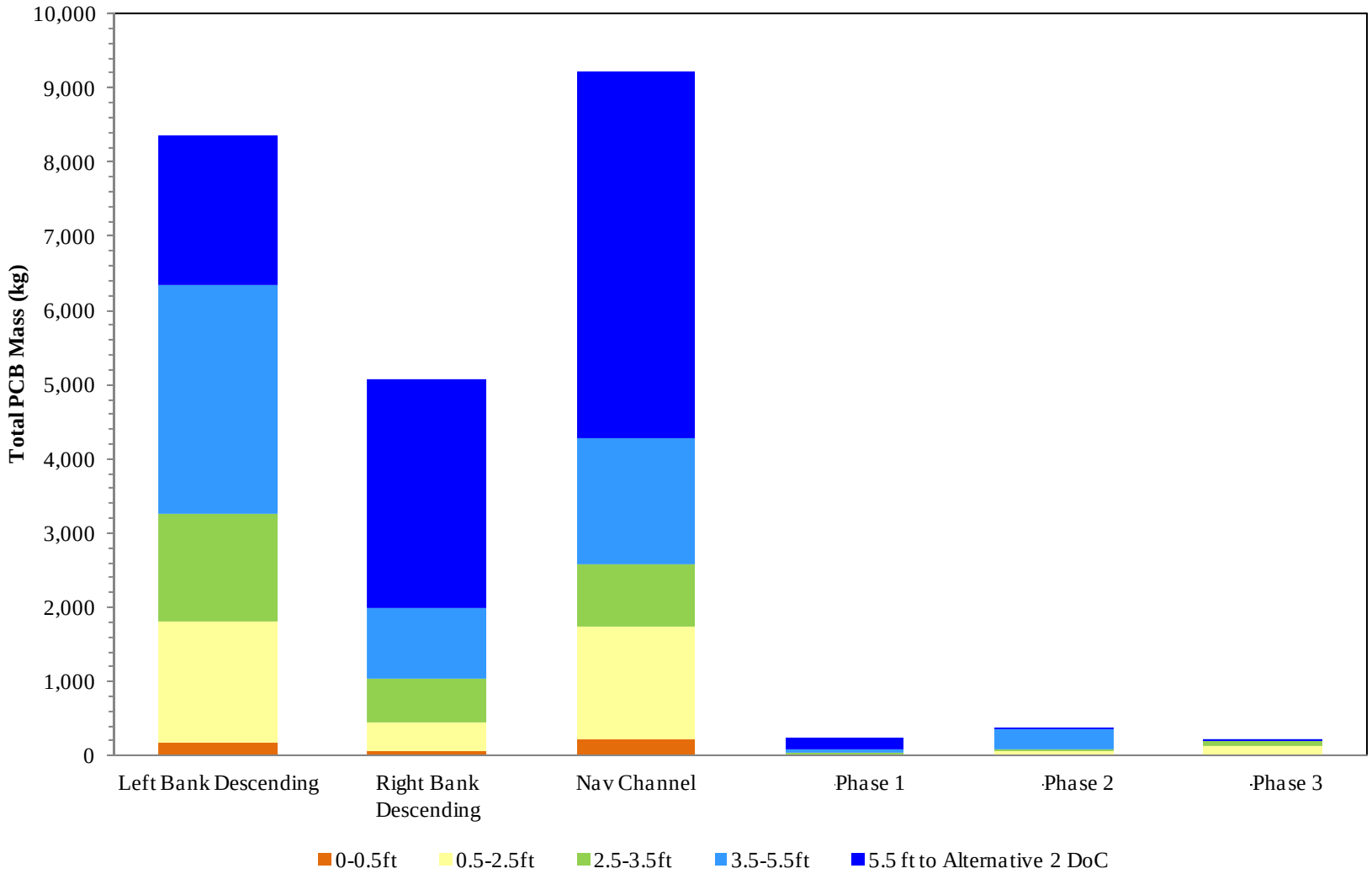
2014

R2-0027396



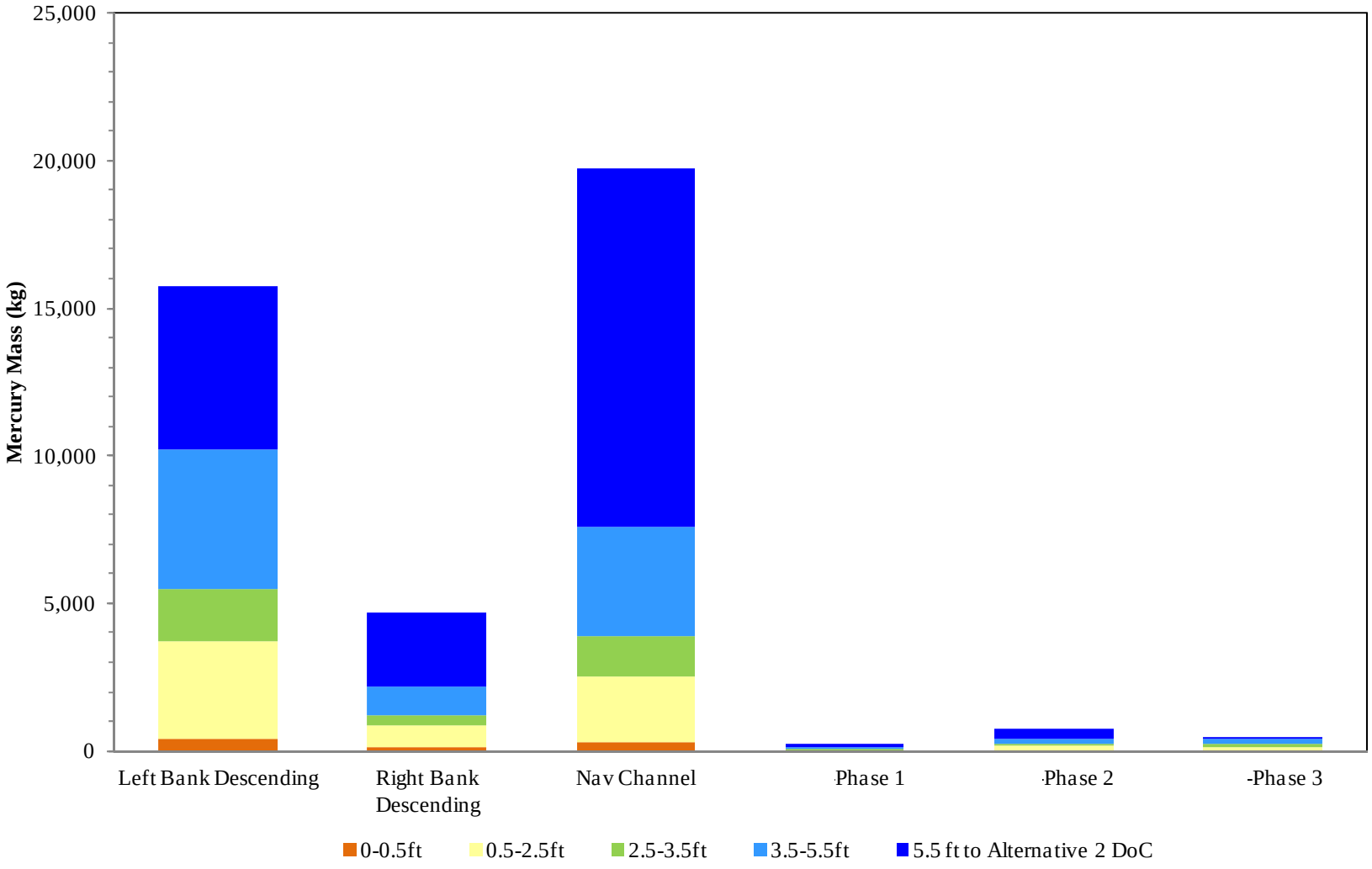
	Total 4,4´-DDx Mass Distribution by Remedial Area and Depth Horizon (RM0 to RM8.3) *Lower Eight Miles of the Lower Passaic River*	Figure 2-10 2014

R2-0027397



	Total PCB Mass Distribution by Remedial Area and Depth Horizon (RM0 to RM8.3) *Lower Eight Miles of the Lower Passaic River*	Figure 2-11 2014

R2-0027398



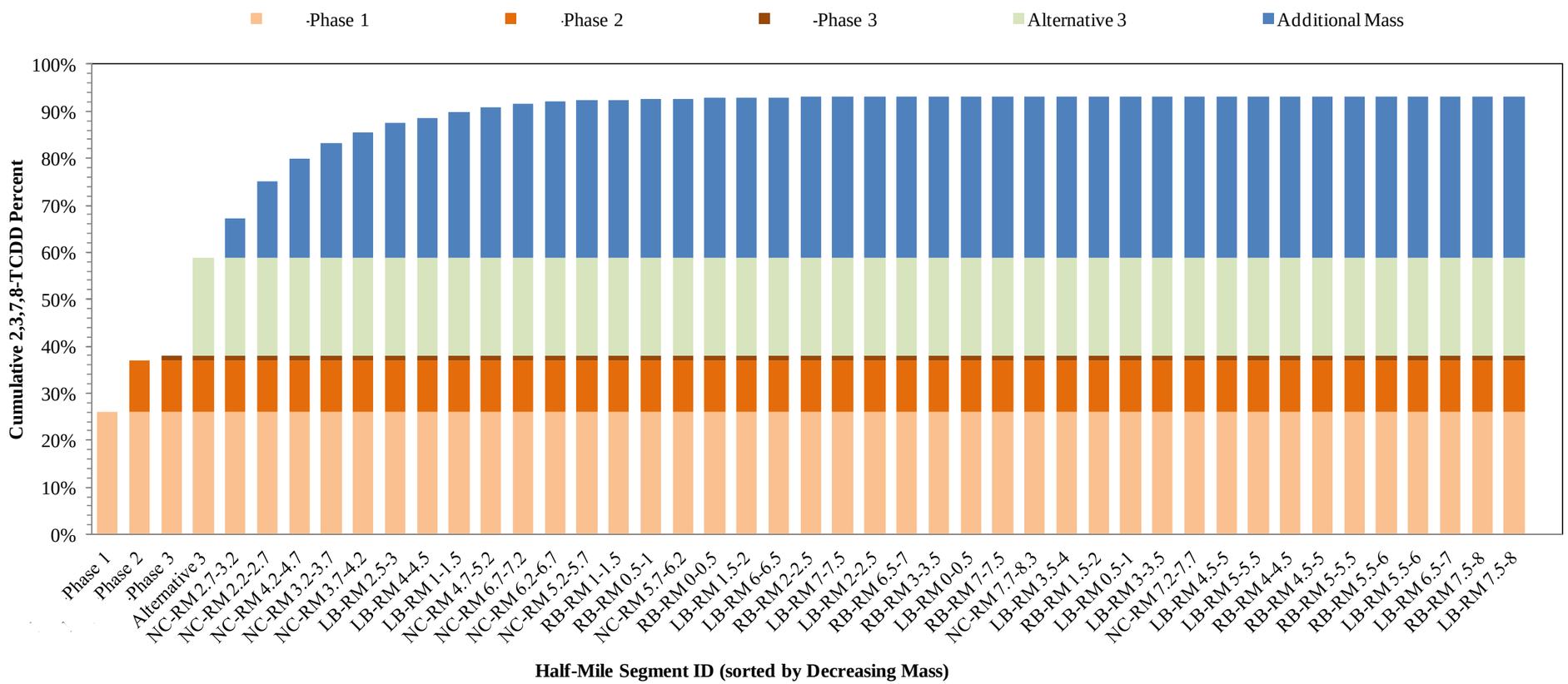
Mercury Mass Distribution by Remedial Area and Depth Horizon (RM0 to RM8.3)

Lower Eight Miles of the Lower Passaic River

Figure 2-12

2014

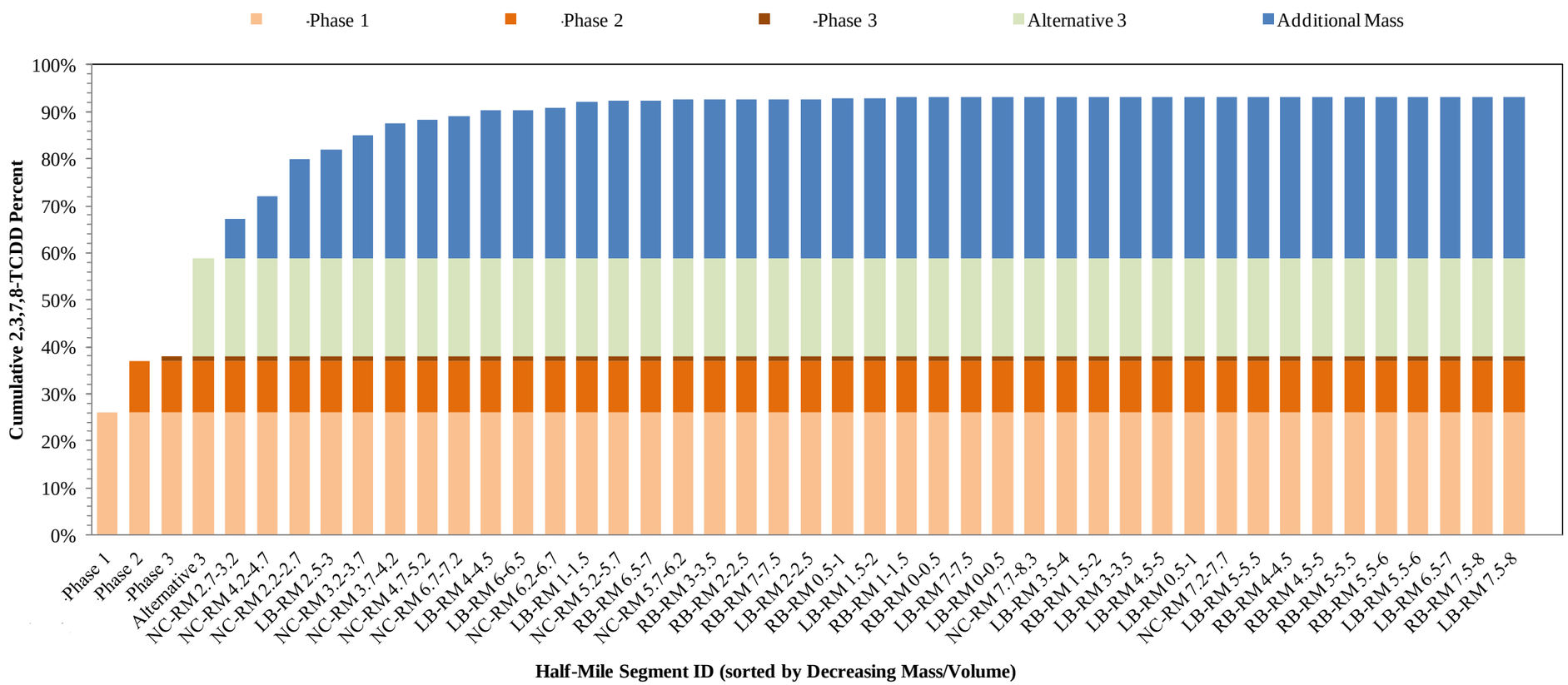
R2-0027399



Note the following:

- Uncertainties in mass estimates are on the order of 50%.
- Phase 1, 2,3 TSI Removal Area and Alternative 3 are represented by their global estimates.
- Cumulative mass not equal to 100% because mass was not estimated for half-mile segments with no data.

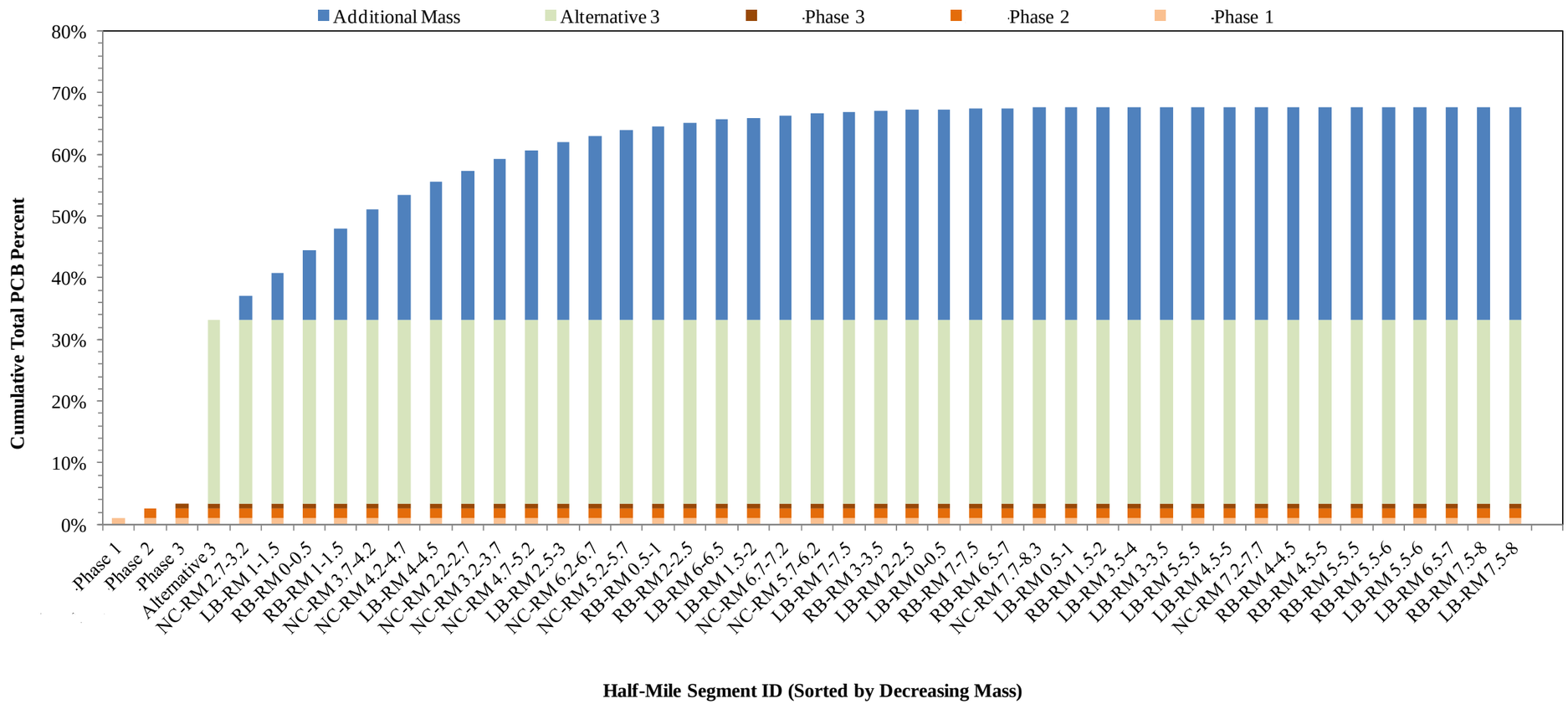
	Percent Increase in 2,3,7,8-TCDD Mass in Full Dredge Depth (Sorted by Decreasing Mass) *Lower Eight Miles of the Lower Passaic River*	Figure 3-1a 2014



Note the following:

- Uncertainties in mass estimates are on the order of 50%.
- Phase 1, 2,3 TSI Removal Area and Alternative 3 are represented by their global estimates.
- Cumulative mass not equal to 100% because mass was not estimated for half-mile segments with no data.

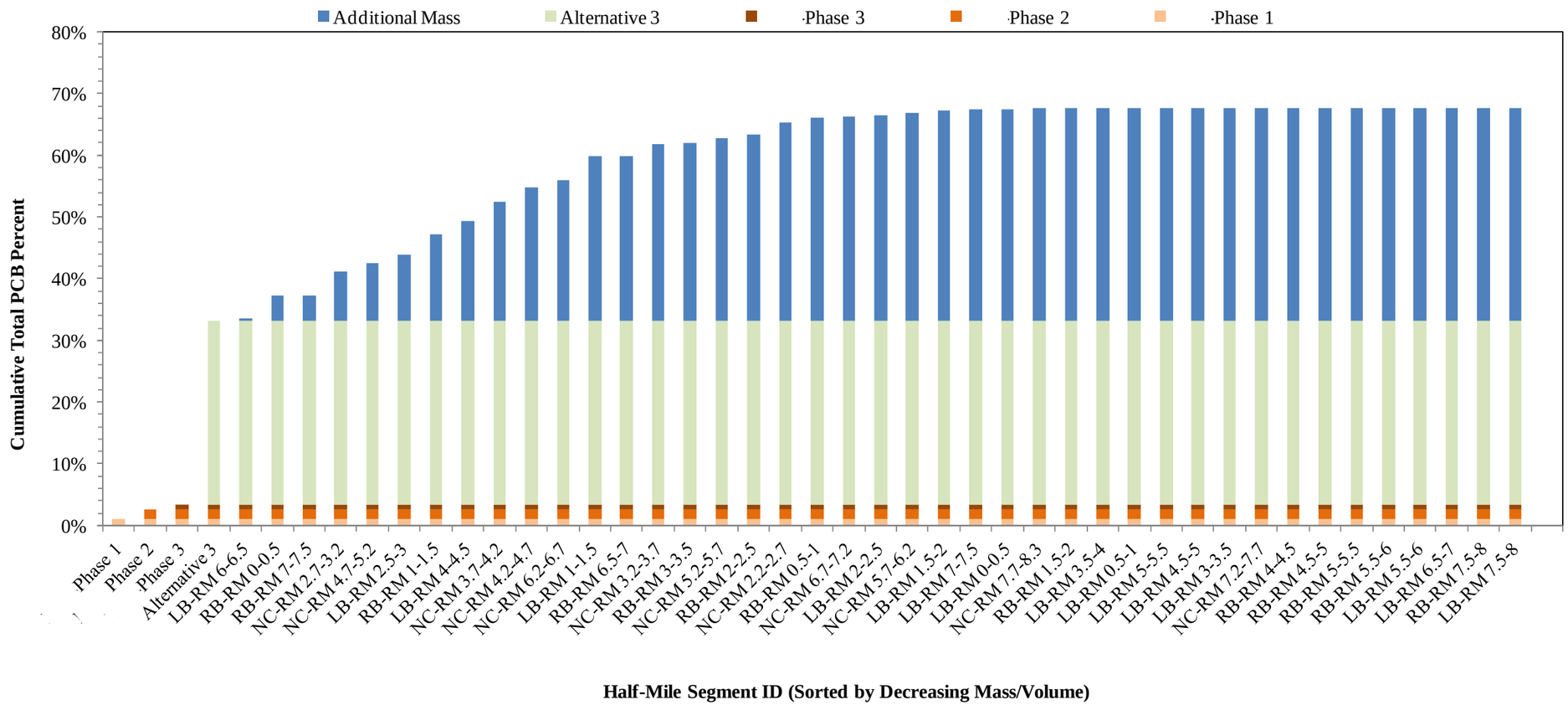
	Percent Increase in 2,3,7,8-TCDD Mass in Full Dredge Depth (Sorting by Decreasing Mass/Volume) *Lower Eight Miles of the Lower Passaic River*	Figure 3-1b 2014



Note the following:

- Uncertainties in mass estimates are on the order of 50%.
- Phase 1, 2,3 TSI Removal Area and Alternative 3 are represented by their global estimates.
- Cumulative mass not equal to 100% because mass was not estimated for half-mile segments with no data.

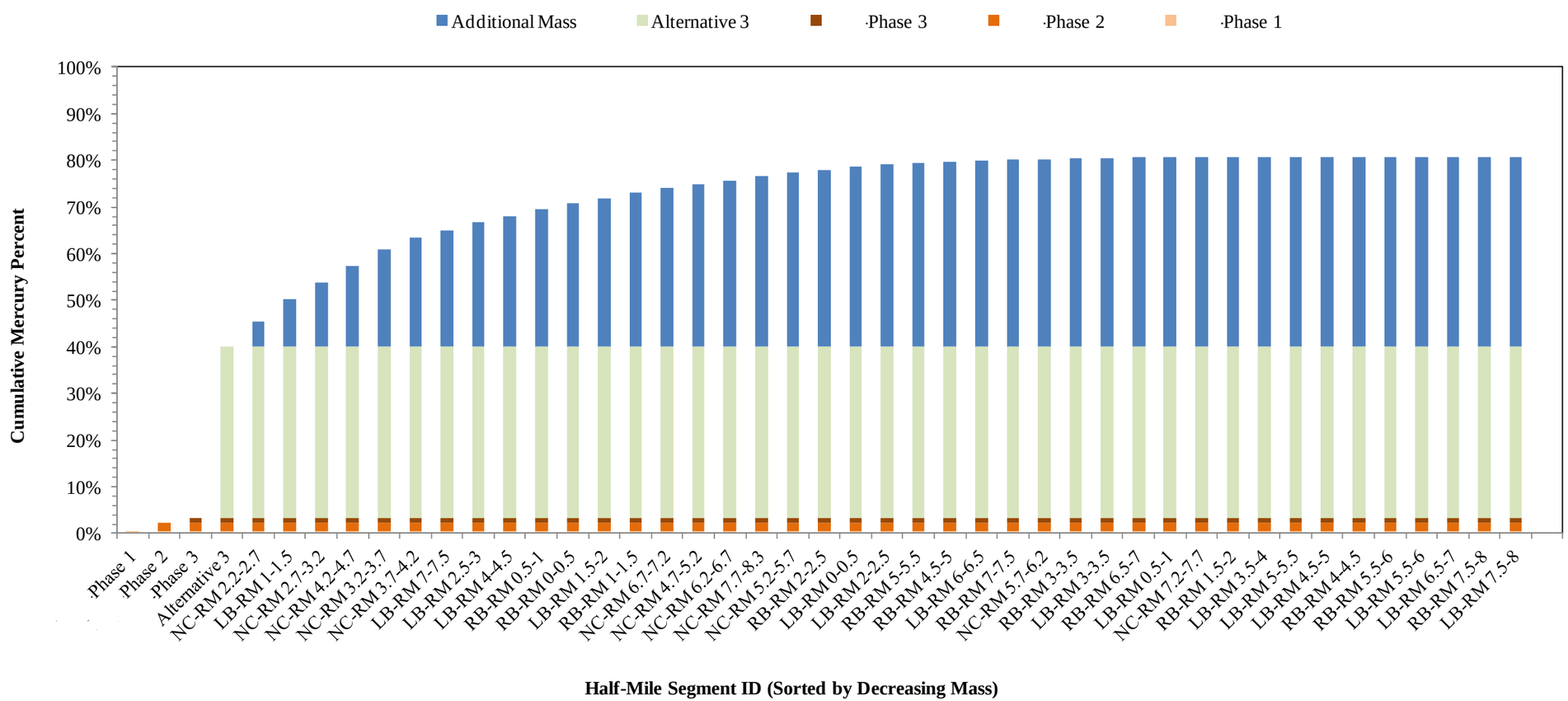
	Percent Increase in Total PCB Mass in Full Dredge Depth (Sorted by Decreasing Mass) *Lower Eight Miles of the Lower Passaic River*	Figure 3-2a 2014



Note the following:

- Uncertainties in mass estimates are on the order of 50%.
- Phase 1, 2,3 TSI Removal Area and Alternative 3 are represented by their global estimates.
- Cumulative mass not equal to 100% because mass was not estimated for half-mile segments with no data.

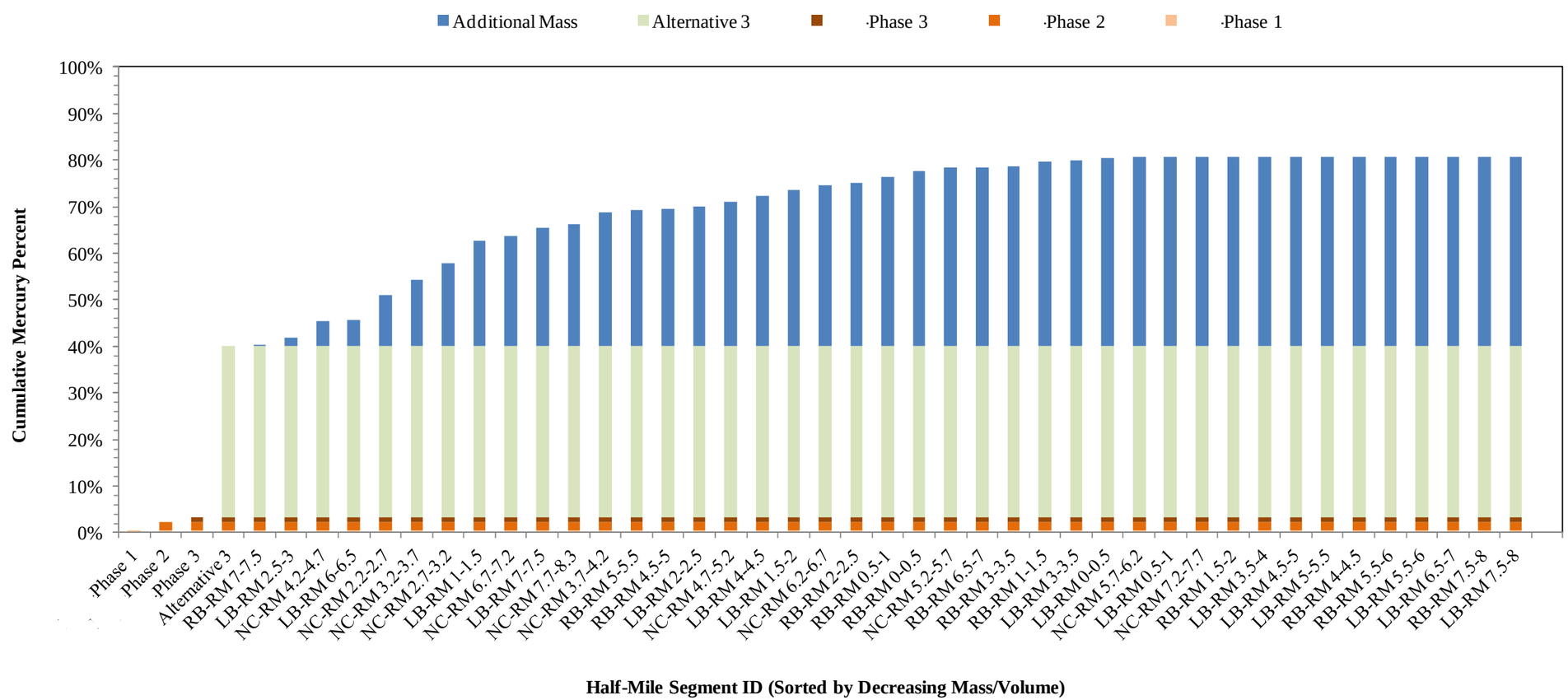
	Percent Increase in Total PCB Mass in Full Dredge Depth (Sorting by Decreasing Mass/Volume) *Lower Eight Miles of the Lower Passaic River*	Figure 3-2b 2014



Note the following:

- Uncertainties in mass estimates are on the order of 50%.
- Phase 1, 2,3 TSI Removal Area and Alternative 3 are represented by their global estimates.
- Cumulative mass not equal to 100% because mass was not estimated for half-mile segments with no data.

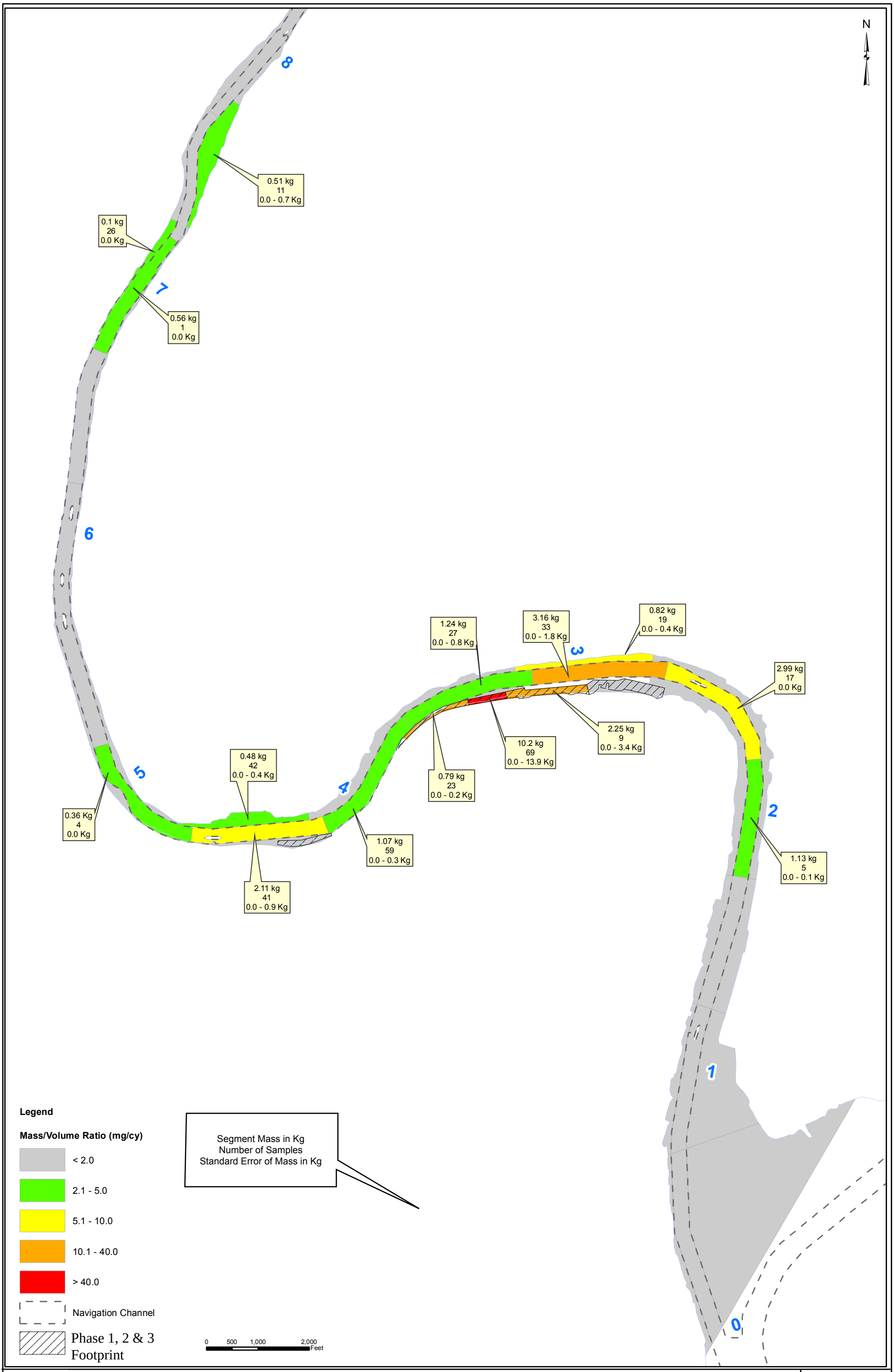
	Percent Increase in Mercury Mass in Full Dredge Depth (Sorted by Decreasing Mass) *Lower Eight Miles of the Lower Passaic River*	Figure 3-3a 2014



Note the following:

- Uncertainties in mass estimates are on the order of 50%.
- Phase 1, 2,3 TSI Removal Area and Alternative 3 are represented by their global estimates.
- Cumulative mass not equal to 100% because mass was not estimated for half-mile segments with no data.

	Percent Increase in Mercury Mass in Full Dredge Depth (Sorting by Decreasing Mass/Volume) *Lower Eight Miles of the Lower Passaic River*	Figure 3-3b 2014



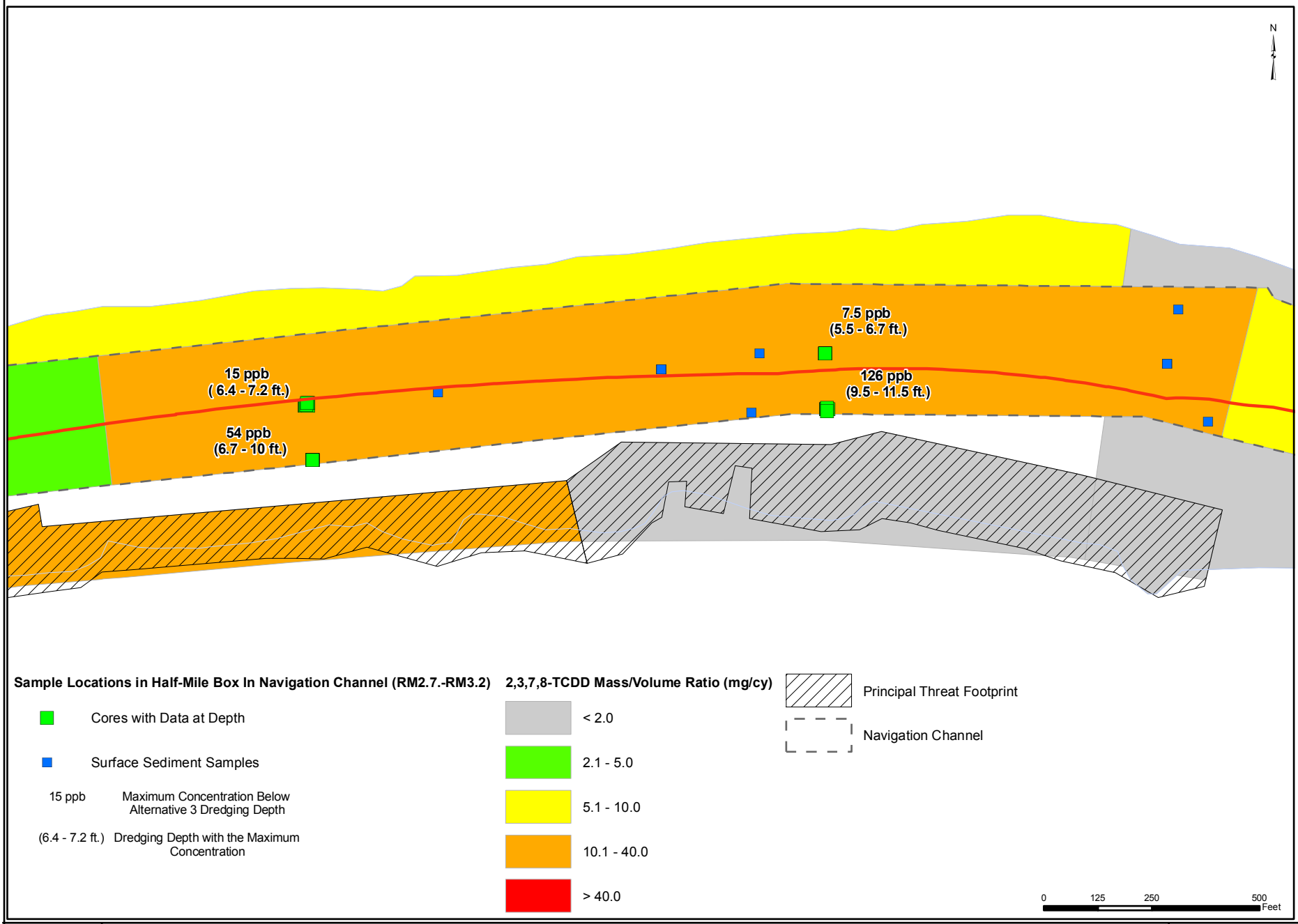
Mass Removal Estimate for 2,3,7,8-TCDD - Half-Mile Segments, Alternative 2 Design Depths

Lower Eight Miles of the Lower Passaic River

Figure 3-4

2014

R2-0027406



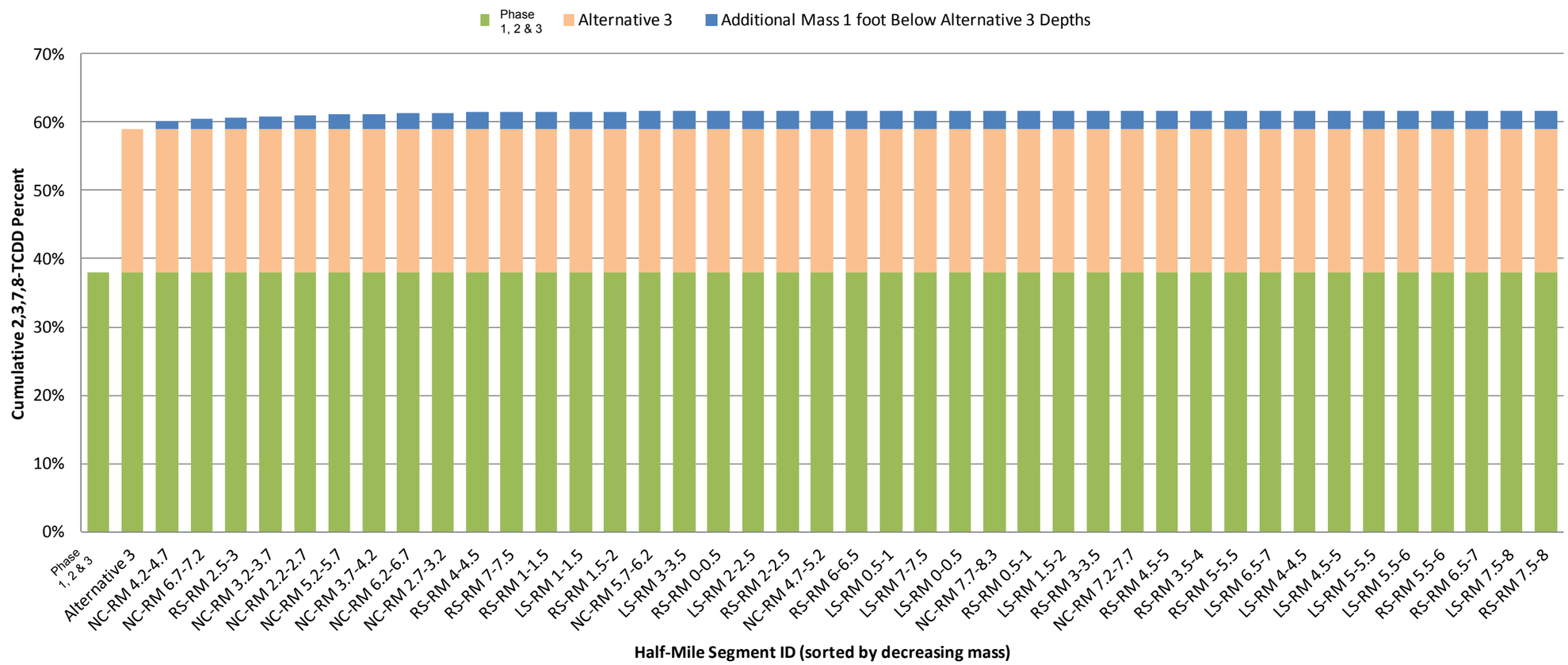
Data Used for Developing 2,3,7,8-TCDD Mass Estimates for Half-Mile Segment in Navigation Channel (RM2.7 to RM3.2)

Lower Eight Miles of the Lower Passaic River

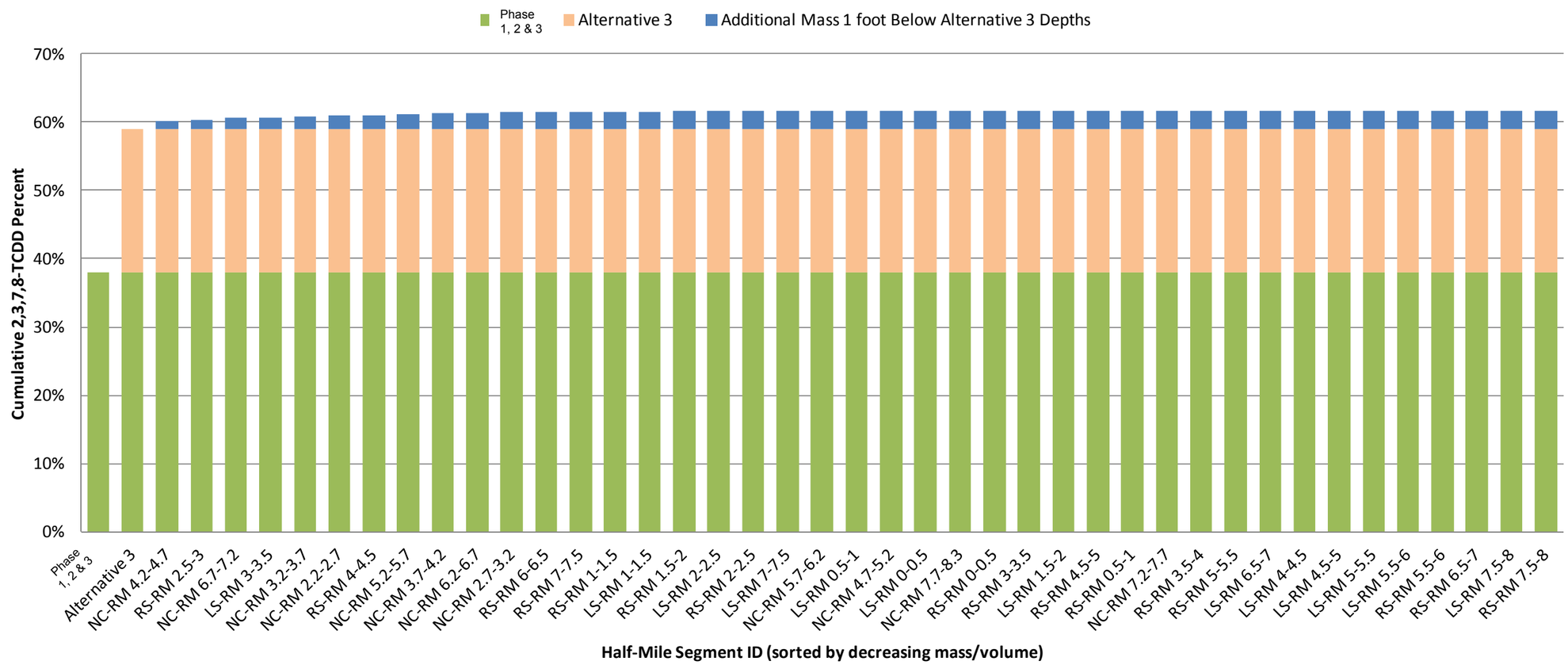
Figure 3-5

2014

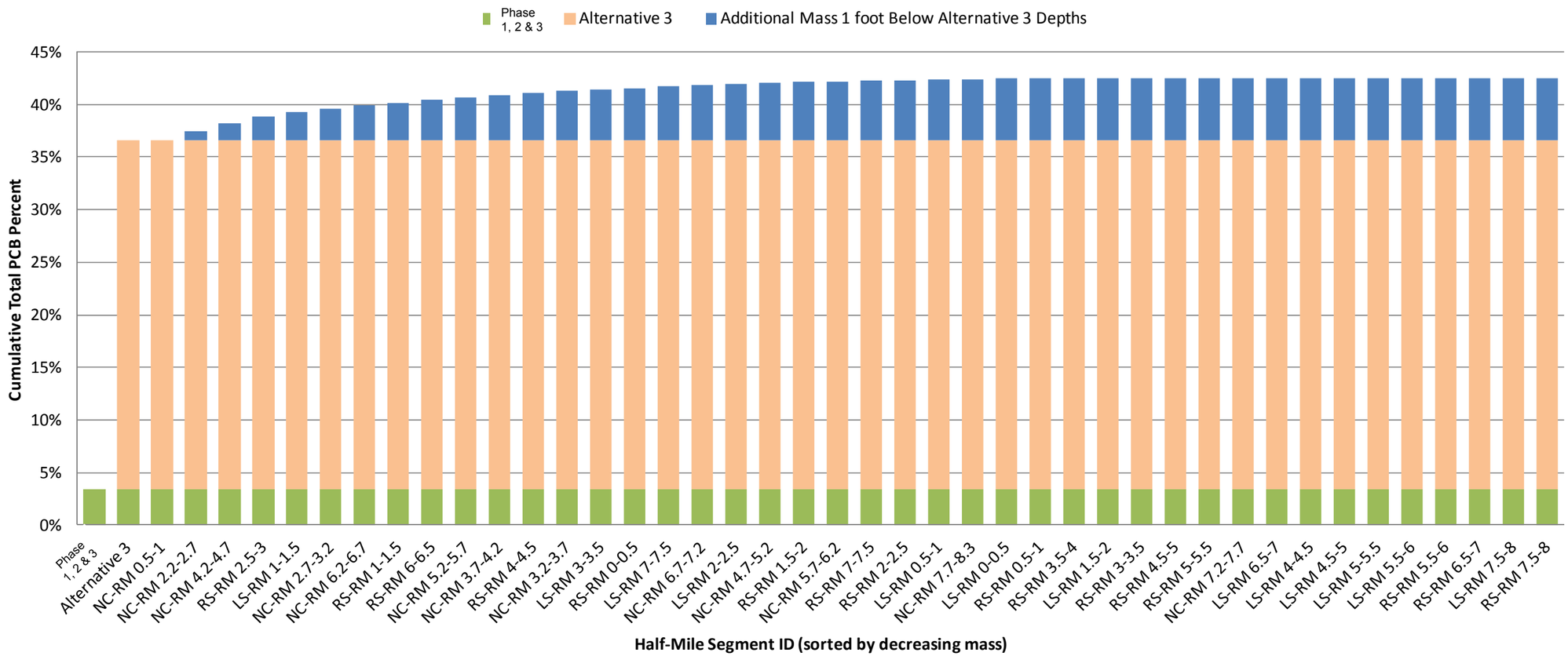
R2-0027407



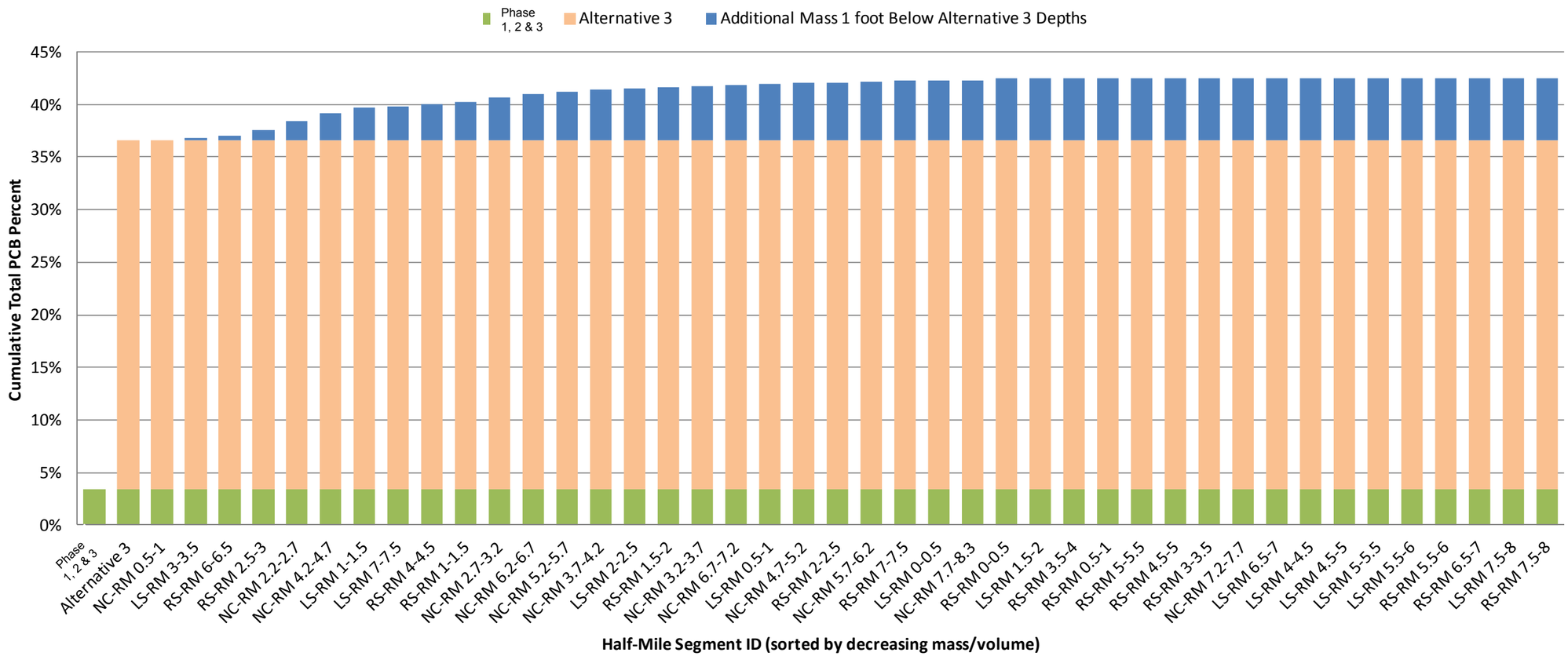
	Percent Increase in 2,3,7,8-TCDD Mass 1-foot below Alternative 3 Depth (Sorted by Decreasing Mass) *Lower Eight Miles of the Lower Passaic River*	Figure 3-6a 2014



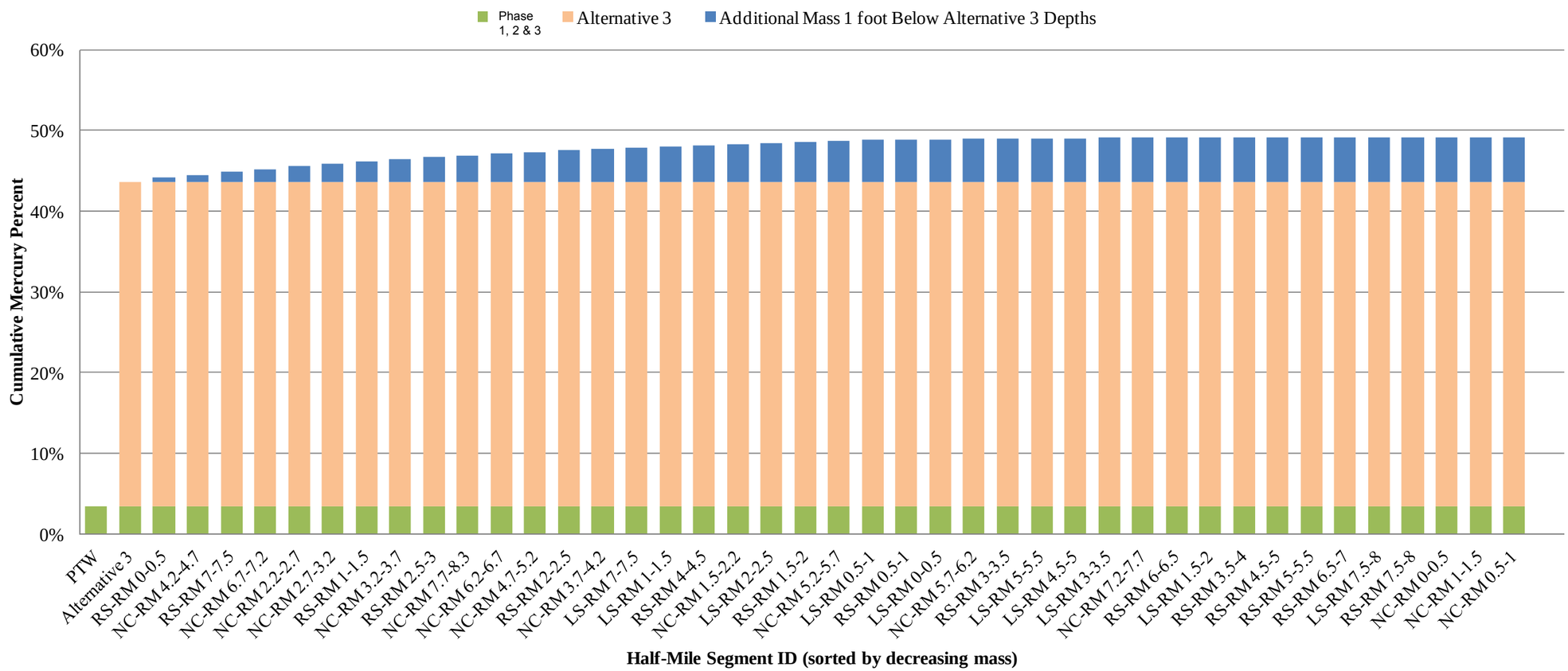
	Percent Increase in 2,3,7,8-TCDD Mass 1-foot below Alternative 3 Depth (Sorted by Decreasing Mass to Volume Ratio) *Lower Eight Miles of the Lower Passaic River*	Figure 3-6b 2014



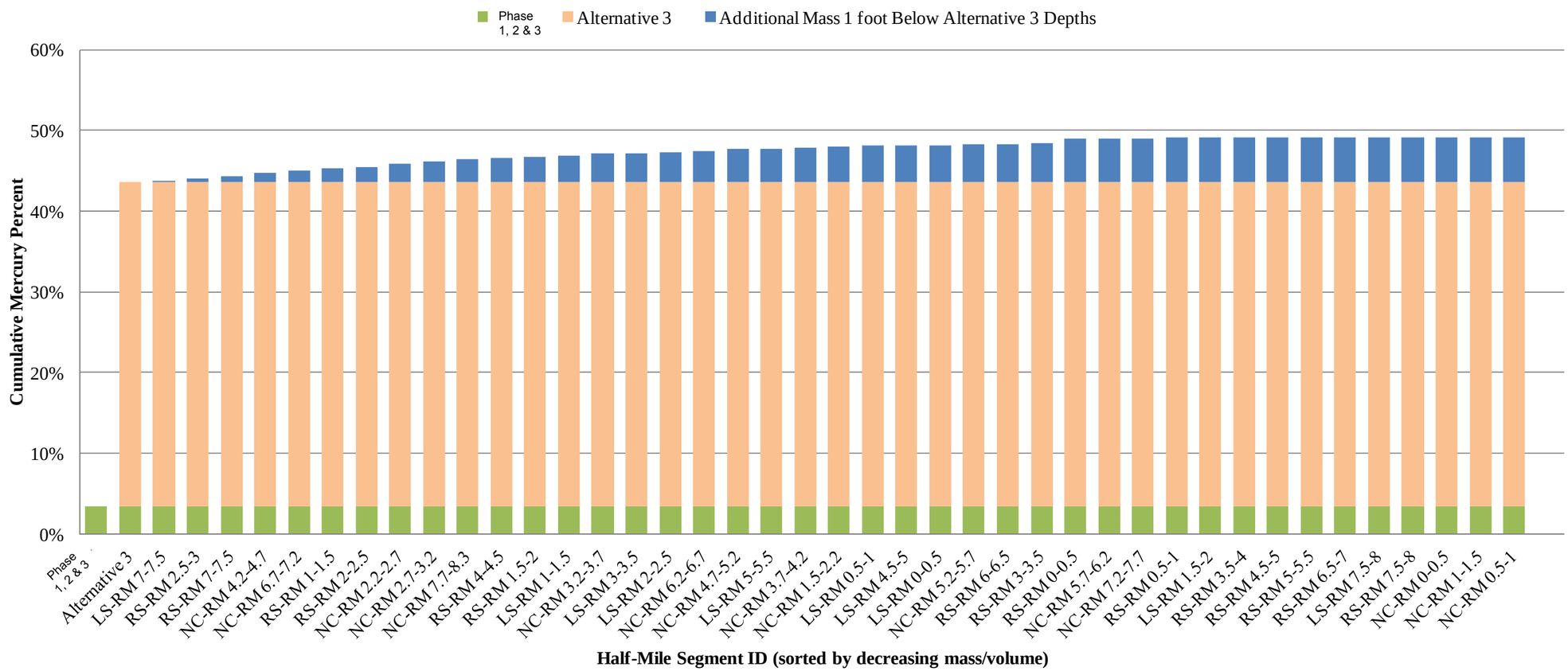
	Percent Increase in Total PCB Mass 1-foot below Alternative 3 Depth (Sorted by Decreasing Mass) *Lower Eight Miles of the Lower Passaic River*	Figure 3-7a 2014



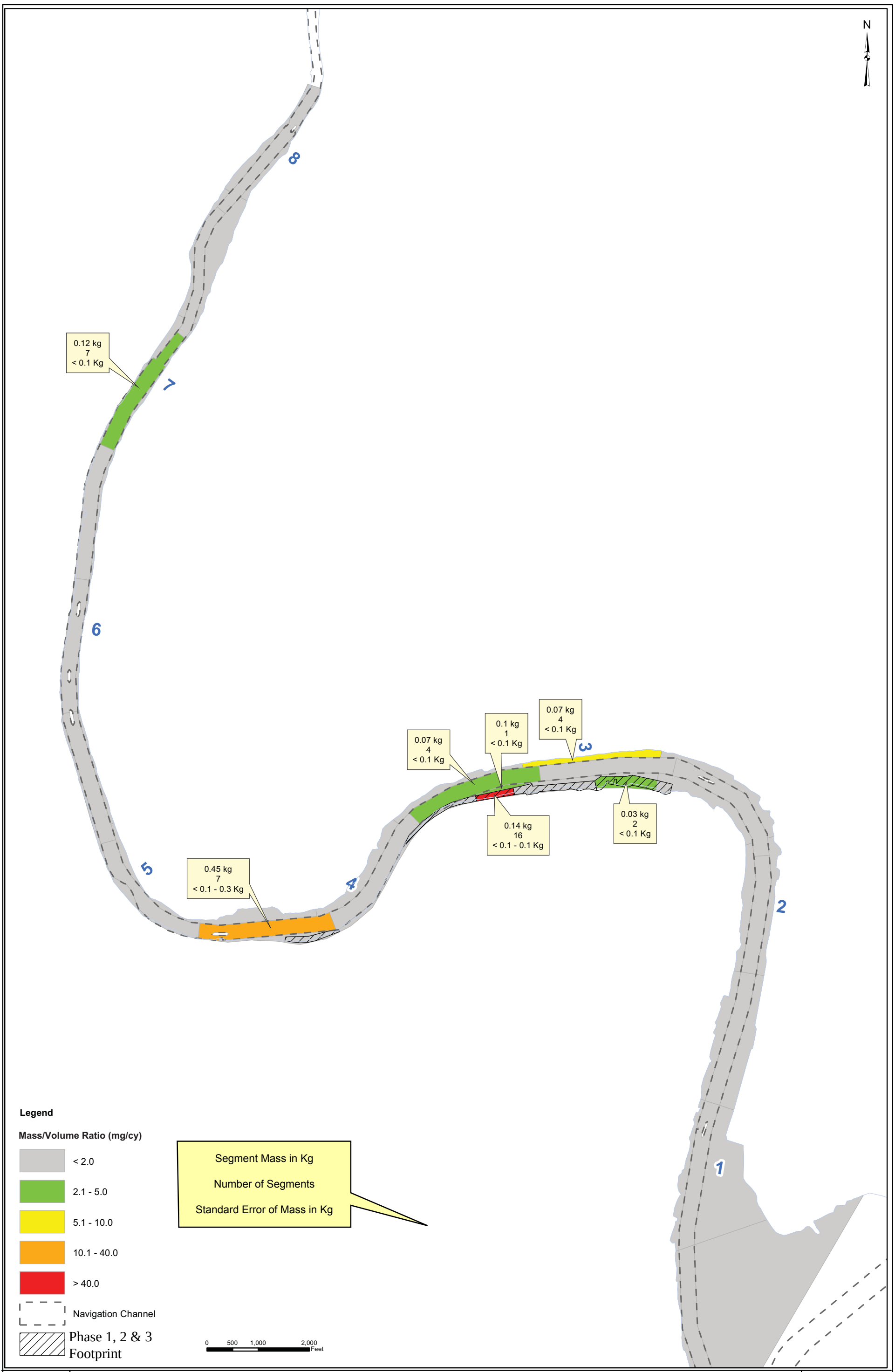
	Percent Increase in Total PCB Mass 1-foot below Alternative 3 Depth (Sorted by Decreasing Mass to Volume Ratio) *Lower Eight Miles of the Lower Passaic River*	Figure 3-7b 2014



	Percent Increase in Mercury Mass 1-foot below Alternative 3 Depth (Sorted by Decreasing Mass) *Lower Eight Miles of the Lower Passaic River*	Figure 3-8a 2014



	Percent Increase in Mercury Mass 1-foot below Alternative 3 Depth (Sorted by Decreasing Mass to Volume Ratio) *Lower Eight Miles of the Lower Passaic River*	Figure 3-8b 2014



Mass Removal Estimate for 2,3,7,8-TCDD - Half-Mile Segments, Horizon 2.5 - 3.5 ft

Lower Eight Miles of the Lower Passaic River

Figure 3-9

2014

R2-0027414

ATTACHMENTS

Attachment A

Depth of Contamination

R2-0027416

1 EVALUATION OF DEPTH OF CONTAMINATION FOR HISTORICAL SEDIMENT CORES

The historical coring programs did not advance their cores to refusal (or to the red sand/clay layer). An understanding of the depth of contamination (DoC) for these historical cores is necessary to help delineation of dredging depths for FFS Alternative 2. The approach to managing this data gap is described in this section.

1.1 Vertical Contaminant Classification

The DoC of sediments at each coring location was determined by comparing the contaminant concentration in the bottom core segment relative to an analyte-specific threshold that represents the contaminant concentrations in uncontaminated sediment, or background concentrations (refer to Table A-1 for a summary of analyte-specific thresholds). Based on this comparison, each sediment core was classified into one of three Vertical Contaminant Classification categories, as described below. Note that since the four contaminants were examined independently, a given core location may be classified differently for each contaminant because of differences in depositional history, proximity to major sources, and sensitivity in analytical procedures.

1. *Core with bottom concentration below reporting limit.*
   This category represents a core where the concentration in the bottom is less than or equal to the analyte-specific threshold. In other words, the coring device penetrated deep enough into the sediment bed to capture the thickness of contaminated sediment and the bottom of the core reached uncontaminated sediment. The DoC in this instance equals the bottom of the first core segment (viewing from the bottom-up) where the concentration exceeds the analyte-specific threshold.
2. *Contaminant concentration decreasing at depth.*

R2-0027417

This category represents a core where the contaminant concentration in the bottom segment is greater than the analyte-specific threshold, but less than 50 percent of the maximum concentration in the core[1]. This condition indicates that although during core collection the coring device did not penetrate into uncontaminated sediment, most, although not all, of the contaminant inventory at the sampling location has been captured by the core. The actual DoC is not expected to extend much beyond the core bottom; however, a precise DoC is unknown. Therefore, the core is considered incomplete. Subsequent analyses were performed to extrapolate the DoC for use in the contaminant inventory, as described in below.

3. *Contaminant concentration increasing at depth.*

   This category represents a core where the contaminant concentration in the bottom segment is greater than 50 percent of the maximum concentration in the core. Note that in many of these cores the maximum concentration was located in the bottom-most segment. Therefore, the DoC is poorly known since concentrations may continue to increase with depth before ultimately declining. This category possesses the most uncertainty regarding the DoC. Similar to the category "Contaminant concentration decreasing at depth", subsequent analyses were performed to extrapolate the DoC for use in the contaminant inventory, as described below.

1.2 Analyte-Specific Threshold

The key parameter used in this analysis, the analyte-specific threshold, was intended to represent the contaminant concentrations in uncontaminated sediment, or background concentrations. However, it is difficult to establish background concentrations with

[1] The division on "incomplete" cores into two categories is based on comparing the bottom-segment concentration to the maximum concentration in the core. Since duplicate precision is approximately 30 percent, then concentration changes less than 50 percent were not considered significant for core classification.

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confidence because the analysis of samples with such low concentrations generates variable results. For example, background concentrations determined detectable by one analytical method or laboratory could be determined nondetectable by another method or laboratory. To manage this issue, the analyte-specific threshold for each contaminant was defined by evaluating both background levels and detection limits. Histograms were generated showing the distribution of detected concentrations and nondetected values and a threshold concentration was selected that included most detected concentrations and excluded most nondetected values.

1.3 Extrapolated DoC

Because the majority of the cores had bottom segments that were greater than the analyte-specific threshold and the actual DoC for most cores is unknown, a large degree of uncertainty is associated with the results of the contaminant inventory. To fill this data gap, the sediment inventories were extrapolated, as summarized below.

- *Cores with "contaminant concentrations decreasing at depth"*
  Sediment inventory results were increased by 25 percent. This value was selected based on the assumption that the peak contaminant concentration occurred at the mid-point of the core profile, followed by a steady reduction in contaminant concentration with depth. The actual DoC is not expected to extend much beyond the sampling length of the core.
- *Cores with "contaminant concentrations elevated or increasing at depth"*
  This category represents cores with the most uncertainty with regards to depth of contaminant concentration. Sediment inventory results for these cores were doubled based on trends found in the profiles of cores that did capture the entire DoC. In cores categorized as "Contaminant with bottom concentration below reporting limit," approximately 65% of the contaminant inventory was found in the portion of the core between the top of the core and the depth of the peak concentration. Applying this information to cores with concentrations increasing at depth and assuming the bottom segment represents the peak concentration, then

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65% of the inventory would be represented by the core. To account for the contaminated sediments not captured by the core, the inventory would be multiplied by at least a factor of 1.5. With no indication of whether the peak has been captured by the core, a factor of 2 was applied to adjust for likelihood that the peak had not been captured for cores with "contaminant concentrations elevated or increasing at depth." The selection of the factor of 2 is further supported by the DoC values observed in cores collected by EPA in 1991. These cores included several deep cores indicating DoC values of 15 feet or more, with several deep cores where the actual DoC was not captured by the core. By applying a factor of 2 to the cores with "contaminant concentrations elevated or increasing at depth," estimated depths of contamination are similar to the DoC values for the 1991 cores.

1.4 Summary of DoC Estimates

A review of the historical sediment core data revealed that for each contaminant except for Total PCB, most cores did not penetrate deeply enough into the sediment bed to capture the thickness of contaminated sediment and establish the actual DoC. Table A-2 presents a summary of core classifications for each of the four contaminants examined. Except for Total PCB, a fraction of the historical cores penetrated to a depth where contaminant concentrations were considered equal to, or close to, background levels (Core Classification: "Bottom concentration below reporting limit"). In contrast, over 60 percent of historical cores examined for Total PCB established the actual DoC.

The "contaminant concentration decreasing at depth" category and the "contaminant concentration elevated or increasing at depth" category represent incomplete cores, meaning the DoC was not established by the core. Combining these two categories for each contaminant, 39 to 79 percent of the historical sediment cores included in this analysis *did not* penetrate to a layer of uncontaminated sediment.

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2 DEPTH OF CONTAMINATION DETERMINATION FOR ALTERNATIVE 2

This section summarizes the methodology used to determine the DoC for Alternative 2 Deep Dredging with Backfill, which is being evaluated in the FFS report. Alternative 2 would involve the removal of fine-grained sediment from the horizontal limits of the federally authorized navigation channel as well as from the adjacent shoal areas. The DoC was estimated for volume and mass estimation purposes.

2.1 DoC in Shoal Areas

The depth of sediment to be removed from the shoals was determined using sediment cores collected during the CPG2008 and historical sampling programs and geotechnical cores collected in 2005.

Geotechnical and CPG 2008 cores provided data on the depth of fine-grained sediment, which is associated with the presence of organic contamination in the sediments; and mercury and TCDD were used as indicators for identifying the maximum DoC in the sediment. TCDD was used because it is a primary contaminant of concern for the Lower Passaic River. Mercury was selected as a surrogate to identify DoC because mercury contamination occurs deeper in the sediment bed relative to 2,3,7,8-tetrachlorodibenzodioxin (2,3,7,8-TCDD) and polychlorinated biphenyls (PCBs) (see Section 1).

Each dataset (i.e. 2005 Geotechnical, CPG 2008 Grain Size, CPG 2008 Chemical, and historical cores) was evaluated separately. To determine the DoC the river was subdivided into several sections. To characterize the DoC and sediment removal volume in these sections, locations of the cores were plotted and then assigned to respective sections of the river. The average depths of contamination indicated by the different datasets were compared and professional judgment was used to select the DoC for the

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associated transect. For example, if multiple cores indicated a significant variability in the DoC, the depth of fine grained sediment was used as an indicator of DoC.

To account for dredging inaccuracies (i.e., overdredge allowance); six inches were added for estimated depths of fifteen feet or less and one foot was added for depths greater than fifteen feet. Table A-5 presents the final depths in shoal areas used for Alternative 2.

2.2 DoC in Navigation Channel

Within the horizontal limits of the federally authorized navigation channel, the depth of fine-grained sediment has been shown to correspond well with the depth of historical dredging. For this reason, the depth of dredging within the horizontal limits of the navigation channel was assumed to be the historically constructed channel depth plus an additional three feet to account for historical overdredging (two feet) and dredging accuracy (one foot). The resulting sediment removal depth would be 33 feet MLW for RM0.0 to RM2.5, 23 feet MLW for RM2.5 to RM4.6, 19 feet MLW for RM4.6 to RM7.1, 19 feet MLW for RM7.1 to RM8.1, and 13 feet MLW for RM8.1 to RM8.3.[2] Following removal of the sediment from within the horizontal limits of the federally authorized navigation channel to the depth specified above, it is assumed that minimal fine-grained sediment would remain in the channel. This is supported by CPG2008 core data, which show the presence of red/brown clay at these depths.

[2] River Miles (RM) are based on the United States Army Corps of Engineers (USACE) river mile system, which follows the centerline of the federally authorized navigation channel.

Table A-1: Summary of Analyte-Specific Threshold for Core Classification

Analyte	Approximate Background (µg/kg)	Selected Threshold (µg/kg)	Percent Nondetected Values Below Threshold [a]	Percent Detected Values Below Threshold [a]
Total 4,4'-DDx	0 [d]	10	95 percent	2.5 percent
2,3,7,8-TCDD	0 [c]	0.002	95 percent	2.0 percent
Mercury	200 [b]	200	75 percent	5.0 percent
Total PCB	0 [d]	125	95 percent	2.5 percent

Notes:

a: Based on histograms.

b: Background mercury concentration from Bopp *et al.* , 2006.

c: Historical analytical methods were not intended to detect background levels of 2,3,7,8-TCDD.

d: Both Total PCB and Total 4,4'-DDx are man-made compounds and do not occur naturally in the environment. Zero assumed as background concentration.

Table A-2: Core Categories for Estimation of Sediment Inventories

Core Category	Total 4,4'-DDx Count [a] (percent)	2,3,7,8-TCDD Count [a] (percent)	Mercury Count [a] (percent)	Total PCB Count [a] (percent)
Bottom Concentration below reporting limit	41 (34 percent)	23 (21 percent)	32 (28 percent)	70 (61 percent)
Concentration decreasing at depth	36 (30 percent)	59 (54 percent)	28 (24 percent)	14 (12 percent)
Concentration elevated or increasing at depth	43 (36 percent)	27 (25 percent)	56 (48 percent)	30 (26 percent)
Total	120 (100 percent)	109 (100 percent)	116 (100 percent)	114 (100 percent)

Notes:

a: Core count based on 1991 and 1995 data.

Table A-3: Dredging Depth in Shoal Areas for Alternative 2

Transect	River Mile	Dredging Depth in Shoal Areas (feet)
Kearny Mudflats	-	3.5
A	0	19.5
B	0.6	17
C	0.9	15
D	1.4	19
E	1.7	14
F	2.5	7
G	2.9	10
H	3.5	14.5
I	3.8	6.5
J	4.3	18
K	4.7	8
L	5.3	12.5
M	5.8	12.5
N	6.4	6
O	6.7	6
P	7	4
Q	7.1	13.5
R	8.1	2.5
S	8.3	2.5

Data Evaluation Report No. 6:

"Biota Analysis"

Prepared by:
The Louis Berger Group, Inc.

In conjunction with:
Battelle

LOWER EIGHT MILES OF THE LOWER PASSAIC RIVER
DATA EVALUATION REPORT NO. 6: BIOTA ANALYSIS

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Figure 3-36a American Eel Total DDx Lipid Normalized Concentration in Tissue *vs.* Total DDx TOC Normalized Concentration in Sediment
Figure 3-36b Blue Crab Total DDx Lipid Normalized Concentration in Tissue *vs.* Total DDx TOC Normalized Concentration in Sediment
Figure 3-36c Mummichog Total DDx Lipid Normalized Concentration in Tissue *vs.* Total DDx TOC Normalized Concentration in Sediment
Figure 3-36d White Perch Total DDx Lipid Normalized Concentration in Tissue *vs.* Total DDx TOC Normalized Concentration in Sediment
Figure 3-37a American Eel Low Molecular Weight PAH Lipid Normalized Concentration in Tissue *vs.* Low Molecular Weight PAH TOC Normalized Concentration in Sediment

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Figure 3-37b Blue Crab Low Molecular Weight PAH Lipid Normalized Concentration in Tissue *vs.* Low Molecular Weight PAH TOC Normalized Concentration in Sediment

Figure 3-37c Mummichog Low Molecular Weight PAH Lipid Normalized Concentration in Tissue *vs.* Low Molecular Weight PAH TOC Normalized Concentration in Sediment

Figure 3-37d White Perch Low Molecular Weight PAH Lipid Normalized Concentration in Tissue *vs.* Low Molecular Weight PAH TOC Normalized Concentration in Sediment

Figure 3-38a American Eel High Molecular Weight PAH Lipid Normalized Concentration in Tissue *vs.* High Molecular Weight PAH TOC Normalized Concentration in Sediment

Figure 3-38b Blue Crab High Molecular Weight PAH Lipid Normalized Concentration in Tissue *vs.* High Molecular Weight PAH TOC Normalized Concentration in Sediment

Figure 3-38c Mummichog High Molecular Weight PAH Lipid Normalized Concentration in Tissue *vs.* High Molecular Weight PAH TOC Normalized Concentration in Sediment

Figure 3-38d White Perch High Molecular Weight PAH Lipid Normalized Concentration in Tissue *vs.* High Molecular Weight PAH TOC Normalized Concentration in Sediment

Figure 3-39a American Eel Total PAH Lipid Normalized Concentration in Tissue *vs.* Total PAH TOC Normalized Concentration in Sediment

Figure 3-39b Blue Crab Total PAH Lipid Normalized Concentration in Tissue *vs.* Total PAH TOC Normalized Concentration in Sediment

Figure 3-39c Mummichog Total PAH Lipid Normalized Concentration in Tissue *vs.* Total PAH TOC Normalized Concentration in Sediment

Figure 3-39d White Perch Total PAH Lipid Normalized Concentration in Tissue *vs.* Total PAH TOC Normalized Concentration in Sediment

Figure 3-40a American Eel Copper Concentration in Tissue *vs.* Copper Iron Normalized Concentration in Sediment

Figure 3-40b Blue Crab Copper Concentration in Tissue *vs.* Copper Iron Normalized Concentration in Sediment
Figure 3-40c Mummichog Copper Concentration in Tissue *vs.* Copper Iron Normalized Concentration in Sediment
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Figure 3-41a American Eel Lead Concentration in Tissue *vs.* Lead Iron Normalized Concentration in Sediment
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Figure 3-42a American Eel Mercury Concentration in Tissue *vs.* Mercury Iron Normalized Concentration in Sediment
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Figure 3-42c Mummichog Mercury Concentration in Tissue *vs.* Mercury Iron Normalized Concentration in Sediment
Figure 3-42d White Perch Mercury Concentration in Tissue *vs.* Mercury Iron Normalized Concentration in Sediment

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1 INTRODUCTION

This document is part of a series of data evaluation reports that were prepared to support the Remedial Investigation (RI) and Focused Feasibility Study (FFS). Reports in this series describe different aspects of the Lower Passaic River. Where necessary, data evaluation reports are cross-referenced to direct the reader to other reports that contain further explanation. Topics discussed in this series include major sediment and water investigations conducted in the river, boundary conditions for the river, historical sediment contamination, surface sediment contamination, contaminant inventory calculations, and biological accumulation of sediment-borne contamination. The following data evaluation report examines the last of the topics in the series, the biological accumulation of sediment-borne contamination. Specifically, this report describes the life histories of four aquatic species, the contaminant concentrations present in the tissues of these species, and the relationships between tissue concentrations and sediment concentrations of eleven contaminants of concern. The relationships developed in this report are needed in the calculation of preliminary remedial goals for the sediments of the Lower Passaic River.

1.1 Overview of the FFS Study Area

The FFS Study Area is located within the Lower Passaic River Study Area (LPRSA), which is the 17-mile, tidal portion of the Passaic River from Dundee Dam [located at River Mile (RM[1]) 17.4] to the confluence with Newark Bay at RM0 and the watershed of this river portion, including the Saddle River (RM15.6), Third River (RM11.3) and Second River (RM8.1) [Figure 1-1]. During a comprehensive study of the Lower Passaic

[1] The FFS uses the "River Mile" (RM) system developed by the United States Army Corps of Engineers (USACE), which follows the navigation channel of the Lower Passaic River. The Data Evaluation Reports (Appendix A), Empirical Mass Balance (Appendix C) and Lower Passaic River-Newark Bay model (Appendix B) were initially developed at the beginning of the 17-mile Remedial Investigation and Feasibility Study (RI/FS), and thus follow a RM system developed for that RI/FS, which follows the geographic centerline of the river. RM0 is defined by an imaginary line between two marker lighthouses at the confluence of the Lower Passaic River and Newark Bay: one in Essex County just offshore of Newark and the other in Hudson County just offshore of Kearny Point. River miles then continue upriver to the Dundee Dam (RM17.4). The two RM systems are about 0.2 miles apart.

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River, the sediments of the lower eight miles were found to be a major source of contamination to the rest of the river and Newark Bay. Therefore, the United States Environmental Protection Agency (USEPA) completed the FFS to evaluate alternatives to address those sediments in the lower eight-mile stretch from RM0 to RM8.3, near the border between the City of Newark and Belleville Township. The entire 17-mile Lower Passaic River is the subject of another Remedial Investigation/Feasibility Study (RI/FS) being implemented by the Cooperating Parties Group (CPG; a group of approximately 70 potentially responsible parties who signed an agreement with USEPA in 2007), under USEPA oversight. The Upper Passaic River watershed (the portion of the Passaic River located above the Dundee Dam) contributes solids, water, and contaminants that cross over the head-of-tide, which is represented by the Dundee Dam[2], into the Lower Passaic River.

1.2 Overview of the Analysis of Biota Tissue Contamination

This report examines the correlation of contaminant concentrations in tissue samples for four representative aquatic species (blue crab, mummichog [a small minnow-like fish], white perch, and American eel) with the surface sediment concentrations in the Lower Passaic River. The selection of these species for this analysis was based on the availability of data for them over a wide range of the river (typically RM0 to RM15) and over several periods of study (typically 1999, 2000, 2009 and 2010). These species also form the main basis for estimating exposure point concentrations (EPCs) in biota in the human health and ecological risk assessments for the FFS. The contaminants examined in this report represent the contaminants of potential concern (COPCs) and contaminants of potential ecological concern (COPECs) for the site, including 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD), Total polychlorinated biphenyls (PCBs), pesticides (including the sum of Dichlorodiphenyltrichloroethane (DDT) and its metabolites, referred to here as “Total DDx”, Total Chlordane and Dieldrin), polycyclic aromatic hydrocarbons

[2] The Dundee Dam represents a hydraulic boundary. The head-of-tide actual location is downstream of the dam because even though the tides can influence the water level near the dam, the upper-most extent of saltwater (i.e., the salt front) typically stops several miles below the Dundee Dam (refer to Lower Passaic River System Understanding of Sediment Transport [HQI and Sea Engineering Inc, 2011] for further details on the salt front migration).

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(PAHs) (including Low Molecular Weight (LMW) PAHs, High Molecular Weight (HMW) PAHs and Total PAHs), and metals (copper, lead, and mercury).

Biota and sediment data used in this analysis were taken from the project database (available through the www.ourPassaic.org website),the Contaminant Assessment and Reduction Program (CARP) database (available through http://www.carpweb.org/main.html), the USEPA biota-sediment accumulation factor (BSAF) database (available through http://www.epa.gov/med/Prods_Pubs/bsaf.htm) and the Regional Environmental Monitoring and Assessment Program (REMAP, available through http://www.epa.gov/emap/remap/html/data.html). New York/New Jersey (NY/NJ) Harbor sediment data from USEPA's Regional Environmental Monitoring and Assessment Program (REMAP) database was used to provide additional sediment contaminant concentrations, typically at lower concentrations relative to the Lower Passaic River. Biota tissue data available from the CARP database were used to represent contaminant tissue concentrations corresponding to the REMAP sediment sampling locations throughout the harbor.

The analysis of spatial and temporal trends of tissue concentrations for the four species was limited to RM0 to RM8.3 (the FFS Study Area). However, the analysis to study the relationship in contaminant concentrations between the sediment and tissue concentrations considered Lower Passaic River data between RM0 and RM15.

This analysis focuses on the following areas:

- Evaluating the temporal and spatial distribution of contaminant concentrations in fish tissue with respect to river mile - to identify environmental factors important to understanding variations in contaminant concentrations in fish and crab tissue.
- Establishing a basis to estimate mean sediment exposure concentrations corresponding to biota tissue samples obtained from the Lower Passaic River and the NY/NJ Harbor area - to support the subsequent analyses (biota and sediment samples were generally not collected as matched pairs)

- Examining the relationship between contaminant concentrations in sediment and tissue over a broad range of environmentally relevant concentrations (including conditions anticipated following implementation of remedial options) - to establish a robust basis on which to develop Preliminary Remediation Goals (PRGs).
- Determining a quantitative basis to estimate COPC concentrations in fish tissue based on sediment concentrations. This took the form of regression models as well as BSAF and bioaccumulation factor (BAF) terms for the contaminants of concern for the Lower Passaic River. The regression and BSAF/BAF models provide a quantitative basis to relate acceptable contaminant concentrations in fish and crab tissue based on human or ecological risk assessments to associated sediment PRGs.

A brief overview of the derivation of the formulas used in this report is given below. The formulas are described further in Section 3. For organic contaminants, per USEPA guidance (Burkhard, 2009), the concentration of a contaminant in organism tissue can be described as a function of the amount of lipid in the fish, the concentration of the contaminant in the sediment and other factors that correlate with the bioavailability of the contaminant in the sediment, typically, the total organic carbon (TOC). Based on the observations of Burkhard *et al.*, 2013, Cretney and Yunker 2000 and Hellou *et al.* 1995 for organic contaminants this can be expressed as:

$$C_O = \frac{\alpha_o * {C_s}^{\beta_1} * {f_l}^{\beta_2}}{{f_{oc}}^{\beta_3}} \qquad \text{Eq. 1-1}$$

where C_0 is the chemical concentration in the organism (micrograms per kilogram [µg/kg] wet weight), f_l is the lipid fraction of the organism (g lipid/g wet weight), C_s is the chemical concentration in surficial sediment (µg/kg dry weight) and f_{oc} is the fraction of organic carbon in the sediments (g TOC/g dry weight). The α_0 term is a constant and the β terms represent exponents on the various factors. In this report, individual fish samples were correlated with area-wide mean sediment concentrations,

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since sediment and fish collection efforts were largely separate.[3] Since each sediment concentration has its own TOC measurement, the individual fish samples were correlated with the mean TOC-normalized sediment concentration using a single coefficient for this concentration as follows:

$$C_O = \alpha_o * \left(\frac{C_s}{f_{oc}}\right)^{\beta_1} * f_l^{\beta_2} \qquad \text{Eq. 1-2}$$

When C_0 is linearly related to these factors, the β's converge to unity and α_0 becomes the BSAF:

$$C_O = BSAF * f_l * \frac{C_s}{f_{oc}} \qquad \text{Eq. 1-3}$$

Equation 1.3 can be easily factored to yield Equation 1.4 wherein the BSAF is a constant defined for organic contaminants (Ankley *et al.*, 1992) as:

$$BSAF = \frac{C_0/f_l}{C_s/f_{oc}} \qquad \text{Eq. 1-4}$$

For conditions where the β's are not unity, Equation 1-2 can be expressed in log form as:

$$Ln(C_O) = Ln(\alpha_o) + \beta_1 Ln\left(\frac{C_s}{f_{oc}}\right) + \beta_2 Ln(f_l) \qquad \text{Eq. 1-5}$$

Recognizing that $Ln(\alpha_o)$ is simply another constant, this equation becomes:

$$Ln(C_O) = \beta_0 + \beta_1 Ln\left(\frac{C_s}{f_{oc}}\right) + \beta_2 Ln(f_l) \qquad \text{Eq. 1-6}$$

Equation 1-6 is a formulation whose coefficients can be determined by regressing on the logs of the tissue concentration, the lipid fraction and the TOC-normalized sediment concentration. This formulation and its application across species types are further discussed in Section 3. Depending on the behavior of the data for organic contaminants, the relationships between sediment and tissue were determined using the relationship given by Equation 1-3 or Equation 1-6.

[3] Unlike the other data sets, the 1999 and 2000 mummichog sampling efforts did provide matched sediment samples. In these instances, fish tissue samples were matched to their corresponding sediment samples.

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For inorganic contaminants, a similar formula basis was developed using a BAF, normally defined as (Nordberg *et al.*, 2009):

$$BAF = \frac{C_0}{C_s} \qquad \text{Eq. 1-7}$$

where the terms are defined as above. However, inorganic contaminants are closely associated with the fine-grained, iron and aluminum–bearing fraction of the sediments, much as organic contaminants are associated with the TOC (see for example, Langston 1982, Summers *et al.* 1996, Schiff and Weisberg, 1999). As a result, normalizing to iron typically reduces the impact of variation in sediment grain size on sample concentration. However, unlike organic contaminants, inorganic contaminants are not closely associated with the lipid fraction of the organism. Integrating these concerns, a formula similar to Equation 1-2 was developed for inorganic contaminants, excluding the lipid term:

$$C_O = \alpha_o * \left(\frac{C_s}{f_{Fe}}\right)^{\beta_1} \qquad \text{Eq. 1-8}$$

where f_{Fe} is the mass fraction of iron in the sediment (g iron/g dry weight) and the other terms are defined as above. Again, when C_0 is linearly related to the sediment concentration, β_1 converges to unity and α_0 becomes the iron-normalized BAF:

$$C_O = BAF * \frac{C_s}{f_{Fe}} \qquad \text{Eq. 1-9}$$

where the BAF is defined as a constant relating the tissue and iron-normalized sediment concentrations:

$$BAF = \frac{C_0}{C_s/f_{Fe}} \qquad \text{Eq. 1-10}$$

Like Equation 1-2, Equation 1-8 can be transformed to:

$$Ln(C_O) = \beta_0 + \beta_1 Ln\left(\frac{C_s}{f_{Fe}}\right) \qquad \text{Eq. 1-11}$$

This equation is similar in form to Equation 1-6, and like Equation 1-6, can be the basis of a regression on the logs of the fish tissue concentrations and the iron-normalized sediment concentration. For inorganics, the relationship between tissue and sediment were described by either Equation 1-9 or 1-11, again depending on the behavior of the data available. Additional discussion on these formulations is provided later in this report.

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This report is comprised of the following sections in addition to the introduction:

- *Section 2, An Examination of Species Life History and the Spatial Distribution of Contaminant Tissue Concentrations*: presents contaminant concentrations in blue crab, mummichog, white perch and American eel *vs.* river mile along with a summary of life history information relevant for understanding broad differences in exposures among the four aquatic species.
- *Section 3, Relating Sediment and Tissue Contaminant Concentrations*: provides the methodology and supporting analyses for developing the regression relationships between sediment and tissue concentrations, as well as BSAF and BAF results.
- *Section 4, Summary*: summarizes the findings of the tissue concentrations vs. river mile, and the regression, BSAF and BAF results developed for the FFS.
- *Section 5, Acronyms*: defines the acronyms used in this report.
- *Section 6, References*: lists the references used in this report.

2 AN EXAMINATION OF SPECIES LIFE HISTORY AND THE SPATIAL DISTRIBUTION OF CONTAMINANT TISSUE CONCENTRATIONS

The first objective of this analysis was to evaluate the spatial and temporal trends in contaminant tissue concentrations for the FFS Study Area. Plots of tissue contaminant concentration vs. river mile were created for each of the four species and eleven contaminants (or contaminant classes). Figures 2-1 through 2-4 represent the results for blue crab, mummichog, white perch and American eel, respectively. Each of these figures is comprised of parts a through k, corresponding to the eleven contaminants. The tissue concentration plots are used to review biota tissue data among the various studies (*i.e.*, temporal trends) and to identify differences across river mile (*i.e.*, spatial trends) as likely important components in explaining concentration variance.

Tissue data for the years 1995, 1999, 2000, 2001, 2009, and 2010 were used to assess the variation of the biota tissue contaminant concentrations with respect to river mile. However, as discussed in Section 3, the 1995 tissue data were not used for the sediment-tissue correlation. Additionally, there were a limited number of additional biota tissue observations in other data sets from 1991 to 1998. These data sets were deemed too small to incorporate in the analysis given differences in reported parameters, ambiguities in sample tissue types and the potential differences in the analytical methodologies used among data sets.

Overall, there are 26 aquatic species available in the project database considered in this analysis, but only eight of these species have more than 20 samples available (see Table 2-1). The four species evaluated in the FFS risk assessments and identified for detailed analysis in this report were selected based on the spatial and temporal availability of measurements, their importance to human consumption and their trophic level; the latter criterion was considered in order to represent the Lower Passaic River estuarine food web. A species' trophic position (*e.g.*, detritivore, benthivore, and piscivore) strongly

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influences the nature of environmental exposures encountered by organisms and ultimately the accumulation of bioavailable compounds in their tissues. In the end, the four species (*i.e.*, blue crab, mummichog, white perch, and American eel) with the greatest number of samples (ranging from 72 to 169 samples) were selected since they spanned a broad range of trophic levels while also having a large number of samples to support both spatial and temporal analyses. Three of the four species *(i.e.*, blue crab, white perch, and American eel) are also considered important for human consumption. The right side of Table 2-1 presents the sample tally for these four species based on their most abundant tissue type. This tally represents the maximum number of samples potentially available for the more quantitative analysis described in Section 3 of this report. The four species and their general life history attributes that are important to understanding broad differences in tissue concentration trends are described briefly below.

2.1 Representative Species Life Histories

2.1.1 Blue Crab

The blue crab (*Callinectes sapidus*) is an opportunistic epibenthic omnivore that forages for both dead and living prey items at the sediment/water interface. The life cycle consists of a series of larval, juvenile and adult stages (Hill *et al.*, 1989; Van Den Avyle *et al.*, 1984), and growth is limited to molting periods when the hard exoskeleton is shed. At various stages in the life cycle, blue crabs consume plankton, benthic macroinvertebrates, fish, plants, mollusks, crustaceans (including other blue crabs) and organic detritus. With the exception of the early life stages and overwintering adults, much of the crab life cycle is associated with estuarine habitat. After mating (primarily in low salinity waters in the upper portion of an estuary), female crabs migrate to high salinity waters to spawn in spring and early summer (Meise and Stehlik, 2003; Turner *et al.*, 2003). First stage larvae (called zoeae) are filter feeders in the water column associated with the spawning grounds. After undergoing a series of molts approximately 30 – 50 days in total duration, they transform into the more crablike second stage larvae (called megalops). The benthivorous megalops phase lasts between 1-3 weeks, with

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individuals still primarily found in higher salinity areas within the lower estuary (Hill *et al.*, 1989; Van Den Avyle *et al.*, 1984).

Juvenile crabs undergo a series of molts and gradually migrate into shallow, less-saline waters of upper estuaries and rivers where they grow and mature (Hill *et al.*, 1989; Van Den Avyle *et al.*, 1984). Sexual maturity is reached at 1 to 1.5 years of age in Chesapeake Bay (Williams, 1965; Van Engel 1958) and the maximum life span for blue crabs is about 3 years (Williams, 1965). Migratory behavior in blue crabs is related to life cycle phases (as discussed above) as well as season: most crabs move to deeper, warmer waters during winter and return to rivers, tidal creeks and salt marshes the following spring (Livingston, 1976; Subrahmanyam and Coultas, 1980).

In addition to attributes such as body size/life stage (Hines *et al*., 1987; Jensen, 2004; Harding and Mann, 2010) that can influence how they interact with their environment, blue crabs have been shown to adjust foraging behavior based on environmental factors such as habitat patchiness and prey abundance (Clark *et al.*, 1999a,b; Clark *et al.*, 2000; Eggleston *et al.*, 1992,1997; Etherington & Eggleston, 2003; Medici, 2004). In particular, several studies have demonstrated that crabs forage in a prey density-dependent fashion (*i.e.*, higher success rates in more dense prey patches), although agonistic[4] interactions among individual blue crabs is also positively correlated with prey patch density (Clark *et al.*, 1999a, b).

Adult crabs are good swimmers and capable of speeds on the order of 24 meters/hr (24 m/hr or 80 ft/hr). Hines *et al.* (1995) and Wrona (2004) used ultrasonic telemetry to quantify movement of adult crabs in the Duplin River estuary in Georgia. Wrona found that the short-term foraging range of reproductively mature females was much larger than males, averaging 1,052 m^2 (0.26 acres) over an 8-day period whereas males averaged 108 m^2 (0.027 acres). Mated females (in the process of emigrating to higher salinity spawning areas) were determined to move at speeds of 657 m/day (2,100 ft/day) whereas the non-

[4] Agonistic behavior is generally defined as combative behavior between members of the same species, typically competing for access to a resource, such as food or a mate.

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migratory males averaged only 82 m/day (270 ft/day) in non-directional movement (Wrona, 2004). Presumably, the movement patterns of non-mated females more closely approximate those of males; however, predation pressure, mate availability and physiological considerations were determined to influence the relative abundance (and movement patterns) of males and females in tidal creeks *vs.* river channels in the Rhodes River, a sub-estuary of the Chesapeake Bay (Shirley *et al.*, 1990). To summarize, the distribution and movements of blue crabs within the Lower Passaic River and the broader Lower Passaic River/Newark Bay estuary are relatively complex with an overall pattern dominated by life cycle and smaller scale patterns influenced by habitat quality (spatial heterogeneity and abundance of prey, predation risks and intra-specific competition), sex, and physiological condition. Adult crabs are capable of moving quickly in the environmental in response to these factors and it is likely that they account for a substantial amount of variability in the crab tissue contaminant concentration dataset.

2.1.2 Mummichog

The mummichog (*Fundulus heteroclitus*) is a small forage fish found along the Atlantic coast from the Gulf of St. Lawrence to northeastern Florida. Due to its ability to tolerate high variability in salinity and temperature as well as polluted waters, it is found in most estuarine habitat at relatively high densities and it is an important component of the estuarine food web. It consumes detritus and invertebrates in shallow estuarine habitats including tidewater channels, salt grass marshes and mudflats at low tide (Abraham, 1985; Kneib *et al.*, 1978; Steimle, 2001).

Mummichog reach sexual maturity during their second year and the typical lifespan is three years. In New Jersey (and northwards), mummichog spawn between June and August (Hardy, 1978a); it is a prolific breeder capable of spawning eight or more times a season (Abraham, 1985). In winter, mummichog may burrow 150-200 mm (6 to 8 in) into the mud or move to the mouth of the tidal channel near where they have been living; in the subsequent spring they usually return back up the same channel (Abraham, 1985; Fritz *et al.*, 1975; Smith and Able, 1994).

The mummichog is considered "one of the most stationary of fishes," according to Bigelow and Schroeder (1953) and the species does not migrate as part of their life cycle (Butner and Brattstrom, 1960; Green *et al.*, 2012). Local movement is generally influenced by food availability and potential tradeoffs between predation and growth (Halpin, 1997, 2000; Teo and Able, 2003). Lotrich (1975) found that adult mummichog (*i.e.*, fish over 60 mm (2.4 in) long) typically maintained a summer home range of 36-38 m (118-125 ft) along one bank of tidal creek in Delaware; although some individuals were reported to move as much as 375 m (1,200 ft). In a tag/recapture study conducted in southern New Jersey salt marshes, most (44%) young-of-year mummichog were recaptured within 0 to5 m (0-16 ft) of the release site, with the remainder captured up to 299 m (980 ft) away up to 166 days after tagging (Able *et al.*, 2006). In a study conducted in the upper Miramichi River estuary in New Brunswick, a total of 639 (15.5% of those marked) mummichog were recaptured, with 617 (96.6%) found within 200 m (660 ft) of the point of initial release. The remaining 22 recaptured fish moved distances ranging from 600 to 3600 m (1,970 to 11,800 ft) up- and downstream of initial capture and marking sites (Skinner *et al.*, 2005). Of the four species examined for the Lower Passaic River, the mummichog likely exhibits the highest site fidelity.

2.1.3 White Perch

The white perch (*Morone americana*) was selected to represent higher trophic-level fish. This species is considered semi-anadromous (*i.e.*, using tidal fresh water to spawn but residing primarily in mesohaline (*i.e.*, salt concentration between 5 and 18 parts per thousand [ppt]) river water rather than marine) and can tolerate a wide range of salinities. The white perch diet can be planktivorous, benthivorous or piscivorous depending on age, season, and food availability. In general, smaller fish feed on zooplankton (fry) and aquatic insects (juveniles), while larger fish feed on small fish, crabs, and shrimp (Stanley and Danie, 1983; St. Pierre and Davis, 1972; Weis, 2005; Shoji *et al.*, 2005). The species is widespread and abundant throughout its range (coastal areas of New Brunswick and Nova Scotia southward to South Carolina) and is commonly consumed by humans.

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White perch spawn in a wide variety of habitats including estuaries (at salinities up to 4.2 ppt according to Hardy [1978b]), rivers, lakes and marshes, and both resident and migratory populations may coexist in an area The spawning migration begins in spring with large schools of adults moving shoreward and upriver to shallow areas in tidal creeks and freshwater areas (Stanley and Danie, 1983; Holsapple and Foster, 1975). After spawning, migratory populations will generally seek deeper water. Juvenile fish use inshore portions of estuaries and creeks as nursery habitat, where they reside for up to a year following hatching. Most fish mature in 2 years (Hardy, 1978b).

Studies of site fidelity in white perch have been confounded by the presence of both resident and migratory populations occurring in the same estuary as well as habitat niche preferences by different cohort classes (McGrath, 2005; Kerr, 2008). Mansuetti (1957) tagged over 3,000 white perch in the Patuxent Estuary, Maryland and concluded that this population of white perch rarely moved outside the river system. White perch residing in the Bay of Quinte in Lake Ontario, Canada were found to make no long range movements and almost half of the recaptured fish were caught at the tagging site (Sheri and Power, 1968). White perch were also tagged in the Connecticut River, and one third of the recaptures were at the tagging site. However, the Connecticut River study did find that some animals moved further and occasionally out of the river system into Long Island Sound (Maltezos *et al.*, 1980).

White perch summer movements are generally local and random in nature and rarely exceed more than 19 km (12 mi) (Mansueti, 1957, 1961; Hardy, 1978b). They have been observed to make long, broad spring movements from the lower or mid-estuary to upstream tidal fresh water for spawning. During fall and winter, white perch usually move to deep water and do not migrate back until the spring (Mansueti, 1957). Similar to the blue crab, seasonality is expected to affect how well correlated are tissue and local sediment concentrations.

2.1.4 American Eel

The American eel (*Anguilla rostrata*) life cycle includes ocean, estuarine and riverine phases (Facey and Van Den Avyle, 1987). Anguillid eels are viewed as textbook catadromous species, spawning in the open sea, migrating to freshwater habitats to grow and returning to the ocean to complete their life cycle (Lamson *et al.*, 2006). This species is widespread and abundant throughout the northern part of its range (southern tip of Greenland south to Panama) and is commonly consumed by humans.

Adults breed in the southwest portion of the North Atlantic Ocean near the Sargasso Sea. The leptocephalus larvae are transported passively in ocean currents to the East Coast of North America. At or near the coast, the larvae metamorphose into transparent "glass" eels that are approximately 50-60 mm (2-2.4 in) long. In late winter and spring, glass eels migrate into waters with reduced salinity within the estuary and develop grayish-green pigmentation as they begin feeding; they are now referred to as "elvers". Moving up rivers and streams, American eels may spend many years in freshwater while foraging and growing. Sexually immature individuals in freshwater and estuaries are known as yellow-phase eels. Upon reaching sexual maturity, the pigment changes to silver, the percentage of body fat increases, and the size of the eye increases. As these morphological changes occur, the eels begin to migrate out of freshwater habitats and ultimately return to the mid-oceanic breeding area (Facey and Van Den Avyle, 1987).

The nocturnal feeding yellow eels consume a diverse diet of both live and dead prey including insects, worms, crayfish and other crustaceans, frogs and fishes (Waldt *et al.*, 2012; Facey and Van Den Avyle, 1987). In Lower Chesapeake Bay, American eel feeds primarily on polychaetes, crustraceans (particularly *Callinectes sapidu*s) and bivalves (including *Mya arenaria*) (Wenner & Musick, 1975); it is likely that Lower Passaic River eels have a similar diet.

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American eel exhibits only limited movement outside of the spawning migration. Strickland (2002) reported that the majority of eels did not disperse more than 500 m (1,600 ft), and Morrison and Secor (2002) reported that a majority (>70 percent) of eels in the estuarine portion of the Hudson River were recaptured within 1 km (0.6 mi) of the original tagging area. Estimates of the home range of eels extend to 3.4 hectares (ha) (8.4 acres) in small streams, tidal rivers and tidal creeks (Gunning and Shoop, 1962; Bianchini *et al.*, 1982; Bozeman *et al.*, 1985); from 2.4 to 65.4 ha (5.9 to 161 acres) in a large lake (LaBar and Facey, 1983); and <100 m (<330 ft) along a tidal creek during the summer in a Massachusetts salt marsh (Ford and Mercer, 1986). Compared to the mummichog, the American eel foraging behavior and diet likely contribute to a weaker relationship between tissue and local sediment concentrations; however, it is anticipated to exhibit higher site fidelity than either the blue crab or white perch.

2.1.5 Evaluation of Potential Seasonal Effects on Mean Contaminant Tissue Concentrations

As discussed in the descriptions of blue crab and white perch, these species exhibit significant dispersal behavior (related to time of year, age and physiological condition) that may affect the level of exposure to contaminants in the Lower Passaic River. For this reason, the contaminant concentrations in the tissue samples for these two species were further examined to determine whether this behavior could be contributing to the variability observed in the analytical tissue dataset. The contaminant tissue burdens in organisms that had only recently arrived at the Lower Passaic River would be more reflective of exposure conditions elsewhere and their elimination from the model datasets would likely increase the predictive power of the regression and BSAF/BAF models. Depending on the results of this evaluation, accounting for this behavior might produce better relationships between sediment and tissue concentrations. For blue crab, relatively few specimens were collected outside of the non-migratory time period (described below). For white perch, approximately 40 percent of the specimens were obtained outside the non-migratory period. In both cases, however, little difference in variability was observed between the entire set of specimens for each species and the subset of

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specimens whose tissue burdens were unambiguously associated with Lower Passaic River sediments.

This evaluation consisted of the following steps: (i) based on review of species life history characteristics and requirements, identify those months when adults are typically outside of the Lower Passaic River; (ii) extend the typical return period by a month[5] to account for variability in dispersal behavior among individuals and to allow organism tissues to equilibrate to the exposure conditions within the Lower Passaic River; and, (iii) statistically compare the contaminant tissue concentrations for the subset of samples captured within the time period established in (ii) to the entire data set. The analyses are described below.

Blue Crab: Blue crab exhibits both annual and reproductive migratory phases. It is likely that juveniles (male and female) and adult males overwinter in deeper water habitat in Newark Bay channels and then return to the Lower Passaic River sometime in late spring/summer. Because this migration should affect the level of exposure to Lower Passaic River sediment contamination, the Lower Passaic River blue crab samples were parsed into two groups depending on the likelihood that the individual specimens had only recently migrated to the place of capture within the Lower Passaic River.

In this analysis, the first group includes all the available blue crab samples for muscle+hepatopancreas[6] for the Lower Passaic River and the second group consists of samples collected from 2 June to 31 December only. As discussed above, the subset of samples was intended to include only those organisms that have been in the Lower Passaic River for sufficient time so that contaminant concentrations in tissue would be reflective of these surficial sediments whereas crabs caught outside this time period may

[5] Although trophic status, organism condition (e.g., lipid content) and contaminant hydrophobicity are important factors, 30 days is a reasonable estimate of the time period necessary for quasi-equilibrium conditions to develop between contaminant concentrations in surficial sediment and tissue media based on laboratory uptake and depuration studies. (Ankley *et al.*1992; Morgan and Lohmann, 2010)

[6] This tissue type represents the largest group of tissue samples for blue crab. Use of a single sample type in this analysis eliminates variation in contamination concentrations among tissue types from the calculations. The selection of tissue types for analysis is discussed in detail in Section 3.

have recently migrated to the Lower Passaic River. Excluding the 1995 data set[7], there were 53 blue crab samples collected in the Lower Passaic River from May to October. Out of these 53 samples, only four were collected outside the 2 June to 31 December period, yielding 49 samples to comprise this data subset.

The data distributions, means comparison and equality of variances statistical tests were examined for both groups of crab samples for each contaminant. The Tukey-Kramer honestly significant difference (HSD) test (a component of the analysis of variance [ANOVA])) was applied to identify population means that were significantly different from each other. Equality of variances was performed using Welch ANOVA test. The statistical tests were performed on both absolute and lipid-normalized tissue concentrations. Figure 2-5 shows the results of the statistical analyses for nearly all contaminants examined for blue crab in this report. Due to lack of sufficient data, Total Chlordane and Dieldrin could not be examined for blue crab. Each figure is divided into four panels. In each figure, the left panels show the results for absolute tissue concentrations and the right panels show the results for the lipid-normalized tissue concentration. The top panels show the result of the means comparison between the two groups of samples, while the bottom panels show the result of Welch ANOVA equal variances. It can be seen that the two groups of samples have similar concentration ranges and the mean concentrations are not statistically different for all examined contaminants. This is illustrated by the Tukey-Kramer circles shown at the right in the diagram of the top panel figure. Circles represent the geometric mean (center of the circle) and its uncertainty (circle radius) for each of the sample groups examined. Tukey-Kramer circles that do not touch or intersect only slightly are indicative of sample groups that are statistically different from each other.[8]

[7] The 1995 dataset was not included due to its small number of samples and to concern that differences in analytical methods between older and newer studies could contribute substantial uncertainties to the model estimates.

[8] The size of the circle reflects the uncertainty in the mean value, with larger circles reflecting larger uncertainty. Thus, small sample sizes or highly variable data sets have larger circles than those of large data sets or low variability data sets. Circles for means that are significantly different either do not intersect, or intersect slightly, so that the outside angle of intersection is less than 90 degrees. If the circles intersect by

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The bottom panel figure shows the differences between group means to the grand mean and to the median of the samples whose tissue burdens were not unequivocably associated with Lower Passaic River surficial sediments. The Prob>F, which represents the p-value, was presented at the bottom of the figure. Prob > F value of 0.05 or less are (identified with an asterisk) considered evidence of unequal means across the levels. From these figures, it was concluded that the variances between the two groups are not statistically different. In conclusion, the results showed that the parsed data set of Lower Passaic River blue crab and the original data were not statistically different. Given the similarity in variance between the two groups and the limited number of data from migratory periods, all available blue crab data were used in the regression analyses as well as in the BSAF and BAF calculations.

White Perch: As described above, the life history of white perch is fairly complicated and both migratory and local populations may coexist in an estuarine complex and foraging adults can disperse kilometers in search of food. Each year, fertile females migrate upriver to spawn and based on the Newark Bay Study Area (NBSA) finfish survey data, all adults have migrated through the NBSA by the end of April and adults begin their reverse winter migration in late Fall. Assuming a month equilibration period for Lower Passaic River sediment and fish tissue concentrations, it is likely the variability of contaminant concentrations in white perch caught from the Lower Passaic River between 1 June and 31 October will be low compared to other sampling periods. Similar to blue crab samples, white perch samples in the Lower Passaic River were collected from May to October. The tissue samples examined in the analysis were "fillet with skin on" and "whole body minus head and viscera", which were assessed to be similar in nature and together comprised the largest group of tissue samples for white perch.[9] Like the blue crab samples, the white perch samples were separated into two groups. The first group consists of all available white perch samples and the second group consists of white perch

an angle of more than 90 degrees, or if they are nested, the means are not considered significantly different at an alpha level of 0.05 (95 percent confidence level).

[9] Use of a single sample type in this analysis eliminates variation in contamination concentrations among tissue types from the calculations. The selection of tissue types for analysis is discussed in detail in Section 3.

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samples collected between 1 June and 31 October. There were 37 white perch samples collected between May and October, 11 of which were collected in May, yielding 26 white perch samples to comprise the second group representing non-migratory conditions. Tukey-Kramer HSD means comparison and Welch equality of variances statistical tests were performed for these two groups. Figure 2-6 shows the statistical tests results. The layout of the figures is similar to Figure 2-5 for blue crab. In this instance, the contaminants copper and lead could not be examined for white perch due to lack of sufficient data. The results of the statistical tests suggest that the mean tissue concentrations of the two groups are not statistically different. More importantly, the results show that except for Total PCBs and Dieldrin, the variances are not statistically different, meaning that the data do not demonstrate higher levels of variance in one period *vs.* the other. For Total PCBs and Dieldrin, the results indicate that there may be statistically significant differences in variance, but examination of the estimates of the standard deviations themselves indicates that the differences are not great (less than a factor of two). Given that the variances were not statistically different for the majority of the parameters examined for white perch, all the available white perch data were used in the regression analyses as well as in the BSAF and BAF calculations.

2.2 Concentration Trends in Biota Tissue

The specific tissue sample types[10] for each of the four aquatic species for the Lower Passaic River described in Section 2.1 varied among studies but were grouped together when appropriate. The available tissue types included the following:

[10] Different tissue have been collected in the different tissue sampling programs generally determined by species-specific tissue preparation steps related to human consumption. For finfish, humans generally consume only muscle (i.e., fillets) tissue but there are ethnographic differences in whether the fish is cooked with the skin on or not. In general, exposures to organic hydrophobic contaminants would be expected to be higher in the “skin-on” samples due to the presence of subdermal lipid deposits. The “whole body less head and viscera” tissue type is considered to be comparable to the skin-on fillet in terms of exposure. Generally, tissue burdens associated with the “whole body” tissue type are most representative of exposures by piscivorous wildlife species and in some sampling programs, “carcass” (i.e., the mass remaining after removal of fillet tissue) samples were analyzed so that the whole body tissue concentrations could be reconstructed.

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Available Tissue Types

Fin Fish	Blue Crab
whole body	whole body
skinless fillet	hepatopancreas
skin-on fillet	muscle+hepatopancreas
whole body less head and viscera	all edible tissue
carcass	carcass

The available contaminant tissue concentrations were plotted in Figures 2-1 to 2-4 with different symbols to represent the different tissue types. Each figure presents a diagram of the tissue concentrations as measured *vs.* river mile as well as a diagram of the lipid-normalized concentration *vs.* river mile. Also noted on the figures are the years corresponding to various sampling events used in creating the plot.

Eleven contaminants were examined in this report. The contaminants include 2,3,7,8-TCDD, Total PCBs, pesticides, PAHs, and metals, among others (see Table 2-2 for a complete listing). Tables 2-3 through 2-6 provide summary statistics of contaminant concentrations for each of the four species. These tables summarize all of the available data for each species, across all tissue sample types within the FFS Study Area. These tables summarize the data presented in Figures 2-1 to 2-4. The tables incorporate the samples used in the regression, BSAF and BAF analyses presented later in this report, as well as other sample types that were not used in the calculations.[11] In these tables, non-detect contaminant concentrations were included as one-half of the method detection limit.[12] In the following four subsections, the main observations regarding the spatial and

[11] The regression, BSAF and BAF analyses also use samples obtained outside the FFS Study Area to maximize the range of data used in the calculations. This is discussed further in Section 3.

[12] Non-detect results are treated in different ways throughout this DER depending upon the application. In this instance, non-detect results are included at one-half the detection limit to represent the full distribution of measurements when constructing the summary statistics for each contaminant-fish tissue pair. More sophisticated techniques to represent the possible distribution of non-detect results were not warranted here since these tables were constructed for descriptive purposes only. Other means of handling non-detect results are discussed as they occur elsewhere in this DER.

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temporal contaminant concentration trends in each of the four species are presented. Before discussing the individual results by species, a few overarching observations can be made as follows (termed "Summary Points" in the rest of this report):

1. The spatial distributions of contaminant tissue concentrations were similar in character to those observed for surface sediments. Specifically, tissue concentrations were highly variable on small spatial scales within the Lower Passaic River while trends in the mean concentrations with river mile were shallow, if not non-existent.[13] Local variation in tissue concentration is often an order of magnitude or more (*i.e.*, maximum/minimum = 10 or more) while mean concentrations varies by about a factor of two (*i.e.*, maximum/minimum = 2) and often less.
2. Various tissue types for a given species and contaminant often exhibit the following behaviors (*e.g.*, see Figure 2-1a):
    a. Great differences in absolute concentration between tissue types of the same species (*e.g.*, the 2,3,7,8-TCDD concentrations in hepatopancreas tissue for blue crab is roughly 15 to 20 times greater than those in muscle tissue)
    b. Similar amounts of local variation in contaminant concentration within a tissue type (*e.g.*, 2,3,7,8-TCDD concentrations in any blue crab tissue type varies about a factor of three at any given river mile)
    c. Parallel trends in mean contaminant concentrations with river mile (*e.g.*, 2,3,7,8-TCDD concentrations in blue crab across all four tissue sample types are either flat or increased about 50 percent from RM1 to RM8).
3. For most contaminants, mean tissue concentrations gradually increase upstream, although trends are very weak and only marginally significant. Lipid-normalized tissue concentrations show less local variation than the

[13] Trends with river mile were assessed qualitatively, using a weighted mean curve. The weighted mean function fits a curve to the data, using the locally weighted Least Squared error method. The result of this curve fit is to plot a best-fit smooth curve through the center of the data. This is an extremely robust fitting technique. Unlike the standard linear regression method, this technique is much less sensitive to outliers. In each case, the curves presented are intended to qualitatively capture the trend of contaminant tissue concentrations with river mile.

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absolute tissue concentrations but still confirm observations of little trend of the mean lipid-normalized tissue concentrations with river mile.

4. There are significant variations in the mean lipid content over time for three of the four species examined (see Figure 2-7). Specifically, blue crab, mummichog and white perch all show decreased lipid concentrations with time; the decrease in mean lipid concentration for the latter two species is statistically significant. This determination is based on a comparison among the 1999, 2000 and post-2005 samples for blue crab, mummichog and white perch, and a comparison between the 2000 and post-2005 samples for American eel. These lipid content variations help explain much of the study-to-study variation in contaminant tissue concentrations. This is an important observation since concentrations of several contaminants otherwise appear to decline in biota tissue with time, absent of lipid normalization. The cause of lipid content variation with time is not known but may represent variation in mean specimen size or age, seasonal or reproductive status, or represent true environmental variation.[14] Unfortunately, the project database is incomplete with regard to meristic data such as sample length and weight, (indicative of specimen age) and sex[15] was not typically recorded. As a result, it is difficult to determine why these differences in mean lipid content exist and further exploration of this observation was beyond the scope of this report.

5. Year-to-year variations in lipid-normalized contaminant tissue concentrations do not indicate consistent trends with time and are often inconsistent across species (*i.e.*, concentrations of one contaminant may increase in one species between studies while decreasing between studies in another species, or even

[14] Data for the four species examined here were collected by either Tierra Solutions, Inc. alone or by the CPG, which included Tierra Solutions. Inc. Although detailed information on the older lipid measurements is not available, it is expected that the lipid analyses among the programs are comparable since the same entity was involved in both studies (Tierra Solutions, Inc.). As a result, differences between sampling events should not be due to analytical differences.

[15] Evaluation of the lengths and weights of samples could determine whether earlier sampling events preferentially collected older specimens with higher lipid content. Pre-spawning females generally have higher lipid content then females during the rest of the year or males and another explanation to the trend in mean lipid content would be provided if earlier sampling events included a greater fraction of pre-spawning females.

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another tissue type). Overall, there is little support for consistently increasing or decreasing concentrations of any contaminant in biota tissue across all species with time. The lack of consistent temporal trends across species suggests other factors such as seasonal effects or analytical differences may be responsible for any apparent changes in average or median contaminant tissue concentrations over time for the period 1999 to 2010. As discussed in Section 2.1, seasonal effects are expected to be particularly important for understanding variability in blue crab and white perch tissue concentrations. More importantly, the lack of consistent temporal trends across the species and tissue types and the similar degree of variability and lack of trend with river mile, consistent with the sediment results, indicates that these variations in contaminant concentrations in biota tissue do not represent variations in the average level of exposure but are probably attributable to factors related to analytical differences among studies, variations in sample types (*e.g.*, variation in number, size, age or tissue type of specimens in a typical sample), seasonal variations in the time of collection, or other environmental factors not related to the average sediment exposure concentration.

2.2.1 Blue Crab

Summary statistics of contaminant concentrations for all available tissue samples for the blue crab are shown in Table 2-3. The mean tissue concentrations for the examined contaminants are as follows: 2,3,7,8-TCDD (90 picograms/gram [pg/g]); Total PCBs (1,268 µg/kg); Dieldrin (9.1 µg/kg); Total Chlordane (12 µg/kg); Total DDx (194 µg/kg), LMW PAHs (61 µg/kg); HMW PAHs (84 µg/kg); Total PAHs (144 µg/kg); copper (27 milligrams/kilogram [mg/kg]); lead (0.40 mg/kg); and mercury (0.11 mg/kg). Of the four species examined in detail, contaminant concentrations in blue crab tissue are comparable to those observed in whole body mummichog composites and substantively lower than those observed in white perch and American eel, based on mean and median values. The differences in organic contaminants and mercury are consistent with the trophic levels of the species. Specifically, blue crab and mummichog are lower trophic level species and thus have lower concentrations of the organic compounds and mercury. Overall, the

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observations of contaminant concentrations in blue crab are consistent with the five Summary Points listed in section 2.2.

Concentration plots of blue crab tissue contaminant concentration *vs.* river mile for the organic contaminants are shown on Figures 2-1a to 2-1h on both an absolute and on a lipid-normalized concentration basis. Concentrations for the inorganic contaminants (Figures 2-1i to 2-1k) are presented only on an absolute concentration basis, since their absorption is generally unrelated to lipid content. The lipid-normalized tissue concentrations are discussed further below.

As noted in Summary Point 2, the various tissue types for blue crab (*i.e.*, hepatopancreas, muscle, muscle+hepatopancreas, and carcass) yield roughly parallel trends in contaminant concentrations with river mile. For examples, the four tissue types all yield flat or gradually increasing concentrations with river mile for 2,3,7,8-TCDD, Total PCBs, Dieldrin, Total Chlordane, Total DDx, copper and lead. The one downward trend for Total DDx in muscle tissue is attributed to differences in the magnitude of reported values for 1999-2000 samples *vs.* the 2009 samples. Either data set by itself would suggest a flat trend with river mile. These trends are largely consistent with the observed trends of most surface sediment contaminants concentrations with river mile, which are typically flat or, in the case of 2,3,7,8-TCDD only, slightly increasing from RM0 to RM8. See for example, Figures 2.3-1, 2.3-3, 3.1-4, 3.1-6 for surface trends in 2,3,7,8-TCDD and Total PCBs in Data Evaluation Report No.4. These observations are consistent with Summary Points 1 and 3.

Flat to declining trends with river mile were observed for the PAH sums (LMW PAH, HMW PAH and Total PAH) and mercury in the four tissue types. Surface sediment concentrations of these contaminants do not exhibit downward trends but also tend to be flat with river mile. The reason for the slight downward trend with river mile in contaminant tissue concentrations is unknown but it can also be seen that these trends are minor variations compared to the variability in tissue concentrations for any tissue type at any given river mile. Although the statistics are not presented here, in nearly all cases the

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trends in contaminant tissue concentrations with river mile were not statistically significant.

When examined by tissue type, contaminant concentrations are higher in the hepatopancreas than in any tissue type for all contaminants except mercury (Figures 2-1a to 2-1j). Muscle tissue had the lowest concentrations for all contaminants except mercury. Contaminant concentrations in muscle+hepatopancreas and carcass, fall between the muscle and the hepatopancreas levels. As discussed below, this was expected for the muscle+hepatopancreas tissue samples. In nearly all cases, the trends with river mile were consistent across tissue types, as noted in Summary Point 2. For mercury, the concentrations in muscle and hepatopancreas tissue were reversed, with the highest concentration found in the muscle and the lowest in the hepatopancreas (Figure 2-1k). Mercury and certain other inorganics are known to preferentially bind to protein sulfhydryl groups (*i.e.*, muscle rather than hepatopancreas; Abrahamson *et al.*, 1983; Cuvin-Aralar and Furness, 1991) and this pattern is routinely observed in other uptake studies (Ribeyre *et al.*, 1997 Vieira *et al.*, 2011).

The upper diagrams presented in Figures 2-1a to 2-1h show the absolute concentrations. In some instances, there are apparent differences in the magnitude of the concentrations for similar tissue types depending on the year of collection. See for example, Figure 2-1e, wherein the 2009 Total DDx concentrations in muscle tissue (filled red squares) are distinctly higher than the prior studies (filled blue and green squares). Conversely, in the same figure, the 2009 hepatopancreas concentrations (red triangles) are lower than the prior studies (blue and green circles). Overall, the diagrams show a high degree of variance within and among tissue types. In the lower diagram in Figure 2-1e, the lipid-normalized concentrations for the various tissue types are shown. The variance within the various studies is greatly reduced, as are the differences among tissue types. The reduced differences among tissue types for the lipid-normalized data can be most readily discerned by comparing the weighted average trend lines shown in each diagram in Figure 2-1e. The lines clearly cluster more closely for the lipid-normalized results. Similar reductions in concentration differences among tissue types can be seen in the

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remaining Figures 2-1a to 2-1h. The observation of reduced variability among tissue concentrations is characteristic of nearly all of the biota tissue-contaminant pairs for all four species examined, providing support for this basis of analysis. The results suggest that much variation among studies can be best explained by variations in the lipid content and not by changes in exposure.

Given the reduction in variability achieved by lipid-normalization, the differences in lipid concentrations across the main studies for all four species were examined. The results are shown in Figure 2-7. In each diagram, the distributions of log values of lipid concentrations in a single tissue type for each species are presented. At the far right of each diagram is a set of circles representing the Tukey-Kramer test for statistically significant differences. Statistical differences among mean log values are indicated when both red and gray circles are shown. Circles of the same color do not differ on a statistically significant basis based on 95 percent confidence intervals. The variation in blue crab lipid content between the 1999 and post-2005 studies may be significant at a lower level of confidence (the 90th percentile) and the three studies together show a steady decline in lipid content in blue crab tissue concentrations over time.

Unlike contaminant concentrations, which might be expected to vary with time in response to changes in exposure conditions, lipid content variations are not expected to have long-term trends. Rather lipid content variations within a species are attributed to seasonal conditions (winter *vs.* summer), reproductive stage, age and size of an animal, among other factors. Normalizing contaminant concentrations to lipid content is a means to remove sample-to-sample contaminant concentration variations that can be attributed to lipid content variation and to identify those variations which must be explained by changes in the animals' environment.

Based on the observation that lipid content was not constant across studies for three of the four species examined, the possibility of temporal variations among studies was quantitatively examined on a lipid-normalized basis, to avoid the confounding of changes in lipid content with real changes in contaminant tissue concentrations presumably

resulting from changes in exposure. The distributions of lipid-normalized contaminant concentrations in the muscle+hepatopancreas tissue samples for different years of collection are shown in Figure 2-8[16]. In each diagram, the distributions of lipid-normalized contaminant tissue concentrations are shown in log scale for each data set, similar to the construction of Figure 2-7. Nine of the 11 contaminants were examined in this manner for all four species (see Figures 2-9, 2-10 and 2-11 for mummichog, white perch and American eel, respectively). Comparisons of 2009 Dieldrin and Total Chlordane data to data collected a decade earlier cannot be made for blue crab nor for any of the finfish species, because the majority of the historical data were non-detect, thereby precluding the calculation of a true average or median concentrations for the earlier studies.

In general, there are no systematic trends in lipid-normalized tissue concentrations (*i.e.*, all median concentrations for all contaminants do not increase or decrease across the studies) but there are statistically significant differences among studies for individual compounds. Sometimes, there appear to be systematic changes for one compound (*e.g.*, the increasing trend in mercury concentration over time; see Figure 2-8e) but these trends are not consistent across the species (see Figures 2-9e, 2-10e and 2-11e for the other three species examined) nor with the surface sediment observations (mercury results for surface sediment indicate a decline over the period 1995 to 2008; see Data Evaluation Report No. 4).

This observation is more closely examined in Figure 2-12, which presents lipid-normalized concentrations of 2,3,7,8-TCDD *vs.* time for three different tissue types for blue crab, plus whole body results for white perch and mummichog. These tissue types were selected because they represent the longest periods of monitoring. In each instance, a standard linear regression is constructed through the data. Of importance to note is that

[16] Because of the skewed nature of the contaminant concentrations in the fish tissue data sets, including the blue crab, data were viewed in log scale. Comparison calculations to assess differences over time among the data sets were assessed in log space to avoid the effects of outliers and track changes in the central tendency of the data. Calculating mean log values is mathematically equivalent to the geometric mean and a statistical surrogate to the median of the distribution. The median is considered the best estimate of the central tendencies of these distributions since it is not strongly affected by outliers, unlike a simple arithmetic mean.

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three of the diagrams show no trend or an increasing trend with time, while two show a statistically significant decreasing trend with time. Moreover, the two downward trends with time are statistically significant and represent blue crab muscle and blue crab hepatopancreas. These trends directly contradict the trend for the blue crab muscle+hepatopancreas samples as well as those for white perch and mummichog.

The blue crab tissue data combined with the results for the other three species do not present a consistent picture of time variability. Given the inability to produce consistent temporal tends with time, the tissue data were examined for the variation in the central tendency (*i.e.*, the median) over time as shown in Figures 2-8 to 2-11 and described in greater detail below. As noted in Summary Point 5, the lack of consistent temporal trends across the species and tissue types and the similar variability and trend with river mile, consistent with the sediment results indicates that these variations in contaminant concentrations in biota tissue do not represent variations in the average level of exposure but are probably attributable to factors related to analytical differences among studies, variations in sample types (*e.g.*, variation in number, size, age or tissue type of specimens in a typical sample), seasonal variations in the time of collection, or other environmental factors not related to the average sediment exposure concentration.

2.2.2 Mummichog

Analysis of the mummichog tissue concentrations paralleled the analyses done for blue crab. Unlike blue crab, however, only one tissue type was available for mummichog: whole body. The summary statistics of the contaminant concentrations in the mummichog whole body tissue samples are shown in Table 2-4. The mean tissue concentrations for the examined contaminant are as follows: 2,3,7,8-TCDD (68 pg/g); Total PCBs (549 µg/kg); Dieldrin (3.8 µg/kg); Total Chlordane (8.8 µg/kg); Total DDx (63 µg/kg), LMW PAHs (69 µg/kg); HMW PAHs (41 µg/kg); Total PAHs (108 µg/kg); copper (3.5 mg/kg); lead (0.84 mg/kg); and mercury (0.042 mg/kg). The mean and median concentrations for mummichog whole body tissue samples were comparable to those of blue crab muscle+hepatopancreas but substantially less than white perch and American eel for organic contaminants and mercury, consistent with its trophic level, as

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noted previously. Like the blue crab results, the mummichog results also support the five main Summary Points listed in Section 2.2.

Concentration plots of mummichog contaminant tissue concentrations *vs.* river mile for each contaminant are shown on Figure 2-2a to 2-2k, following the previously described diagram layout. Like the blue crab figures, both absolute concentrations and lipid-normalized concentrations are shown for the organic contaminants. These figures show contaminant distributions consistent with Summary Points 1 and 3. In particular, the mummichog tissue concentrations do not show any trend with river mile for Total DDx, LMW PAHs, HMW PAHs, Total PAHs, and copper. A very slight downward trend was suggested for the mercury results. The tissue concentrations showed gradual increasing trends with river mile for 2,3,7,8-TCDD, Total PCBs, Dieldrin, Total Chlordane, HMW PAHs and lead.

The variations in lipid content in mummichog samples are shown in Figure 2-7a. The variations among studies are statistically significant, as noted in Summary Point 4. Lipid-normalized results shown in Figures 2-2a through 2-2i generally exhibited similar or shallower trends with river mile than the absolute concentrations and similar or slightly lower local variability. In all cases except 2,3,7,8-TCDD, local variability was greater than any mean increase or decrease with river mile.

LMW PAH and Total PAHs exhibited a local minimum in mummichog tissue concentrations near RM3 to RM4 (see Figures 2-2f and 2-2h). This pattern was not seen for any other contaminants in mummichog tissue nor in any other contaminant-species pair. The reason for this local minimum is not known.

The results for 2,3,7,8-TCDD provided some observations unique to mummichog (see Figure 2-2a). Unlike the other contaminants, 2,3,7,8-TCDD concentrations did not vary widely at most locations but instead closely followed a curve gradually increasing with river mile. The notable exception to this were three samples collected in 1999 in the immediate vicinity of the 80 Lister Avenue site (RM3.2), which had four to 10 times

higher concentrations than the other high value in the area. The reason for the minimal variability in the tissue concentrations of 2,3,7,8-TCDD is unknown but may be due in part to study design. Unlike all other samples, the 1999 mummichog samples were obtained from caged fish rather than wild caught specimens. Additionally, the 1999 mummichog samples represent the bulk of the available mummichog results. The inability of these fish to move freely in their environment may account for the lower variance in 2,3,7,8-TCDD concentrations. However, this lower variability was not observed for other contaminants in mummichog tissue. Figure 2-2a also shows that 2,3,7,8-TCDD concentrations in mummichog samples obtained in 2010 tended to be lower than in samples obtained from 1999-2000. However, this difference did not remain when the results were lipid-normalized (see the lower diagram in Figure 2-2a, Figure 2-9a and Figure 2-12). Overall, the lipid-normalized results organic contaminant concentrations (see Figures 2-9a through 2-9e) were consistent with Summary Point 5.

2.2.3 White Perch

White perch sample collection was not continuous with river mile but instead was focused on a limited number of river mile locations. This sample distribution is unlike the more continuous sample distributions achieved for blue crab and mummichog. This distribution reflects the different capture techniques used for white perch. Blue crab and mummichog were captured with small traps or arrayed in small cages distributed fairly evenly along the lower 8 miles of the Lower Passaic River. White perch were captured at a limited number of locations in relatively large quantities using nets at approximately RM1.5, RM2.6 to RM3, and RM4.2 to RM6.2. The tissue samples as collected are associated with large river mile intervals in comparison to the discreet locations specified for the blue crab and mummichog. Finer resolution of the sample locations was not provided. However, this is not considered a substantive limitation for the use of these samples since white perch have an extensive home range and would not be expected to be associated only with sediment exposures at a single location. (See the discussion in Section 2.1)

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Summary Statistics of the contaminant concentrations in the tissue samples for white perch are shown in Table 2-5. Like the blue crab summary, these values are based on several different tissue types. The mean tissue concentrations for the examined contaminants are as follows: 2,3,7,8-TCDD (168 pg/g); Total PCBs (2,912 µg/kg); Dieldrin (19µg/kg); Total Chlordane (68µg/kg); Total DDx (257 µg/kg), LMW PAHs (144 µg/kg); HMW PAHs (83 µg/kg); Total PAHs (227 µg/kg); copper (10 mg/kg); lead (0.22 mg/kg); and mercury (0.27 mg/kg). Both mean and median contaminant concentrations in white perch are consistently higher than those of mummichog or blue crab, in the range of 1.5 to 10 times higher. For 2,3,7,8-TCDD, white perch had the highest mean and median concentrations of any of the four species examined. These concentrations are consistent with its trophic level relative to blue crab and mummichog. The white perch results support the five Summary Points listed in Section 2.2.

Concentration plots of white perch contaminant tissue concentrations *vs.* river mile for each contaminant are shown on Figure 2-3a to 2-3k, following the previously described diagram layout. Flat or slightly increasing concentrations with river mile were observed for 2,3,7,8-TCDD, Total PCBs, Dieldrin, Total Chlordane and Total DDx. Flat to decreasing trends with river mile were observed for the three PAH and metal parameters. Whole body concentrations were consistently higher than those of fillet with skin or fillet without skin for all parameters except mercury (circle symbol *vs.* triangle and square symbols in Figure 2-3). Like blue crab, lipid-normalized concentrations exhibited lower variability among tissue types than the simple concentrations, as evidenced by the closer agreement among the weighted average lines shown in the lower diagram in Figures 2-3a to 2-3h. Mercury was lowest in whole body samples and highest in skinless fillet, paralleling the observations for blue crab. Neither of the two fillet tissue types consistently had greater concentrations across all contaminants. These observations were consistent with Summary Points 1, 2 and 3. Of particular note for PAHs were a pair of particularly low fillet with skin samples at RM7, which showed a marked decline relative to the other fillet with skin samples as well as the other tissue types. The reason for this decline is unknown but may be in part due to the very small number (*i.e.*, two) of fillet with skin samples at this location. Like mummichog, statistically significant decreases in

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lipid content were observed for white perch (see Figure 2-7b) and are the basis for Summary Point 4.

Lipid-normalized concentrations in white perch did not show any consistent trend relative to previous studies although a few contaminants did show statistically significant higher concentrations in 2009 than in 1999/2000 (see Figures 2-10 and 2-12). In particular, the lipid-normalized concentrations for white perch yielded an increasing trend with time that was statistically significant but these changes were not consistently observed in other biota nor in the sediment data; thus the variations observed are likely attributable to the same factors identified for blue crab and mummichog (*i.e.*, analytical differences among studies, variations in sample types, seasonal variations in the time of collection, or other environmental factors not related to sediment exposure concentration). These observations support Summary Point 5.

2.2.4 American Eel

The American eel sample collection technique (*i.e.*, nets) was similar to that used for white perch. American eel were primarily captured at a limited number of locations, specifically RM1, RM3, RM5 and RM7. Again, like the white perch, this sample location resolution should not substantively limit the use of these data since these animals have home ranges on the scale of a few tenths of a mile and would not be expected to be associated only with the sediment exposures at a single location. (See the discussion in Section 2.1)

The summary statistics of the contaminant concentrations in the tissue samples for American eel are shown in Table 2-6. Like the blue crab and white perch summaries, these values are based on several different tissue types. The mean tissue concentrations for the contaminant examined are as follows: 2,3,7,8-TCDD (21 pg/g); Total PCBs (2,685 µg/kg); Dieldrin (31 µg/kg); Total Chlordane (55 µg/kg); Total DDx (389 µg/kg), LMW PAHs (58 µg/kg); HMW PAHs (16 µg/kg); Total PAHs (74 µg/kg); copper (1.2 mg/kg); lead (0.28 mg/kg); and mercury (0.36 mg/kg). Mean and median contaminant concentrations for organic compounds and mercury in American eel tissue are

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comparable to white perch and measurably higher than mummichog and blue crab for all contaminants except 2,3,7,8-TCDD. American eel had the lowest mean and median levels of 2,3,7,8-TCDD among all four species. While most contaminant concentrations are consistent with its trophic level, it is unknown why the mean concentration of 2,3,7,8-TCDD in American eel is lowest of the four species examined here. The observations for American eel are consistent with Summary Points 1 through 3 and 5 listed in Section 2.2. As noted in Summary Point 4, American eel did not show any changes in lipid content over time, unlike the other three species examined here (see Figure 2-7b).

Concentration plots of American eel contaminant tissue concentration *vs.* river mile for each contaminant are shown on Figures 2-4a to 2-4k, following the previously described diagram layout. Although five different tissue types are listed in the figure legend, only two tissue types, whole body and skinless fillet, exhibited enough spatial coverage to allow examination for spatial trends. Similar to previous observations, flat to slightly increasing trends in concentration with river mile were observed for all contaminants except LMW PAHs, Total PAHs and copper. For these three contaminants, eel tissue concentrations showed a flat to decreasing trend with river mile. Similar to the observations for blue crab and white perch, whole body concentrations were higher than for the fillet without skin samples for all contaminants except mercury. This is expected for the organic compounds given their affinity for lipid, which is more concentrated in the whole body samples than in the fillet without skin samples. These observations are consistent with Summary Points 1, 2 and 3.

Lipid-normalized organic contaminant concentrations for American eel whole body samples collected post-2005 are comparable to or slightly higher than those collected in 2000 (See the lower diagrams in Figures 2-4a to 2-4h and 2-11a to 2-11c). Like white perch, these lipid-normalized concentrations did not show any consistent trend among studies although several contaminants did show statistically significant higher concentrations post-2005 relative to 2000, as was observed for white perch and mummichog. These increases between post-2005 and 2000 were not consistently observed in other biota when examining the results from 1999 to 2009 nor were they

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observed in the surface sediment data. Based on this, the variations are attributed to the same factors identified for blue crab, mummichog, and white perch including analytical differences among studies, variations in sample types, seasonal variations in the time of collection, or other environmental factors not related to sediment exposure concentration. These observations support Summary Point 5.

3 RELATING SEDIMENT AND TISSUE CONTAMINANT CONCENTRATIONS

This section summarizes the various analyses to relate contaminant concentrations in fish and crab tissue with those observed in sediment. As noted in Section 1, most sediment-tissue relationships were developed using multivariate regression analysis. In a limited number of cases where the concentration range of sediment and tissue data were limited, biota-sediment accumulation factors (BSAFs and BAFs)[17] were estimated. These regressions and factors are used extensively in the evaluation of a variety of sediment management issues, including dredge material disposal and development of sediment toxicity benchmark concentrations, as well as to predict contaminant bioaccumulation in the ecological and human health risk assessments. In the analyses presented below, these factors are based on the correlation between contaminant concentrations in aquatic biota tissue samples and the concentrations in surface sediment samples as observed for the Lower Passaic River and the NY/NJ Harbor. These relationships are an important component in forecasting site-related risks at CERCLA sites in the absence of any remediation (the No Action alternative) as well as in forecasting the reduction in risk that may be anticipated in response to various remedial activities.

The relationship between sediment and tissue as expressed by BSAFs and BAFs has been the focus of extensive study for many years. Theoretical estimates of the BSAF and BAF involve thermodynamic considerations related to the rates of absorption and depuration, as well as the solubility of the contaminant of interest in water and animal fat (*i.e.*, lipid). Extensive analyses by authors such as MacKay (1982) indicate that a single constant BSAF or BAF factor should apply if an animal is in equilibrium with its environment, yielding a linear relationship between sediment and tissue concentrations. However, dynamic conditions may result in non-equilibria between animal and environment, potentially adding an apparent nonlinear response to reflect the approach to equilibrium.

[17] The basic regression formula and the definitions of BSAF and BAF are presented in Section 1.2 of this report.

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Recent work by Burkhard *et al.*, 2013, Cretney and Yunker, 2000 and Hellou *et al.*, 1995 provide evidence showing a non-linear relationship between sediment and tissue, suggesting various factors relating to black carbon, animal metabolism and time to equilibrium as possible explanations for the non-linear relationships observed. Recent work by MacKay *et al.*, 2013 indicate some of the complexities involved in the development of these factors. Work by Melwani *et al.*, 2009 also suggest that lipid normalization of fish tissue concentrations does not always reduce population variance, suggesting that the role of lipid in understanding fish tissue concentrations is not straightforward. Morrison *et al*., 1996 is an example of a non-equilibrium steady state model of contaminant uptake in biota.

For the purposes of the FFS, this analysis attempts to develop empirical regression-based relationships between sediment and tissue using site-specific data. By combining Lower Passaic River data with that from the NY/NJ Harbor, the regression analyses can often be conducted over a wide range of exposure concentrations. When data sets are more limited or do not span a wide range of concentrations, a less sophisticated relationship is developed through the estimation of a BSAF or BAF. The goal of this analysis was to develop site-specific regressions relating contaminant concentrations in fish and crab tissue with those found in sediment for use in the comparative risk analysis of the alternatives being considered in the FFS. The development of site-specific regression-based relationships or BSAFs and BAFs is preferable over the use of generic literature values (Burkhard, 2009). Literature values may under or overestimate the extent of biological uptake because site conditions that affect contaminant bioavailability and uptake potential are not considered, cannot be easily measured or cannot be reflected in non-site-specific relationships. Relationships between fish and crab tissue concentrations and sediment concentrations were developed for four different species, including blue crab, mummichog, white perch and American eel.

While this report is part of the FFS, which focuses on the lower eight miles, data from the entire length of the Lower Passaic River were considered so as to capture a range of sediment contamination conditions, to reflect the variations in concentration to the extent

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they are important to biota body burdens and to maximize the amount of data available for use. Additionally, data from the NY/NJ Harbor and data from the USEPA database were also included in the regression analyses. Using data from several data sets provided a wide range of concentrations as a basis for the regression analyses. As discussed below, the data set for the Lower Passaic River itself was eventually limited to data obtained between RM0 and RM12.

3.1 Data Integration

Estimates of biota tissue contaminant concentration, sediment contaminant concentration, lipid content and TOC were needed for all sample pairs considered in an analysis in order to generate a regression or BSAF for the organic contaminants. Similarly, estimates of biota tissue contaminant concentration, sediment contaminant concentration, and sediment iron concentration were needed for all sample pairs considered in an analysis in order to generate a regression or BAF for the inorganic contaminants.

3.1.1 Compilation of Tissue Data for Use in the Regression Analysis

Tissue samples from the various studies were comprised of individual specimens or composites of multiple specimens. Although multiple sample types (e.g., muscle tissue with and without skin, whole body, viscera) were available for some species, this analysis focused on sample types that were representative of either whole body (pertinent for ecological receptors although also useful for human consumption of larger animals) or edible tissue (pertinent to human receptors). Additionally, the sample types selected also needed to be available across much of the length of the Lower Passaic River and preferably over multiple studies so as to constitute a representative data set to support the regression analysis. The sample types by species are listed below:

- Blue Crab: “muscle and hepatopancreas” (Lower Passaic River 2009), “whole body soft tissue” (Lower Passaic River 1999-2000), or “all edible tissue”

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(Lower Passaic River 1999; NY/NJ Harbor 1999);

- Mummichog: "whole body" (Lower Passaic River 1999-2000, 2010; NY/NJ Harbor 1999-2001)
- White Perch: "fillet with skin on" (Lower Passaic River 2009) or "whole body minus head and viscera" (Lower Passaic River 1999-2000 and NY/NJ Harbor 1998-2000);
- American Eel: "whole body" (Lower Passaic River 2000, 2009) or "whole body minus head and viscera" (NY/NJ Harbor 1999-2001)

These sample types and species represented the largest and most spatially extensive sample sets available. Table 3-1 presents a summary of the numbers of samples available for each contaminant, providing the number of samples available for each species and for sediment from the Lower Passaic River, and for each species and for sediment from the NY/NJ Harbor areas. This table summarizes the sample data used in the regression, BSAF and BAF calculations described later in this section.

The biota tissue contaminant concentrations were used as reported; no further combining of sample results was needed for their use in the analysis. However, to be included in the analysis, each animal sample had to have a reported value for the contaminant in question as well as a reported value for the lipid content. Non-detect contaminant concentrations in tissue samples resulted in the exclusion of the sample from the analysis due to the large uncertainty that use of these sample results would have introduced into the analysis.[18]

In part, because of the large number of non-detects in some data sets, analytical results were not available for all animal types from all studies. For example, Dieldrin and Total Chlordane were reported as non-detect for all tissue samples for both the 1999 and 2000 studies. Thus no data for these contaminants from these studies were included in the regression analyses.

[18]The large uncertainty in the use of non-detect results for fish tissue arises from the following considerations. First, a non-detect result represents only an upper bound to the estimate of the actual fish tissue concentration; the actual fish tissue concentration may be orders of magnitude lower but is unknown. Thus the non-detect result represents a result with a high degree of uncertainty but in one direction relative to the detection limit. Since the uncertainty is not symmetric about the estimate, use of non-detect results has the potential to introduce biased estimates to the regression analysis. Second, the fish tissue estimate is used as a single value in the regression calculation; its value is not tempered by multiple values before its inclusion in the regression calculation, unlike the sediment contaminant concentration.

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Table 3-1 also presents a tally of the number of non-detects for each tissue-contaminant pair. For the Lower Passaic River data, nearly all tissue samples were detections for the data sets included. Out of 1625 reported results, there were 12 non-detects. Thus for use of these data, the exclusion of non-detect results will have little impact on the resulting relationships. For the harbor data, there were 25 non-detects out of 453 reported results. Again, nearly all tissue-contaminant pairs had quantitative results. For the harbor data most of the non-detects were associated with the blue crab-PAH pairs.

In addition to having a reported value, each tissue-contaminant pair had to have a corresponding quantitative estimate of sediment contamination, based on one or more sediment samples. Thus tissue samples with no corresponding sediment samples were excluded from the analysis. This resulted in the exclusion of the 1999-2000 CARP data for Dieldrin and Total Chlordane. Nearly all of the available harbor sediment data for these compounds was non-detect and so did not provide a quantitative estimate. The integration of the sediment data is described below.

PCB results were available in a number of forms depending on the data set, including Aroclor, congener and homologue concentrations. Of the three forms, only Aroclor results were reported for nearly all samples considered (sediment and tissue) across all sampling programs. Only the 2003 REMAP sediment data set did not have Aroclor data. The use of this data set is addressed below. Since Aroclor-based results were available in all but one of the data sets used, Aroclor results provide an internally consistent basis for comparing fish tissue concentrations with those in sediment. Thus, the regressions to determine a BSAF for PCBs were run on the sum of Aroclors. The sum was defined as the sum of detected Aroclors. Non-detect results for individual Aroclors were not included in the sum.[19] Data were compiled in this manner for both biota tissue and

[19] Non-detects for individual Aroclors were set to zero in samples with other detected Aroclors based on the analytical procedures related to Aroclor identification and analysis. In the process of identifying and quantifying PCBs as Aroclors, the analyst runs several different Aroclor standards and establishes the peak patterns specific to the instruments used that represent each Aroclor. When quantifying samples, the analyst then identifies which of the standard patterns most closely match the pattern observed in the sample. Based on this pattern agreement, the analyst then uses the calibration for that Aroclor (or Aroclors if more than one pattern is identified) to estimate the quantity of PCBs present in the sample. Aroclors that are not identified are set to non-detect. However, in choosing a pattern and quantifying the PCBs present as Aroclors, the analyst has attempted to quantify the entire PCB mass present. Since Aroclor patterns actually

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sediment. Thus in the development of the BSAFs for PCBs, Aroclor concentrations in sediment were correlated to Aroclor concentrations in biota tissue. The conversion of the Aroclor-based PCB concentrations used in this report to a Total PCB basis (sum of 209 congeners) can be accomplished using the relationship developed in Data Evaluation Report No. 5.[20] This relationship was applied in the risk assessment to the tissue and sediment PCB Aroclor concentrations to obtain the final Total PCB values used in the risk assessment.

Lipid content for each animal sample was used as reported in g lipid / g tissue.

While not included in the various calculations, data from the USEPA BSAF database were included in various graphical presentations to compare the results of this analysis with previous USEPA work.[21] As will be discussed later, the addition of USEPA BSAF data to graphical presentations of the regression and BSAF results helps to place the observations of this analysis in context of prior USEPA investigations. The incorporation of data from the REMAP and CARP databases substantively expanded the dataset available for all tissue-sediment relationship calculations. In particular, these databases expanded the calculations to include conditions that were close to background for the site as well as to likely sediment PRGs in many instances.

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overlap (many PCB congeners are found in several different Aroclors), adding a value to represent the undetected Aroclors to the sum of Aroclors for the sample essentially amounts to double counting. The analyst has already attempted to represent the entire mass of PCBs present.

[20] Total PCB concentration by congeners can be estimated from the Total PCBs by the sum of Aroclors as follows:

$$\text{Total PCB}_{\text{congeners}} = 1.25 * \text{Total PCB}_{\text{Aroclors}}$$

where: Total $PCB_{congeners}$ is the concentration in sediment or tissue determined by the sum of individual congeners, assigning zero to non-detect congener results, and
Total $PCB_{Aroclors}$ is the concentration in sediment or tissue determined by the sum of individual Aroclors, assigning zero to non-detect Aroclor results.

This equation was obtained by a regression based on hundreds of sediment samples spanning over four orders of magnitude in Total PCB concentration. This analysis was reported in Data Evaluation Report No. 5 (see Figure 2-1a in DER#5).

[21] The USEPA BSAF database contains only lipid-normalized tissue concentrations and TOC-normalized sediment concentrations. Besides not being site-specific to the Lower Passaic River, these data could not be used in the regression formulations which required the tissue concentration and the lipid fraction to be reported separately.

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3.1.2 Compilation of Sediment Data for Use in the Regression Analysis

Compiling sediment data for use in the regression analyses involved several tasks, including:

- Identification of the most appropriate studies for characterizing Lower Passaic River surface sediment concentrations
- Identification of relatively low level NY/NJ Harbor data
- Establishing a spatial basis to calculate mean surface sediment concentrations for each tissue sample from the Lower Passaic River
- Establishing a basis to estimate Lower Passaic River surface sediment concentrations for the 1999 and 2000 mummichog studies
- Establishing a basis to calculate mean surface sediment concentrations for the REMAP-CARP samples
- Conversion of the 2003 REMAP sediment PCB data to an Aroclor basis
- Establishing an upstream boundary on the Lower Passaic River for data used in the regression analysis

Each of these topics is described briefly below.

Identification of the most appropriate studies for characterizing Lower Passaic River surface sediment concentrations. The Lower Passaic River sediment data used in the analysis were derived from the 1999, 2000 and 2008 to 2009 sediment collection efforts. Data from the 1995 collection effort were not used based on its reported values for TOC. TOC measurements for sediment samples in this dataset were significantly higher than any other sediment data set, typically 75 to 100 percent higher than in most other sediment data sets (see Data Evaluation Report No. 4). Based on this observation, the 1995 TOC values to be used in normalizing the sediment concentration values for the BSAF calculations were considered an outlier population and not consistent with the remaining data sets. As a result, the 1995 sediment data set was excluded from the subsequent regression, BSAF and BAF calculations.

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Despite the exclusion of the 1995 data set, many sediment samples were still available to characterize the surface of the Lower Passaic River. Table 3-1 summarizes the availability of surface sediment samples from the Lower Passaic River. Note that the table includes samples from the lower 13 miles of the Lower Passaic River, an interval designed to match the available fish tissue data. As noted previously, this report attempts to use as much of the available biota data as possible as a basis for developing the relationships between surface sediment contamination and that observed in fish and crab tissue.

Identification of relatively low-level NY/NJ Harbor data. In addition to sediment results from the Lower Passaic River, relatively low sediment contaminant concentrations (*i.e.*, often at or below PRGs developed for the FFS) were obtained from the 1998 and 2003 NY/NJ Harbor USEPA's REMAP program and from the 1998 to 2000 CARP program. Contemporaneous biota tissue samples were also obtained from these areas under the CARP program. These regions include Upper New York Bay (Upper Bay), the Hudson River off Manhattan, Jamaica Bay and Raritan Bay. These areas were chosen because there are sufficient numbers of samples for both biota and sediment (see Figure 3-1) in each area to be considered spatially representative and therefore appropriate for inclusion in the regression, BSAF and BAF calculations.

Note that data for only eight out of the 11 contaminants are available from these databases for all four species and sediment. A ninth contaminant, lead was available for blue crab and sediment only. The availability of contaminant results from these databases is indicated in Table 3-1. Table 3-2 summarizes the data for the harbor sediment samples used in these analyses. From Tables 3-1 and 3-2, the data show that the frequency of non-detects was again fairly low, less than 10 percent for all but two parameters, LMW PAH and HMW PAH. For these 2 parameters, all of the non-detect detection limits were lower than the lowest detection. The data from the REMAP and CARP programs were added to the regressions, BSAF and BAF calculations whenever possible. The details on the use of these data are discussed below.

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Establishing a spatial basis to calculate mean surface sediment concentrations for each tissue sample from the Lower Passaic River. An important component in the development of tissue-sediment relationships for each contaminant is the identification of corresponding pairs of biota tissue and sediment contaminant concentrations. However, given the mobile nature of fish and crabs in general and the separate biota and sediment collection programs, identification of the most relevant sediment concentration for each tissue sample result was not intuitively obvious. In addition to the difficulty in correlating biota habitat and sediment samples from the river bottom, tidal and seasonal movements of some animals make this process even more complicated. The only exceptions to this concern were the 1999 and 2000 mummichog sample collection programs, described below.

For all biota samples from the Lower Passaic River, sediment contaminant concentrations were spatially integrated to represent an average level of exposure for the animal or animals in each biota tissue sample, since there was no way to establish the actual area of exposure for each individual specimen. This required an estimate based on the reported location of the biota tissue sample but also required that enough sediment samples be incorporated in the estimate so as to produce a robust estimate of the local average contaminant concentrations.

To assess the best basis for sediment data integration, sediment concentrations were examined as half-mile, 2-mile and 4-mile windows about each biota tissue sampling location. That is, sediment concentrations were estimated as the average of all sediment samples in an area $\pm$ 0.25 mile, $\pm$ 1 mile and $\pm$ 2 miles about each biota tissue sampling location. These intervals yielded sediment concentration averages typically based on, respectively, 8 to 12 samples, 30 to 40 samples and 60 to 80 samples. In this manner, an individual mean sediment concentration estimate was generated for each biota tissue sample for each contaminant. Non-detect values were used in estimating the local

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average sediment concentration, at one-half the detection limit.[22]

The need to average the surface sediment data becomes apparent when comparing surface sediment concentrations with biota tissue concentrations. As an example, Figure 3-2 presents both the TOC-normalized surface sediment 2,3,7,8-TCDD concentrations as well as the lipid-normalized 2,3,7,8-TCDD blue crab tissue concentrations as a function of river mile. Evident in the figure is the relatively minor degree of local variation in crab tissue concentrations (a factor of three to an order of magnitude variation based on the ratio of the maximum over the minimum value at each location) while the sediment data are highly variable, frequently showing three orders of magnitude at a given river mile by the same measure. However, visual inspection of these data indicates that both data sets show only minor variations in their mean concentration with river mile from RM0 to RM12. Above RM12, sediment concentrations decline by orders of magnitude while the crab concentrations suggest little to no difference relative to downstream areas. This observation and its implications are discussed further below.

Although the trends in mean sediment and mean biota concentrations are similar, there are still some variations in biota tissue that may be best reflected by variations in the local sediment mean concentration. Since it was not evident which of the averaging intervals described above would yield the least variability in the regressions for each animal, the trends of the TOC-normalized sediment concentrations and the lipid-normalized biota tissue concentrations for the Lower Passaic River were examined as a function of river mile for a limited number of contaminants. Figure 3-3 shows the trends for 2,3,7,8-TCDD for sediment and blue crab tissue. As seen in Figure 3-2, the scatter in surface sediment concentrations is several orders of magnitude so only the average values determined by the ± 0.25-mile, ± 1-mile and ± 2-miles intervals are shown in Figure 3-3.

[22] Non-detect results are used in estimating the average local sediment concentration for the tissue-sediment regression calculations to ensure the entire range of values measured is incorporated in the estimate of the mean. In this instance, the non-detect results represent low-end values whose uncertainty does not strongly affect the uncertainty of the mean estimate. These values also serve to balance the effect of high-end values so the estimate of the mean is closer to the true mean of the surface sediment concentration. In all instances in the estimation of Lower Passaic River surface sediment concentrations, the frequency of non-detects in sediment samples is sufficiently low so that the calculation of an average concentration is essentially unaffected by the choice of the value assigned to the non-detect result (*e.g.*, one-half the detection limit).

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A weighted-mean curve as well as the individual sample results is shown for crab tissue. As noted above, blue crab results show a relatively smooth trend with river mile and substantively less variation than the sediment results. The trend exhibited by the crab tissue is most like the trend of the sediment concentrations based on the ± 2-mile window shown by the red trace on the plot. This suggests that blue crabs are exposed over a relatively broad range of sediment concentrations, resulting in a mean exposure that parallels the mean sediment concentration based on the ± 2-mile window. This approach effectively generates an operationally defined exposure interval for the species examined, in this case blue crab.

In Figure 3-4, Total PCB results are presented for white perch and sediment. Again the general trend exhibited by the biota tissue samples is better matched using the ± 2-miles than the ± 0.25-mile window. Unlike the results for 2,3,7,8-TCDD, the ± 1-mile interval also appears similar to that of the biota tissue in this instance.

In the ideal instance, the averaging interval would match the approximate home range of each animal, since the sediments in this interval would represent the average exposure for the animal. However, the highly variable nature of the sediment concentrations likely obscures any apparent relationship on the scale of the animal home ranges. Essentially, the tissue concentrations describe a slowly moving mean condition, not strongly sensitive to an occasional outlier sediment value. For a small averaging window, the mean value varies widely over short distances, as can be seen for the ± 0.25-mile window curves in Figures 3-3 and 3-4. This is largely an artifact of whether an extreme value is captured in a given window. Thus, inclusion or exclusion of these extreme values causes the small window means to vary greatly. With the larger windows, there are greater numbers of samples included in each mean, lessening the impact of an extreme value on the mean and reducing the differences between adjacent mean estimates. The mean values of the larger windows more closely approximate the average trend in the river and the trend observed for the tissue samples. This consideration had the greatest impact on estimates of the 2,3,7,8-TCDD concentrations to be used in the regression calculations. Other contaminants generally exhibited less variability in surface sediment concentrations and so the choice of the window size for sediment averaging was less important. This can be

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seen by contrasting Figure 3-3 and Figure 3-4. Based on the results for 2,3,7,8-TCDD, the widest window, ± 2 miles, was chosen as the best window for averaging since it most closely followed the general trend observed for the biota tissue. The ± 2-miles window was used as an averaging basis to estimate the mean surface sediment concentration for all contaminants and all species. The better agreement between tissue and ± 2-miles mean sediment concentration indicates that mean exposure concentrations for the biota studied in the Lower Passaic River do not vary extensively. This has implications for assessing the relationship between tissue and sediment concentrations, as discussed later in this report.

Having established a basis to integrate the surface sediment measurements of the Lower Passaic River into local mean estimates, an individual sediment mean was calculated for each individual tissue sample. The calculation procedure for determining the mean TOC-normalized or iron-normalized surface sediment concentration from the samples identified using this ± 2 mile-window is described in the next section of this report. This procedure for estimating an individual average sediment concentration for each biota tissue sample was applied to all animal samples except the 1999 and 2000 mummichog samples. The procedures for these samples follow below.

Establishing a basis to estimate Lower Passaic River surface sediment concentrations for the 1999 and 2000 mummichog studies. Unlike all of the other biota sampling programs, the 1999 mummichog program sought to obtain matched pairs of caged mummichog and local sediment samples. Three co-located sediment cores were obtained from each animal collection location. These three samples were used to calculate a location-specific mean concentration for each mummichog sample. Recognizing that local heterogeneity may impact this mean estimate given the small size of the sample set, the median value for the three co-located cores was compared with the mean for several contaminants. In all cases except 2,3,7,8-TCDD, there was little to no systematic difference in the mean vs. median values and so the mean was used for all contaminants except 2,3,7,8-TCDD.

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The results for sediment concentration of 2,3,7,8-TCDD are contrasted with those for Total PCBs and lead in Figure 3-5. In these plots, close agreement between mean and median is shown when points fall on the 1:1 line, indicating equal mean and median values. For 2,3,7,8-TCDD, a systematic difference was noted, with the median consistently lower than the mean for the 1999 samples, and so the median was used for the mummichog-related sediment samples for 2,3,7,8-TCDD only. The consistently lower median values were attributed to the median being a better estimate of the local central tendency. The high degree of local variability observed in 2,3,7,8-TCDD concentrations would be expected to cause wider variation in a simple average based on only three locations relative to the median (see Data Evaluation Report No. 3 on the variability of surface sediment concentrations of 2,3,7,8-TCDD). While the use of the median in this instance is probably a best estimate of local concentrations, the selection of the median sediment concentration relative to the mean has the potential to overestimate the true BSAF for 2,3,7,8-TCDD for mummichog, since the median is consistently lower than the mean. This in turn generates a more conservative estimate of the BSAF for mummichog, resulting in a more protective PRG.

For the 2000 mummichog samples, a single sediment sample was obtained with each wild-caught mummichog sample. Given the sampling design and the generally limited home range of these animals, the single samples were used as the basis for the contaminant sediment concentrations.

Establishing a basis to calculate mean surface sediment concentrations for the REMAP-CARP samples. Both the REMAP and the CARP programs tended to gather a few samples in a number of relatively large areas. In correlating tissue and sediment data, samples from relatively large areas were averaged and matched with tissue samples obtained from those areas. In this manner, the sediment concentration for each CARP tissue sample was based on an average of at least four, and more typically eight to ten REMAP and CARP sediment samples. Figure 3-1 shows the groupings of the biota-sediment data for each region (indicated by magenta polygons). In each polygon, the individual biota samples were matched with the average of all surface sediment samples contained within the polygon. Thus for each polygon there is one average sediment

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concentration that is applied to all individual fish and crab samples located within that polygon. This procedure mimicked the resolution of the sediment-tissue sample pairing conducted for the Lower Passaic River. Like the Lower Passaic River calculations, non-detect values were used in estimating the local average sediment concentration, at one-half the detection limit.[23]

Conversion of the 2003 REMAP sediment PCB data to an Aroclor basis. As noted previously, Aroclor-based PCB concentrations were available for all sediment and tissue data sets used in this report except the 2003 REMAP sediment data obtained by USEPA. The REMAP data set provides surface sediment concentrations throughout the NY/NJ Harbor and was identified as an important database for use in the regression, BSAF and BAF calculations. The REMAP data could be combined with the CARP fish tissue concentrations to describe the sediment-tissue relationships at low concentration levels for most contaminants. This was a straightforward process for all COPCs except Total PCBs. The 1998 data had PCB results reported as Aroclors but the 2003 data did not. However, the 2003 REMAP data did include results for 21 individual PCB congeners. Most of the congeners included in this congener set were originally selected as part of the NOAA National Status and Trends Mussel Watch Program and represent an alternate basis for reporting PCB concentrations.

To convert the 2003 REMAP PCB congener data to comparable Aroclor-based concentrations, a set of samples was needed where both Aroclor and congener analyses were conducted. From such a set of measurements, the relationship between the two PCB measurement bases could be assessed. The sediment database obtained by the CPG for the Lower Passaic River provided this basis since it contained a large number of samples

[23] Non-detect results are used in estimating the average local sediment concentration for the tissue-sediment regression calculations to ensure the entire range of values measured is incorporated in the estimate of the mean. In this instance, the non-detect results represent low-end values whose uncertainty does not strongly affect the uncertainty of the mean estimate. These values also serve to balance the effect of high-end values so the estimate of the mean is closer to the true mean of the surface sediment concentration. In most instances in the estimation of NY/NJ Harbor surface sediment concentrations, the frequency of non-detects in sediment samples is sufficiently low so that the calculation of an average concentration is essentially unaffected by the choice of the value assigned to the non-detect result (*e.g.*, one-half the detection limit). Moreover, given the generally large area that must be integrated to estimate these surface sediment concentrations, and the lack of overlap between the range of detected values and the range of detection limits, further analysis of the possible distribution of the non-detect values is unlikely to substantively reduce the uncertainty of the sediment concentration estimate.

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analyzed for both PCB congeners and Aroclors, and spanned a wide range of concentrations.

The CPG data set actually contained results for a much more extensive list of congeners than the 21 reported in the REMAP data set. However, in order to develop a basis to convert the REMAP PCB congener concentrations to an Aroclor basis, just the 21 reported congeners were considered. For this purpose, the sum of 21 PCB congeners was defined as the sum of detected congeners, excluding any non-detect results. Similarly, the sum of Aroclors was defined as the sum of detected Aroclors. This approach was consistent with the handling of the Aroclor results for all sediment and fish tissue samples.

Using the matched pairs of Aroclor and congener sums from the CPG sediment data, a robust regression analysis[24] was completed on the CPG datasets (year 2008-2010) to estimate the sum of Aroclors to the sum of 21 PCB congeners. The regression results are presented in Figure 3-6. Based on this analysis, the Total PCB concentration by Aroclors can be estimated from the sum of 21 PCB congeners as follows:

$$Total\ PCB_{Aroclors} = 2.1872 * Sum\ of\ 21\ PCB\ Congeners \qquad \text{Eq. 3-1}$$

where: Total $PCB_{Aroclors}$ is the concentration in sediment determined by the sum of individual Aroclors, assigning zero to non-detect Aroclors results, and

Sum of 21 PCB Congeners is the concentration in sediment determined by

[24]Robust regression is an alternative to least squares regression when data contain many outliers or influential observations. Robust regression is a form of regression analysis designed to circumvent some limitations of traditional parametric and non-parametric methods. Regression analysis seeks to find the relationship between one or more independent variables and a dependent variable. Certain widely used methods of regression, such as ordinary least squares, have favorable properties if their underlying assumptions are true, but can give misleading results if those assumptions are not true; thus ordinary least squares is said to be not robust to violations of its assumptions. Robust regression methods are designed to be not overly affected by violations of assumptions by the underlying data-generating process.(Wikipedia, 2013)

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the sum of individual congener, assigning zero to non-detect congener results.

The regression itself was based on hundreds of sediment samples spanning over three orders of magnitude in the sum of Aroclors concentration. By using this regression approach, it was possible to estimate the sum of Aroclors from the 2003 REMAP data in an unbiased fashion. This approach does introduce additional variability into the analysis given the wide variation observed in individual sample results. However, this is partially addressed by the large number of biota-sediment sample pairs added to the PCB regression calculation since the uncertainty on the mean trend decreases as more points are added to the analysis. More to the point, while the individual estimates of the sum of Aroclors from the 2003 REMAP data may have a large uncertainty, each tissue sample is paired with the average of five or more sediment samples. These samples will likely be a combination of the 1998 REMAP, 2003 REMAP and the 1998-2000 CARP results, with the end result of significantly reducing the uncertainty on the sum of Aroclors value used in the regression analysis relative to that of a single 2003 REMAP sediment sample estimate.

Establishing an upstream boundary on the Lower Passaic River for data used in the regression analysis. Although the Lower Passaic River constitutes a highly contaminated setting, the available sediment data for use in the regression calculations for the Lower Passaic River do not span a wide range of average concentrations. As noted previously, for the region below RM12, sediment data are locally variable but there is little variation in the overall average. For example, as shown in Figure 3-3, the average TOC-normalized concentration for 2,3,7,8-TCDD based on a $\pm$ 2-mile window (red curve in the figure) varies by about a factor of three from 7,000 to 24,000 pg/g-oc. The crab tissue has a similar range, varying a factor of three from 1,500 to about 4,000 pg/g-lipid. While smaller sediment averaging intervals can yield more sediment variability, these intervals do not mimic the trends observed for the various species sampled. Similar local variability but lack of variation in the mean was observed for all of the contaminants

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examined here. The sediment observations in this regard are discussed at length in Data Evaluation Report No. 4.

The only portion of the Lower Passaic River where mean contaminant concentrations in sediments appeared to vary substantively relative to RM0 to RM12 was the area above RM13. Concentrations of several contaminants declined markedly above RM 12, a feature attributed to mixing of highly contaminated Lower Passaic River sediment with less contaminated solids delivered from the Upper Passaic River above Dundee Dam. It was noted that for contaminants with steep concentration gradients for sediment at the upper end of the estuary (RM12 to RM15), the estimated individual tissue concentrations did not decline as rapidly (if at all) as the sediment concentrations declined. An example of the lack of decline in biota tissue relative to sediment can be seen in Figure 3-2 for the region above RM12 for 2,3,7,8-TCDD in blue crab. While this might suggest a substantive non-linear component for the regression analysis, further investigation showed this was not the likely explanation, at least for blue crab.

To further evaluate the failure of the blue crab tissue concentrations of 2,3,7,8-TCDD to track sediment concentrations above RM12, the ratio of 2,3,7,8-TCDD to Total TCDD was examined for sediment and biota. This dioxin ratio has been used extensively throughout this FFS as a means to track the impacts of Lower Passaic River contamination. The dioxin ratio for nearly all specimens of finfish was 1.0, rather than the range of 0.6 to 0.8 observed in sediments. The value of 1.0 for the dioxin ratio was observed despite the high levels of 2,3,7,8-TCDD found in the finfish tissue. This observation would indicate that finfish tissue samples do not retain the ratio of 2,3,7,8-TCDD to Total TCDD of their exposure environment. The reason for this is unknown but this observation may reflect analytical issues with the other tetradioxins in finfish tissue or it may be due to preferential retention of 2,3,7,8-TCDD by finfish over the other tetradioxins.

However, unlike the finfish, the results from the multiple biota sampling events in the Lower Passaic River demonstrate that the dioxin ratio in blue crab closely resembles its

environment. This is shown in Figure 3-7. In the figure, the dioxin ratio is plotted for both surface sediments and blue crab. Both data sets center around the value of 0.7 for the region below RM13. Both data sets also show a gradual decline in the ratio in the lower river miles, reflecting the influence of lower 2,3,7,8-TCDD ratios in the sediments in this portion of the FFS Study Area. However, above RM13, the two data sets markedly diverge, with blue crab tissue results remaining around 0.7 but sediment declining to 0.05. This divergence in the values is considered a strong indication that dioxin levels in blue crab above RM13 are not derived from sediments above RM13 but rather from the animals' exposure to contaminated sediments below RM13. Based on this observation, calculation of the BSAF values for blue crab was limited to the samples obtained below RM13, where the sediment ratios and blue crab ratios align. Given that the divergence above RM13 was so striking and consistent despite the large number of blue crab samples above RM13, the concern was raised that other species may also be subject to similar conditions. That is, animals captured above RM13 effectively get their exposure from sediments below RM13 despite the fact that they were caught above this river mile.[25] For this reason, the BSAF calculations for all species were conducted using samples limited to the region below RM13. In most instances, this did not represent the exclusion of a large number of samples since relatively few of the other three species studied in detail in this report were caught above this river mile. Instead the samples obtained from around the NY/NJ Harbor area were used to broaden the range of contaminant concentrations examined in the regression analyses.

3.1.3 Calculation of Sediment Concentrations for Use in the Analysis

The previous subsection describes the basis for associating a specific biota tissue sample with a set of sediment samples. In this subsection, the formulas used to compile the sediment data into a single value for each biota tissue sample are described. For all organic contaminants, sediment concentrations were normalized to TOC. This is a

[25] As discussed elsewhere in this report, animals require time to integrate their environmental exposures. Animals that are transient in an area, such as animals moving with the tides or migrating seasonally may be captured prior to reaching a steady-state condition between themselves and their exposures. Thus, animals caught outside their recent primary area of exposure will reflect conditions most consistent with their primary exposure area and not necessarily with the location where they were found.

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standard approach for relating tissue and sediment concentrations, based on the recognition that most organic contaminants are associated with the organic matter of the sediments, and often vary with the organic fraction. This correlation means that the two variables are not independent. Regression analysis is most efficient when regression variables are independent. To avoid this co-linearity between the sediment contaminant concentration and fraction of organic matter, and to reduce the variability in the data used to estimate mean sediment conditions, the variables were combined into a single parameter, *i.e.*, the TOC-normalized contaminant concentration. Since each sediment sample included in a given $\pm$ 2 mile-window had its own organic carbon value, each sample result was divided by its organic carbon value before incorporating the sample result in the estimate of the mean TOC-normalized concentration, as follows:

$$C_{s-oc} = \frac{1}{n}\sum_{i=1}^{n}\frac{C_{s_i}}{f_{oc_i}} \qquad \text{Eq. 3-2}$$

where:

$C_{s\text{-}oc}$	=	mean TOC-normalized concentration of the contaminant in the sediment
$C_{S\,i}$	=	concentration of the contaminant in sediment sample *i*
$f_{oc\,i}$	=	organic carbon concentration in sample *i* in g OC/g sediment.
n	=	the number of samples in the sediment window of interest

The inorganic contaminants were handled in a parallel manner. For all metal contaminants, sediment concentrations were normalized to iron. Normalization to elements such as iron or aluminum is a common geochemical practice to enable the identification of anthropogenic contributions of heavy metals relative to naturally occurring ones (Langston 1982; Windom et al., 1989; Ravichandran, et al.,1995; Summers *et al.* 1996; Schiff and Weisberg, 1999; Abrahim and Parker, 2008). Like organic carbon for organic contaminants, most metal contamination is associated with fine-grained particles, which are also high in iron and aluminum. Thus iron and

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aluminum are surrogates for the fraction of fine-grained particles within the sediments. Similar to the organic contaminant behavior, the inorganic contaminant concentrations are partially correlated with the concentration of iron in the sediment. To avoid this co-linearity between the sediment inorganic contaminant concentration and concentration of iron, and to reduce the variability in the data used to estimate mean sediment conditions, the variables were combined into a single parameter, *i.e.*, the iron-normalized contaminant concentration. For the purposes of the Lower Passaic River metal analyses, iron was chosen as the normalizing constituent based its consistent trend throughout both the Lower Passaic River and Newark Bay.

Normalization to iron in sediments for metals serves to reduce variability that is attributable only to variation in fine-grained sediment content, much as normalization to organic carbon reduces variability that is attributable only to variation in the organic carbon fraction in the sediments. In both instances, animal exposure is considered to be driven by the contaminant concentrations on the fine-grained or organic fractions of the sediments. Coarse sand and gravels are not considered to be important media for animal exposure and are factored out by this calculation. The reduced variability provided by iron normalization is presented throughout the discussion of metal contamination in Data Evaluation Report No. 4, Surface Sediment Contamination. Iron-normalized concentrations were calculated as follows:

$$C_{s-Fe} = \frac{1}{n}\sum_{i=1}^{n}\frac{C_{sed_i}}{C_{Fe_i}} \qquad \text{Eq. 3-3}$$

where:

$C_{s\text{-}Fe}$	=	mean iron-normalized concentration of the metal in the sediment
$C_{sed\ i}$	=	concentration of the metal in sample *i*
$C_{Fe\ i}$	=	iron concentration in sample *i* in g iron/g sediment
n	=	the number of samples in the sediment window of interest

For the sediment samples associated with the 1999 mummichog data, the mean sediment

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concentration was simply divided by its associated organic carbon or iron concentration as appropriate. For the 2000 mummichog data, the single sample used as the sediment concentration was simply divided by its corresponding organic carbon or iron value.

In the limited number of instances where a regression was unsuccessful in relating tissue and sediment concentration, lipid normalized tissue concentrations were calculated for all individual samples for the organic contaminant in question for use in the BSAF calculation. When a regression for an inorganic contaminant was unsuccessful, inorganic concentrations in biota tissue were simply used in the BAF calculation as reported, without any other correction applied.

3.2 Regression, BSAF and BAF Formulations

Ideally, sediment to biota accumulation factors (*e.g.*, BSAFs and BAFs) would be developed from carefully paired biota and sediment samples with a broad range of sediment concentrations needed to accurately estimate the slope of the assumed linear relationship. In practice, tissue and sediment samples are not well paired, and some species are captured predominantly in proximity to more highly contaminated sediments whereas others are captured in proximity to lower contaminant concentrations. Because of these practical limitations in study design, BSAFs and BAFs are usually calculated by pairing a narrow range of sediment contaminant concentrations with available biota samples, which often exhibit one and even two orders of magnitude of variation even within a narrow range of assumed sediment contaminant exposure levels. Investigators are left with highly imprecise BSAF and BAF estimates with strong likelihood of inaccuracy due to the small numbers of samples and limited range of contaminant concentrations in sediment.

When several species are collected, it is possible to improve the precision of estimated accumulation functions (i.e., BSAFs and BAFs that vary with environmental conditions) by combining multiple species data into a single multiple regression analysis allowing

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subtle differences in accumulation rates among species while borrowing common information among species providing more stable estimates than would be otherwise available from a within species analysis. The multiple regression approach also allows one to test the assumptions of linearity of the BSAF and BAF equations and to estimate non-linear accumulation functions where appropriate. The tradeoff of this approach is that the perceived fine detail of species-specific relationships may be obscured in situations where the range of sediment contaminant levels is inadequate to statistically differentiate between accumulation factors among species. But in these situations, it is unlikely that the BSAF or BAF would be either more accurate or more precise than accumulation functions informed by the relationships between tissue and sediment concentrations of other species.

So in effect, one compromises species-specific information when data are inadequate to resolve it and leverages the strength of larger data sets from other species bolstering more robust predictions for these under-sampled (or sediment range-constrained) species. To understand the extent to which results from one species may inappropriately dominate estimates for another species, the actual tissue concentrations are plotted against predicted concentrations on a per species basis to provide visual assessment of the bias imparted by incorporation of multiple species in the calculations. Bias is indicated when plots of observed vs. predicted values deviate from the 1-to-1 line.

Pragmatically speaking, the multiple regression (with multiple species) approach circumvents over-interpretation of small sample sizes with imperfect correlations which typically drive greater perceived accuracy than the data can support. This over-fitting of data to an assumed linear BSAF model would otherwise lead to poor prediction of future samples (*i.e.*, out of sample prediction), whereas the multiple regression approach provides a more stable and ultimately accurate means to predict future fish tissue concentrations over a broader range of sediment contaminant concentrations.

The data available for this report contain many of the concerns raised above. The data sets for sediment and biota tissue can both be characterized as being highly variable on a

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local basis but exhibiting relatively shallow trends over much of the length of the Lower Passaic River. Additionally, as discussed earlier in this report, the data sets were not spatially linked, *i.e.*, with the possible exception of the 1999 and 2000 mummichog programs, sediment samples were obtained to describe the general levels of sediment contamination and not the local conditions where a fish was obtained. The variability attributable to the sediment concentration in each pair of values is greatly reduced, however, since the sediment concentration is determined as the mean of ten to as many as eighty individual sediment measurements. Therefore, the mean level of exposure for each biota sample is well based. The discrete tissue sample contaminant concentrations will be the primary source of variability to the regression. While this approach will not necessarily characterize the exact conditions of exposure for the animals of an individual sample, the sediment average should represent the overall average exposure for all animals in an area. With the number of biota tissue samples available, this approach can be expected to provide a reasonable estimate of the average relationship between contaminant concentrations in tissue and those observed in sediment for each species and contaminant.

3.2.1 Regression Model Formulation

The goal of the regression is to define a relationship between fish or crab tissue concentrations and a subset of measureable parameters available to the analysis. For organic contaminants, the parameter list includes contaminant sediment concentration, sediment TOC, and the lipid content of the tissue sample. For inorganic contaminants, the parameter list includes just the sediment concentration and the sediment iron concentration. Given the wide range in both sediment concentrations and in tissue concentrations, the regressions were conducted in log-transformed space to reduce sensitivity to outliers and best approximate the central tendency of the data. Use of log-transformed data also permitted the regression analysis to utilize linear multivariate statistical techniques, which are readily available and relatively straightforward in their application.

For organic contaminants, the basic regression equation is of the form:

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$$Ln(C_f) = \beta_0 + \beta_1 Ln(C_s) + \beta_2 Ln(f_L) + \beta_3 Ln(f_{oc}) + \varepsilon \quad \text{Eq. 3-4}$$

where: C_f = contaminant concentration in fish tissue

C_S = contaminant concentration in the sediment

f_L = fraction lipid in fish

f_{OC} = fraction organic carbon in sediment

ε = normally distributed mean-zero random error

Exponentiating both sides results in the multiplicative model:

$$C_f = e^{\beta_0} \times C_S^{\beta_1} \times f_L^{\beta_2} \times f_{oc}^{\beta_3} \times e^{\varepsilon} \quad \text{Eq. 3-5}$$

Which can be solved for an estimate of a BSAF-like term:

$$\frac{\left(C_f / f_L^{\beta_2}\right)}{\left(C_s^{\beta_1} / f_{oc}^{-\beta_3}\right)} = e^{\beta_0} \times e^{\varepsilon} \quad \text{Eq. 3-6}$$

If $\beta_1 = \beta_2 = -\beta_3 = 1.0$, the left hand side of the equation simplifies to the typical BSAF, so in this particular situation e^{β_0} is an estimator of the BSAF. Under this condition, the BSAF should remain constant over a broad range of concentrations. The data available for this analysis cover a wide range of concentrations and indicate that this is not true in many cases. Rather than force a regression with a values of 1.0 for the βs, the regression analysis used here allows these values to vary. If the data support a value of 1.0 for the βs, this will be the result of the regression if the data are representative. Otherwise, the typical BSAF is probably not the best way to relate fish and sediment concentrations. To evaluate the applicability of a BSAF approach, it is appropriate to test the composite null hypothesis H_O):

$$H_0\text{: } \beta_1 = \beta_2 = -\beta_3 = 1.0$$

$$H_\alpha\text{: } \beta_1 \neq 1.0,\ \beta_2 \neq 1.0 \ or\ \beta_3 \neq -1.0$$

If the data indicate that we reject the null hypothesis (H_0), then the application of the typical BSAF approach is not well supported. Based on the range of individual BASF values and their variation with sediment concentration as observed in the data (to be described later in this section), it was not deemed appropriate to assume the null

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hypothesis for each contaminant-tissue pair but rather to allow the statistics to determine the applicability of the null hypothesis condition.

In general, a regression is most effective when the variables used are independent of one another. As noted previously, the TOC and contaminant concentrations are not independent of one another and so the regression given in Equation 3-4 was simplified to:

$$Ln(C_f) = \beta_0 + \beta_1 Ln\left(\frac{C_s}{f_{oc}}\right) + \beta_2 Ln(f_L) + \varepsilon \qquad \text{Eq. 3-7}$$

or

$$Ln(C_f) = \beta_0 + \beta_1 Ln(C_{s-oc}) + \beta_2 Ln(f_L) + \varepsilon \qquad \text{Eq. 3-8}$$

where $C_{s\text{-}oc}$ is as defined in Equation 3-2.

A parallel derivation for inorganic contaminants can be performed while excluding the f_L term which is not pertinent to inorganic contaminants. This yields:

$$Ln(C_f) = \beta_0 + \beta_1 Ln(C_{s-Fe}) + \varepsilon \qquad \text{Eq. 3-9}$$

where $C_{s\text{-}Fe}$ is as defined in Equation 3-3.

Given the number of species (four) and the number of contaminants (eleven), application of Equations 3-8 and 3-9 would generate 44 separate regression analyses. However, for some contaminants, all high concentration sediment samples are paired with one species, whereas all low concentration sediment samples are paired with another species. In these situations, fitting regression models to individual species with a limited range of sediment concentrations is counter-productive because the resulting regression models are unstable and generally provide poor prediction beyond the range of the data.

Alternatively, a combined species regression model can borrow strength from data from multiple species, while yielding a specific sediment concentration-to-tissue concentration relationship for each species involved. It is believed that this regression simultaneously incorporating multiple species provides a more accurate and stable estimate of the underlying relationships than is otherwise available from individual species analysis. In cases where high and low end sediment concentration data are available for several

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species for the same contaminant, it was found that the regression results (and the effective BSAF or BAF) were relatively similar across species, suggesting that using an average accumulation based on multiple species is preferred to use of individual regressions or individual BSAF ratios based on small sample sizes and a narrow range of sediment concentrations.

To accomplish the combined species regression, Equations 3-8 and 3-9 were modified to incorporate species-specific factors. To incorporate multiple species, the regression model was adapted to include a series of indicator variables for species, represented by the symbol ϕ. The variable ϕ takes on the value of 1 for one species and 0 for all others. By adding an indicator variable to the regression model, the model formulation becomes more complex but the number of regressions is reduced from one per species-contaminant pair (44) to one per contaminant (11). To accomplish this, Equation 3-8 becomes:

$$\begin{aligned} Ln(C_f) = {} & \beta_0 + \beta_1 Ln(C_{s-oc}) + \beta_2 Ln(f_L) \\ & + \emptyset_{AE}[\beta_3 + \beta_4 Ln(C_{s-oc}) + \beta_5 Ln(f_L)] \\ & + \emptyset_{BC}[\beta_6 + \beta_7 Ln(C_{s-oc}) + \beta_8 Ln(f_L)] \\ & + \emptyset_{MM}[\beta_9 + \beta_{10} Ln(C_{s-oc}) + \beta_{11} Ln(f_L)] \\ & + \emptyset_{WP}[\beta_{12} + \beta_{13} Ln(C_{s-oc}) + \beta_{14} Ln(f_L)] \\ & + \varepsilon \end{aligned} \qquad \text{Eq. 3-10}$$

where: ϕ_{AE}, ϕ_{BC}, ϕ_{MM}, and ϕ_{WP} are the indicator variables for American eel, blue crab, mummichog and white perch, respectively.

β_i are the various coefficients for species, species-$C_{s\text{-}oc}$ and species-f_L interactions.

The remaining terms are as defined previously.

When the values for β_3, β_6, β_9, or β_{12} differ significantly from 0, the effective BSAF is inferred to differ among species since these constants become the BSAF when the other βs approach a value of 1. Conversely, when β_3, β_6, β_9, or β_{12} are not different from zero

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one may conclude that the effective BSAF is similar among species and an average equation is applicable for all species under consideration. In the actual regression process, one of the four βs is set equal to 0. In this application, β_{12} representing white perch was typically set equal to zero, and the remaining βs represent differences from the behavior of this species. The choice of which of these four βs to set to zero is unimportant since the regression considers all data and species equally in the analysis.

The other βs in Equation 3-10 represent species-specific interaction related to the TOC-normalized concentration and the lipid content of the tissue samples.

A parallel construction can be conducted for inorganic contaminants, yielding:

$$\begin{aligned} Ln(C_f) = \ & \beta_0 + \beta_1 Ln(C_{s-Fe}) \\ & + \emptyset_{AE}[\beta_3 + \beta_4 Ln(C_{s-Fe})] \\ & + \emptyset_{BC}[\beta_6 + \beta_7 Ln(C_{s-Fe})] \\ & + \emptyset_{MM}[\beta_9 + \beta_{10} Ln(C_{s-Fe})] \\ & + \emptyset_{WP}[\beta_{12} + \beta_{13} Ln(C_{s-Fe})] \\ & + \varepsilon \end{aligned} \qquad \text{Eq. 3-11}$$

where all of the terms are as defined previously.

When the regression for each contaminant is completed, the results for Equations 3-10 and 3-11 can be reduced to species-specific equations for use in later FFS analyses. Specifically, Equation 3-10 can be separated into four species-specific equations as follows:

$$Ln(C_{fAE}) = (\beta_0 + \beta_3) + (\beta_1 + \beta_4) Ln(C_{s-oc}) + (\beta_2 + \beta_5) Ln(f_L) \qquad \text{Eq. 3-12}$$

$$Ln(C_{fBC}) = (\beta_0 + \beta_6) + (\beta_1 + \beta_7) Ln(C_{s-oc}) + (\beta_2 + \beta_8) Ln(f_L) \qquad \text{Eq. 3-13}$$

$$Ln(C_{fMM}) = (\beta_0 + \beta_9) + (\beta_1 + \beta_{10}) Ln(C_{s-oc}) + (\beta_2 + \beta_{11}) Ln(f_L) \qquad \text{Eq. 3-14}$$

$$Ln(C_{fWP}) = (\beta_0 + \beta_{12}) + (\beta_1 + \beta_{13}) Ln(C_{s-oc}) + (\beta_2 + \beta_{14}) Ln(f_L)$$

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Eq. 3-15

where the C_{fi} are the tissue contaminant concentrations of the various species and all of the other terms are as defined in Equation 3-10. Since the βs are all constants, each of these equations is equivalent to the generic form of the relationship for organic contaminants given in Equation 3-8.

Similarly, Equation 3-11 can be separated into four species-specific equations:

$$Ln(C_{fAE}) = (\beta_0 + \beta_3) + (\beta_1 + \beta_4)Ln(C_{s-Fe})$$

Eq. 3-16

$$Ln(C_{fBC}) = (\beta_0 + \beta_6) + (\beta_1 + \beta_7)Ln(C_{s-Fe})$$

Eq. 3-17

$$Ln(C_{fMM}) = (\beta_0 + \beta_9) + (\beta_1 + \beta_{10})Ln(C_{s-Fe})$$

Eq. 3-18

$$Ln(C_{fWP}) = (\beta_0 + \beta_{12}) + (\beta_1 + \beta_{13})Ln(C_{s-Fe})$$

Eq. 3-19

where the C_{fi} are the tissue contaminant concentrations of the various species and all of the other terms are as defined in Equation 3-11. Each of these equations is equivalent to the generic form of the relationship for inorganic contaminants given in Equation 3-9.

Equations 3-10 and 3-11 formed the basis for the regression analysis for the organic and inorganic data (respectively) for the eleven contaminants and four fish species. By conducting a multivariate regression in log-space, the regression expressions described above represent linear combinations of the log-transformed data, with $Ln(C_{s-oc})$, $Ln(f_{oc})$ and $Ln(C_{s-Fe})$ as the independent variables, $Ln(C_f)$ as the dependent variable and the βs as the coefficients of the regression. By allowing the βs associated with the independent variables to vary, the linear multivariate regression technique enables the identification and quantification of non-linear relationships between fish and crab tissue concentrations (C_f) and the environmental variables C_{s-oc}, f_{oc} and C_{s-Fe}. As will be discussed below, the models were successful in the vast majority of cases.

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3.2.2 Determination of BSAF and BAF Values.

When the regression approach described above failed to yield a relationship between tissue and sediment concentrations that met statistical significance and accurately represented the data, an alternate means of relating tissue and sediment contaminant concentrations was applied. Specifically, a BSAF (for organic contaminants) or a BAF (for inorganic contaminants) was determined using the available data. Given that a meaningful regression could not be found, these factors were estimated using the averaging approach described by Burkhard, 2009, as follows:

$$\frac{C_f}{f_{lipid}} = BSAF * C_{s-oc} \qquad \text{Eq. 3-20}$$

where BSAF = the biota-sediment accumulation factor in g-oc / g-lipid, and the other parameters are as defined previously.

This expression was then manipulated to:

$$BSAF = \frac{C_{fish}/f_{lipid}}{C_{s-oc}} \qquad \text{Eq. 3-21}$$

For metals, the formulations are similar, but there is no normalization term for the biota tissue, as follows:

$$C_{fish} = BAF * C_{s-Fe} \qquad \text{Eq. 3-22}$$

which becomes:

$$BAF = \frac{C_{fish}}{C_{s-Fe}} \qquad \text{Eq. 3-23}$$

where BAF = the biota-sediment accumulation factor for metals in g-Fe / g-tissue wet weight, and the other factors are as defined previously.

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Using these formulas, it is possible to calculate a BSAF or BAF for each pair of reported tissue and sediment contaminant concentrations. For sample pairs from the Lower Passaic River, these pairs are comprised of an individual tissue contaminant concentration and the mean concentration of a set of approximately 70 associated sediment samples. For NY/NJ Harbor samples, the sediment concentration is more typically based on about 10 samples. The mean BSAF for an organic contaminant is then given by:

$$\overline{BSAF_{j,k}} = \frac{1}{n} \sum_{i=1}^{n} BSAF_{i,j,k} \qquad \text{Eq. 3-24}$$

where: $\overline{BSAF_{j,k}}$ = the mean BSAF for species *k* and organic contaminant *j*

n = the number of sample pairs available for species *k* and organic contaminant *j*, and

$BSAF_{i,j,k}$ = the estimate of the BSAF determined for single tissue-sediment pair *i* for species *k* and organic contaminant *j*.

A similar formulation for the mean BAF is as follows:

$$\overline{BAF_{j,k}} = \frac{1}{n} \sum_{i=1}^{n} BAF_{i,j,k} \qquad \text{Eq. 3-25}$$

where: $\overline{BAF_{j,k}}$ = the mean BAF for species *k* and inorganic contaminant *j*

n = the number of sample pairs available for species *k* and inorganic contaminant *j*, and

$BAF_{i,j,k}$ = the estimate of the BAF determined for single tissue-sediment pair *i* for species *k* and inorganic contaminant *j*.

In one species-contaminant pair, specifically American eel and copper, a median BAF was used. This was determined from the median of the $BAF_{i,j,k}$ values. The results are discussed in the next section.

3.3 Discussion of Regression, BSAF and BAF Results

Using Equation 3-10 for organic contaminants and Equation 3-11 for inorganic contaminants, eleven regression analyses were run, one for each contaminant, using the

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data identified in Table 3-1. The results of these analyses were used to generate various diagnostic tables and figures to assess the quality of the regression fits. These tables and figures are described below. Overall, the regression models were successful in achieving statistically significant results with adjusted R-squared values in the range of 0.44 to 0.92 in ten of the eleven regression runs. These statistically significant values reflected the models' ability to characterize the relationship between contaminant concentrations in fish and crab tissue and contaminant concentrations in sediment as well as the differences in contaminant concentrations among species.

Using the results of the 11 regression models and combining them according to Equations 3-12 to 3-15 for organic contaminants, and Equations 3-16 to 3-19 for inorganic contaminants, a set of model fit parameters was developed for each species-contaminant pair. The parameters for the successful regression fits are provided in Table 3-3 for organic contaminants and in Table 3-4 for inorganic contaminants. For five of the 44 species-contaminant pairs, the fit was not considered successful and a BSAF or BAF calculation was employed instead. These cases are discussed later in this section.

To be considered a successful regression, the results had to satisfy the following criteria:

- The primary regression model had to yield a statistically significant result.
- An inspection of the individual species plots for the contaminant yielded an unbiased distribution for the predicted *vs.* actual tissue concentrations. (*i.e.*, the regression result is unbiased for the individual species-contaminant pair.)
- An inspection of the regression result expressed as a BSAF or BAF was consistent with the individual BSAF or BAF values determined from discrete samples when plotted against TOC-normalized sediment concentration (*i.e.*, the regression result when expressed as a BSAF or BAF is consistent with individual estimates of the BSAF or BAF).
- An inspection of the relationship between lipid-normalized contaminant concentration in tissue *vs.* the TOC-normalized contaminant concentration in sediment yielded a curve consistent with expected behavior and with the curves for the other species examined for the contaminant (*i.e.*, the predicted behavior

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between fish and sediment is consistent with observations and with the expected parallel behavior observed for the same contaminant in other species).

For all 11 regressions, the regression model was statistically significant, satisfying the first criterion. The R-squared values fell between 0.44 and 0.92 for ten of the 11 models. The exception was the model for copper, which was run on a single species, blue crab. This model was statistically significant but only yielded an R-squared value of 0.16. The regression results for copper for the other species did not satisfy other criteria, as discussed below.

While the high R-squared values for the main regression models are important accomplishments, they do not reflect the ability of the models to assess the relationship between sediment and tissue for each individual species-contaminant pair. However, R-square values for the individual species-contaminant pairs will lack the benefit of having fit the entire set of data for the contaminant in question. Thus, to initially assess the goodness of fit for the model, the predicted *vs.* actual tissue contaminant concentrations were plotted for the model as a whole and then for the individual species. The predicted tissue concentration in each pair was calculated by the regression model using the contaminant sediment concentration, TOC and lipid content values corresponding to the measured fish tissue concentration. These plots are shown in Figures 3-8 to 3-18. Each of these figures is composed of two diagrams, as parts “a” and “b” of the figure. In part “a” of the figure, the entire set of data used in the regression is plotted, with color-coding by species. Note that the scales for each of the figures are natural log-based, and not log-base 10. In part “b” of the figure, the individual species results are plotted, using consistent scales across all species shown. In each diagram, a 1-to-1 line is included for reference.

Evident in the part “a” portion of Figures 3-8 to 3-18 is the good overall quality of fit for these regression models. In each instance, the tissue data scatter symmetrically about the one-to-one line. While the scatter may be greater for some contaminants relative to the others, the models represent the data well, consistent with the high adjusted R-squared

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values noted above. In part “b” of the figures, the same symmetrical scatter carries through to the individual species, consistent with an acceptable fit and with the underlying premise that each species responds to the presence of the contaminant in the sediment in a similar fashion.

As part of the generation of part “b” of each of these figures, an effective adjusted R-squared term was calculated for each of the 44 species-contaminant pairs. This was done by calculating an R-squared term for matched pairs of predicted and measured contaminant tissue concentrations. These R-squared values are reported in Tables 3-3 and 3-4 for organic contaminants and inorganic contaminants, respectively for the 39 successful species-contaminant pairs. For organic contaminants, the R-squared values ranged from 0.08 to 0.923. 2,3,7,8-TCDD had the highest R-squared values, followed by the chlorinated organics. For inorganic contaminants, the R-squared values were consistently lower, between -0.075 and 0.31. While the high values for individual species-contaminant R-squared terms can be used as clear evidence for the strength of the model and its ability to fit an individual species-contaminant pair, a poor R-squared term cannot be used as an indication of a poor model but only a poor fit for an individual species-contaminant pair. This is because, as mentioned above, these individual R-squared values do not reflect the statistical strength obtained by combining the various data sets together. Note that although the individual R-squared terms were low for both mercury and lead, the overall model R-squared values were 0.68 and 0.69.

Besides other factors that can introduce variability, the range in goodness of fit can be at least partially attributed to the range of exposure concentrations. 2,3,7,8-TCDD in blue crab, with an R-squared of 0.923, had a range of sediment concentrations spanning two orders of magnitude while the Total PAHs in mummichog, with an R-squared of 0.08, had a sediment concentration range that was little more than a factor of two. In a similar fashion, the inorganic contaminants data showed a limited range. However, taken together, the data were sufficient to yield well-behaved results that showed consistency across species.

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To support the use of the regression results in the risk assessments for the FFS, the uncertainty on the regression results were summarized as a function of sediment concentration. Specifically, Tables 3-5 and 3-6 provide the upper and lower confidence limits on the regression model curves, expressed as a percentage of the predicted tissue concentration. A review of these tables shows very good model confidence, particularly in the areas where data are available. In these portions of the curve, the 95 percent confidence limits are often of the order of +30/-20 percent.[26] While the estimated uncertainty does increase moving away from the central portion of the data as expected, the use of the model also provides a basis to estimate uncertainty for the tissue-sediment relationship outside the areas bounded by data. This information can be considered in the risk analyses and the remedial decision process.

For five species-contaminant pairs, the regression results did not satisfy the criteria described above. In these instances, a BSAF or BAF was calculated from the individual tissue-sediment pairs. For four of the five species-contaminant pairs: American eel-Total PCBs, white perch-Total PCBs, mummichog-copper, and white perch-copper, the BSAF or BAF was based on the mean of the individual tissue-sediment pairs. For the American eel-copper pair, the BAF values appeared skewed while spanning a wide range. As a result the median BAF was selected for this species-contaminant pair. The results for predicted *vs.* actual tissue values are presented in Figures 3-19 to 3-20 for the organic and inorganic contaminants, respectively. In general, these populations are characterized by a very narrow range of predicted tissue concentrations, reflecting a similarly narrow underlying range of sediment concentrations, thus limiting the usefulness of the regression model. Tables 3-3 and 3-4 contain the values for the BSAFs and BAFs, respectively, along with estimates of the standard deviations and standard errors on these terms.

The next step to assess the quality of the regression was a comparison of the regression model result expressed as a BSAF or BAF against the individual estimates of the BSAF

[26] This information is not included in the tables themselves but can be obtained by matching the table to the figures presented in this subsection.

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or BAF determined from the sample data. The regression curve and BSAFs were plotted against the TOC normalized sediment concentrations for organic contaminants. For inorganic contaminants, the regression curve and BAFs were plotted against the iron-normalized sediment concentration. For ideal agreement, the BSAF or BAF values should fall along the regression curve. More realistically, the data values should scatter along the regression curve. Additionally, the regression curve should plot as a horizontal line if the BSAF or BAF is a constant. Any deviation from the horizontal implies a non-linear relationship between tissue and sediment contaminant concentrations. The results for the regression models and for the five species-contaminant pairs fitted with a single BSAF or BAF are shown in Figures 3-21 to 3-31. Each figure represents a single contaminant. There are four parts to each figure, one for each of the species analyzed.

The initial review of these figures shows that the regression model typically falls within the middle of the data, as desired. A further review of these figures leads to an important observation. For the vast majority of species-contaminant pairs, the BSAF or BAF increases with decreasing sediment contaminant concentration and the regression curve slopes upward to the left in each figure. This is direct evidence of a non-linear relationship between tissue contaminant concentration and sediment contaminant concentration. The indication of increasing sensitivity to sediment concentrations was indicated or suggested in 36 of the 44 species-contaminant pairs. This trend is consistent with Burkhard *et al.*, 2013 and Cretney and Yunker, 2000, who observed the increase in sensitivity at lower concentrations as well. The five contaminants that were not successfully fitted by the regression model were assigned constant BSAFs or BAFs, which plot as horizontal lines in these figures. Two of the species-contaminant pairs suggest behavior indistinguishable from a constant BSAF or BAF, specifically white perch with HMW PAH and blue crab with copper. One species-contaminant pair exhibits decreasing sensitivity with lower concentration, American eel and Dieldrin. The reason for this response is not known. However, the target levels for Dieldrin in American eel based on the risk assessments are within the range of observations, thus any PRG defined for Dieldrin based on American eel will be constrained by data and not based on an extrapolated model curve whose behavior is unusual.

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The last step in the review of the regression model output is to compare the regression model in the context of the lipid-normalized contaminant concentration in tissue *vs.* the TOC-normalized contaminant concentration in sediment. Using a log-log plot simplifies the visual identification of linear *vs.* nonlinear relationships as well as the degree of non-linearity in the regression model result. These plots also enable a direct comparison of the model output to the actual data, which can be independently reviewed for correlation between tissue and sediment contaminant concentrations. Figures 3-32 to 3-42 present the regression model result, BSAF or BAF as appropriate for each of the eleven contaminants. Like Figures 3-21 to 3-31, there are four parts to each figure, representing the result for each of the species examined. The diagrams themselves represent the actual TOC-normalized contaminant sediment concentrations plotted against lipid-normalized contaminant tissue concentrations. The regression model results are presented using the average TOC and average lipid content of the data presented.[27]

Also shown in each plot is a dashed blue line. This line represents the slope of a line with a linear relationship between TOC-normalized contaminant sediment concentrations and lipid-normalized contaminant tissue concentrations. On the log-log scale, any species-contaminant pair with a constant BSAF or BAF will plot parallel to this line. Thus the five species-contaminant pairs that were not fit with a regression model plot directly parallel to this line. Deviations from this slope indicate variation in the BSAF or BAF with sediment contaminant concentration and therefore a non-linear relationship. The greater the deviation from this slope, the greater the degree of nonlinearity in the relationship. Note that since the lipid fraction is held constant for determining the regression curve in each diagram, any deviation for linearity is due to a nonlinear response to sediment contaminant concentration and not to lipid content. Lastly, the direction of the slope difference is also diagnostic. Specifically, regression curves with slopes less than the dashed blue line represent relationships with increasing sensitivity at lower sediment concentrations (*i.e.*, increasing BSAF or BAF at lower sediment

[27] The model results do not use the results presented in Table 3-2, which are generic to the Lower Passaic River and not specific to the data in each diagram, which include areas outside the Lower Passaic.

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contaminant concentrations). Regression curves with slopes steeper than the dashed blue represent the opposite condition.

A review of these figures confirms the same observation as with Figures 3-21 to 3-31, 36 out of 44 of the species-contaminant pairs show increasing sensitivity at lower sediment contaminant concentrations. However, these diagrams also permit an assessment of the nonlinearity of a given pair and permit the comparison of the non-linearity across species for a given contaminant.

In addition to illustrating the relationship between TOC-normalized contaminant sediment concentrations and lipid-normalized contaminant tissue concentrations, many of the plots show horizontal lines. These lines indicate the current proposed target concentrations for the species shown on the plot. That is, these are the acceptable risk-based body burdens for the fish or crab tissue, expressed on a lipid-normalized basis. The placement of these lines on the figures permits an assessment of the certainty associated with a sediment concentration corresponding to these target tissue concentrations. In many instances, the target tissue concentration crosses the regression model curve in the vicinity of actual data, placing a high degree of confidence on the selection of a sediment threshold corresponding to this tissue concentration. See for example, the ecological threshold for any of the 2,3,7,8-TCDD diagrams in Figure 3-32. In each case, the intersection of the regression curve with the target tissue concentration line falls within a cloud of measurement data, adding certainty to the species-contaminant relationship at an important threshold.

This relationship for 2,3,7,8-TCDD and the ecological target concentration can be contrasted with the minimum target concentration related to human health concerns and Total PCB in American eel or white perch. In these instances, the BSAF curves cross the target concentration nearly two order of magnitude below the bulk of the measurements. As a result, there is substantially greater uncertainty in relating the target tissue concentration to a target sediment concentration for these conditions.

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A review of the diagnostic figures prepared from the regression analyses leads to the following conclusions:

- A multivariate regression analysis provided a robust way to assess the available data and maximize the ability to quantify the relationship between tissue and sediment concentrations across a broad range of contaminant concentrations and across species.
- By several measures of quality of fit, the regression model was able to capture the general trends between contaminant tissue concentrations and contaminant sediment concentrations in the vast majority of species-contaminant pairs examined. The regression model utilized lipid content and TOC (organic contaminants), or iron content (inorganic contaminants) in capturing these trends
- The regression successfully characterized relationships between tissue and sediment for 39 of the 44 species-contaminant pairs considered.
- The regression model results can be used to identify areas of greater confidence and areas of less confidence along the model curve.
- For 36 of the 44 pairs examined, the regression results indicate or at least suggest an increase in the effective BSAF or BAF at decreasing sediment contaminant concentrations. That is, there is greater sensitivity to contaminant exposure at lower sediment concentrations for most animals and contaminants examined.
- Based on the success of the regression model, the basis for estimating surface sediment contaminant concentrations developed for this analysis (large area-based average concentrations) was justified as a viable method to estimate surface sediment exposures.
- By incorporating data from the NY/NJ Harbor in the regression analysis, the regressions addressed a broader range of concentrations, leading to better regression strength.
- Incorporating NY/NY Harbor also provided data close to the target tissue concentrations for several of the species considered in the risk assessment.
- Finally, by incorporating NY/NJ Harbor data and Lower Passaic River data, the regression model was able to quantify the change in the effective BSAF or BAF

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over a broad range of conditions, adding confidence to interpolation or extrapolation of the model results.

3.3.1 Correction factors for tissue types not included in the regression

The regression considered four species-tissue combinations. These combinations address a large number of ecological and human health exposure pathways. However, two additional tissue types are needed for the risk assessment analyses for the FFS: whole body concentrations for white perch and fillet concentrations for American eel. These two tissue types did not exist in the available data sets at sufficient quantities to warrant bringing them through the regression analysis. However, enough data of each type exists, along with a corresponding tissue type used in the regression for the 2009 dataset to support the development of a correction factor. The correction factor is intended to adjust the contaminant concentrations estimated for white perch on a fillet basis to a whole body basis, when whole body estimates are needed. The correction for organic contaminants must account for differences in lipid since the tissue types are quite different in lipid content. Failure to account for this will add substantively to the uncertainty in the correction factors for the organic contaminants.

As a basis for this correction factor, both white perch whole body and white perch fillet with skin samples exist in the 2009 dataset. The correction factors were developed for organic and inorganic contaminants separately. For the organic contaminants, the ratio of the concentrations of ten of the 11 contaminants were calculated to develop a single average correction factor for all organic contaminants. Total PAHs was excluded in this calculation since its inclusion would double count the PAHs in the determining the average factor. The choice of a single ratio was made based on the lipophillic nature of the contaminants and the close agreement of the individual ratios. The calculation is illustrated in Table 3-7. Essentially, a factor is determined for each organic contaminant based on the ratio of the mean lipid-normalized concentration in the 2009 white perch whole body samples over the mean of the lipid-normalized concentrations in the 2009 white perch fillet concentrations, *i.e.*, a ratio of the mean values. Note that the data were such that the whole body values available were not determined by an analysis of the parts

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(*i.e.*, fillet result plus offal[28] result). Rather the whole body samples and the fillet samples were obtained from different animals. Thus the fillet results and whole body results were not matched pairs and the correction factors had to be determined based on the ratio of the mean values.

Given the relatively small range in the ratio across all the different compounds, the compound specific means were averaged into a single mean ratio of 1.62. Thus on a lipid-normalized basis, whole body concentrations are on average 1.62 times higher than fillet concentrations. Additionally, the lipid content of the white perch whole body is 2.29 times higher than the fillet lipid content. These factors combine multiplicatively to convert fillet concentration to whole body concentration. Thus on average, the whole body concentration for an organic contaminant is estimated to be (1.62 x 2.29) or 3.71 times higher than the fillet concentration.

A similar set of calculations was performed for inorganic contaminants in white perch whole body and fillet samples for 2009. In this case, however, no lipid correction is needed and the concentrations are not normalized to lipid. Additionally, the tissue ratios for the inorganic contaminants are not sufficiently similar in magnitude to combine them. For white perch, the inorganic contaminant concentrations must be converted by the inorganic specific ratio. The calculation is presented in Table 3-8.

For American eel, a factor was needed to convert the whole body estimates from the regression analysis to a fillet basis. The calculation process is identical to the procedure used for organic and inorganic contaminants for white perch. Like the white perch samples, the American eel samples for whole body and those for skinless fillet were obtained from separate specimens and do not represent matched pairs. In this instance, the mean American eel skinless fillet concentrations for organic contaminants are 0.605 times the mean whole body concentrations or about 40 percent (1-0.605) lower. The calculations for American eel are presented in Tables 3-9 and 3-10.

[28] In this context, offal is the remainder of a specimen after a fillet or similar portion has been removed.

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3.3.2 Comparison of Estimated BSAFs with Literature Values

The USEPA BSAF database[29] consists of approximately 20,000 BSAF values compiled from the literature, representing 20 locations (mostly Superfund sites) for nonionic organic chemicals (*e.g.*, PCBs, PCDDs, PCDFs, PAHs, DDTs and other pesticides. Fresh, tidal, and marine ecosystems are included in the data set, and species in the data set include fish and benthic species (e.g., lobster, crayfish, and benthic invertebrates). One of the explicit objectives cited by USEPA for developing this tool was to evaluate the reasonableness of BSAFs from other locations. The USEPA's analysis included evaluation of a subset of contaminants pertinent to the FFS Study Area including HMW PAHs, Chlordane, Dieldrin, Dichlorodiphenyldichloroethane (DDD)/ Dichlorodiphenyldichloroethylene (DDE)/DDT, Total DDx, Total PCBs and 2,3,7,8-TCDD.

For the purposes of this report, the BSAFs derived for the FFS Study Area from site-specific data are plotted with the regression model curves and the BSAFs available from the USEPA BSAF database. These are shown where available. Specifically, Figures 3-21 through 3-28 show USEPA BSAF values along with those derived for this report. In most instances there is good agreement with the USEPA BSAF values falling close to the cluster of values derived for this report (see Figure 3-22c, for example). In some instances, the USEPA data also confirm the trend between lipid-normali*zed* contaminant tissue concentrations and TOC-normal*ized* contaminant sediment concentrations (a good example is shown in Figure 3-25c). In other instances, the absolute magnitudes of the factors differ but the trend with TOC-normalized contaminant sediment concentration is consistent (see Figure 3- 24a). While there is not exact agreement between the USEPA BSAF values and those derived for this report, there is sufficient agreement to conclude that the magnitude of the factors derived for the Lower Passaic River are consistent with the available data.

[29] Available at http://www.epa.gov/med/Prods_Pubs/bsaf.htm.

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4 SUMMARY

This report is comprised of two separate analyses:

1. An evaluation of the variation of fish and crab tissue concentrations over time and as a function of river mile in the lower eight miles of the Lower Passaic River, and
2. A multivariate regression on contaminant concentrations in fish and crab tissue and in sediment to establish a relationship among these media for different contaminants. This analysis is intended to estimate fish and crab body burdens in response to surface sediment concentrations.

Both analyses were conducted to examine the functional relationship between the sediment contamination in the Lower Passaic River and aquatic biota relevant to the risk assessment process.

Overall, there were 26 fish species available in the project database considered in this analysis, from four main studies of the Lower Passaic River. Of these species, four were selected for detailed analysis based on the spatial and temporal availability of measurements, their importance to human consumption, and their trophic level, the latter criteria in order to represent the Lower Passaic River estuarine food web. The four species selected for analysis were:

- Blue Crab (*Callinectes sapidus*)
- Mummichog (*Fundulus heteroclitus*)
- White perch *(Morone americana)*
- American eel (*Anguilla rostrata*).

The specific tissue sample types for each of these four species varied among studies but were grouped together when appropriate.

Eleven contaminants or contaminant classes were examined in this data evaluation report. The contaminants included 2,3,7,8-TCDD, Total PCBs, pesticides, PAHs, and metals.

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Variation of Fish and Crab Tissue Concentrations over Time and as a Function of River Mile

The evaluation of fish tissue concentrations with river mile led to the following Summary Points:

1. The spatial distribution of contaminant concentrations in biota tissue were similar in character to those observed for surface sediments. Specifically, biota tissue concentrations were highly variable on small spatial scales within the Lower Passaic River while trends in the mean concentrations with river mile were shallow, if not non-existent. Local variation in tissue concentration is often an order of magnitude or more (*i.e.*, maximum/minimum = 10 or more) while mean concentrations varies about a factor of two (*i.e.*, maximum/minimum = 2) and often less.
2. Various tissue types for a given species and contaminant often exhibit the following behaviors (*e.g.*, see Figure 2-1a):
    a. Great differences in absolute concentration between tissue types of the same species (*e.g.*, the 2,3,7,8-TCDD concentrations in hepatopancreas tissue for blue crab is roughly 15 to 20 times greater than those in the muscle samples)
    b. Similar amounts of local variation in contaminant concentration within a tissue type (*e.g.*, 2,3,7,8-TCDD concentrations in any blue crab tissue type varies about a factor of three at any given river mile)
    c. Parallel trends in mean contaminant concentrations with river mile (*e.g.*, 2,3,7,8-TCDD concentrations in blue crab across all four tissue sample types are either flat or increased about 50 percent from RM1 to RM8).
3. For most contaminants, mean concentrations gradually increase upstream, although trends are very weak and only marginally significant. For the organic contaminants, lipid-normalized concentrations show less local variation than the original results but still confirm observations of little trend of the mean lipid-normalized concentrations with river mile.

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4. There are significant variations in the mean lipid content over time for three of the four species examined. Specifically, blue crab, mummichog and white perch all show decreased lipid concentrations with time; the decrease in mean lipid concentration for the latter two species is statistically significant. These lipid content variations help explain much of the year-to-year variation in organic contaminant concentrations. This is an important observation since concentrations of several organic contaminants otherwise appear to decline in biota tissue with time, absent of lipid normalization. The cause of lipid content variation with time is not known but may represent variation in mean specimen size or age, or represent true environmental variation.
5. Year-to-year variations in lipid-normalized organic contaminant concentrations do not indicate consistent trends with time and are often inconsistent across species (*i.e.*, concentrations of one contaminant may increase in one species between studies while decreasing between studies in another species, or even another tissue type). Overall, there is little support for consistently increasing or decreasing concentrations of any contaminant in biota tissue across all species with time. More importantly, the lack of consistent temporal trends across the species and tissue types and the similar degree of variability and lack of trend with river mile, consistent with the sediment results, indicates that these variations in contaminant concentrations in biota tissue do not represent variations in the average level of exposure but are probably attributable to factors related to analytical differences among studies, variations in sample types (*e.g.*, variation in number, size, age or tissue type of specimens in a typical sample), seasonal variations in the time of collection, or other environmental factors not related to the average sediment exposure concentration.

Overall, this analysis documented the extensive presence of contamination in biota tissue throughout the lower eight miles of the Lower Passaic River, along with a strong correlation to the trends and variations observed in the sediments.

Relating Sediment and Tissue Contaminant Concentrations

A multivariate analysis was conducted to relate contaminant concentrations in tissue and sediment for 11 contaminants for the four species best represented in the available data. The available data included both sediment and tissue from the Lower Passaic River below RM13 as well and sediment and tissue data from the NY/NJ Harbor area.

Sediment concentrations for use in the regression analyses were derived in one of several ways. For biota samples from the Lower Passaic River comprised of wild-caught animals (American eel, blue crab and white perch for all collection efforts, and mummichog for 2010), the corresponding sediment concentration was estimated as the average sediment concentration in a four-mile window, extending two miles upstream to two miles downstream of the animal collection location. For the 1999 and 2000 mummichog locations only, sediment concentrations were based on samples collected in the immediate vicinity of the fish collection location. Finally, for biota samples from the NY/NJ Harbor area, the corresponding sediment concentration was based on samples collected in the general vicinity of the biota sample, representative of local conditions throughout most of the bay or waterway in which the biota sample was collected. For example, biota samples from Upper New York Bay were matched with the mean sediment concentration for all samples from Upper New York Bay.

Combining biota tissue samples the Lower Passaic River with those from the NY/NJ Harbor area yielded an extensive set of tissue and sediment concentrations for most contaminants. These data were employed via a series of multivariate analyses run on log transformed concentrations, one for each of the 11 contaminants. For organic contaminants, each multivariate analysis correlated contaminant concentration in tissue with sediment concentration, lipid content, sediment TOC, and species. For inorganic contaminants, each multivariate analysis correlated contaminant concentration in tissue with sediment concentration, sediment iron content and species. Iron-normalization for metals served the same purpose as organic carbon normalization for organic contaminants. In each instance, the normalizing factor serves as a measure of the concentration of fine-grained contaminated particles that presumably represent the matrix

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for biota exposure. In this manner, eleven multivariate analyses were able to generate regression results for 44 species-contaminant pairs. Combining species in the regression allowed the "sharing" of information across species, with the premise that factors affecting contaminant behavior would be similar across species. Of the 44 species-contaminant pair results generated by the multivariate regressions, 39 were considered successful based on statistical criteria and visual inspection of the results. For the five remaining species-contaminant pairs, the relationship was determined by a simple mean or median BSAF or BAF, as appropriate, since the data did not support a more robust model.

The results of these multivariate analyses were reduced to coefficients for use in specific species-contaminant pair calculations. These coefficients are presented in Tables 3-3 and 3-4. Uncertainty estimates for these regression results are presented in Tables 3-5 and 3-6. The results of the multivariate regressions support the following conclusions:

- By several measures of quality of fit, the regression model was able to capture the general trends between contaminant tissue concentrations and contaminant sediment concentrations in the vast majority of species-contaminant pairs examined. The regression model utilized lipid content and TOC (organic contaminants), or iron content (inorganic contaminants) in capturing these trends.
- The regression model results could identify areas of greater confidence and areas of less confidence along the model curves relating tissue and sediment contaminant concentrations.
- For 36 of the 44 pairs examined, the regression results indicate or at least suggest an increase in the effective BSAF or BAF at decreasing sediment concentrations. That is, there is greater sensitivity to contaminant exposure at lower sediment concentrations for most animals and contaminants examined.
- Based on the success of the regression model, the basis for estimating surface sediment contaminant concentrations developed for this analysis (large area-based average concentrations) was justified as a viable method to estimate surface sediment exposures.

R2-0027519

- By incorporating data from the NY/NJ Harbor in the regression analysis, the regressions addressed a broader range of concentrations, leading to better regression strength.
- Incorporating NY/NY Harbor also provided data close to the target conditions for several of the species considered in the risk assessment.
- Finally, by incorporating NY/NJ Harbor data and Lower Passaic River data, the regression model was able to quantify the change in the effective BSAF or BAF over a broad range of conditions, adding confidence to interpolation or extrapolation of the model results.

R2-0027520

5 ACRONYMS

2,3,7,8-TCDD	2,3,7,8-Tetrachlorodibenzo-p-dioxin
BAF	Bioaccumulation Factor
BSAF	Biota-Sediment Accumulation Factor
CARP	Contaminant Assessment and Reduction Program
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COPCs	Contaminants of Potential Concern (Human Health)
COPECs	Contaminants of Potential Ecological Concern
CPG	Cooperating Parties Group for the Lower Passaic River
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
FFS	Focused Feasibility Study
HMW	High Molecular Weight
HSD	Honestly Significant Difference
LMW	Low Molecular Weight
LPRSA	Lower Passaic River Study Area
m/hr	meters/hour
µg/kg	micrograms/kilogram of sediment
mg/kg	milligrams/kilogram of sediment
NBSA	Newark Bay Study Area
NOAA	National Oceanic and Atmospheric Administration
NY/NJ	New York/New Jersey
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
PCDD	Polychlorinated Dibenzodioxin
PCDF	Polychlorinated Dibenzofurans
pg/g	picograms/gram of sediment

R2-0027521

PRG	Preliminary Remediation Goal
ppt	parts per thousand
REMAP	Regional Environmental Monitoring and Assessment Program
RI	Remedial Investigation
RI/FS	Remedial Investigation and Feasibility Study
RM	River Mile
TOC	Total Organic Carbon
Total DDx	Sum of the three DDT metabolites (4,4'-DDE, 4,4'-DDD and 4,4'-DDT)
TSI	Tierra Solutions, Inc.
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency

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TABLES

Table 2-1

Summary of Tissue Sample Count by Species in the Lower Passaic River

Tissue Species	All Datasets Ranged from River Mile 0 to 15[1]		Datasets Used in the Analysis Ranged from River Mile 0 to 11[2]	
	Sample Count	Tissue Type	Sample Count[3]	Tissue Type
Blue crab	168	All edible tissue, hepatopancreas, muscle, carcass, edible muscle, muscle/hepatopancreas, whole body (soft tissue)	78	Muscle/hepatopancreas, Whole body (soft tissue), All edible tissue
White perch	95	Whole body, carcass, fillet with skin, skinless fillet, whole body minus head and viscera	54	Fillet with skin on, Whole body minus head and viscera
Mummichog	78	Whole body, Whole organism	40	Whole body, Whole organism
American eel	75	Whole body, carcass, fillet with skin, skinless fillet, whole body minus head and viscera	21	Whole body
White catfish	38	Carcass, skinless fillet		
Common carp	24	Whole body, fillet with skin		
Channel catfish	22	Carcass, skinless fillet		
Adult Striped Bass	20	Whole body, skinless fillet		
Transplant ribbed mussel	17	Whole body (soft tissue)		
Blackworm	14	Not available		
Brown bullhead	12	Whole body, skinless fillet		
White sucker	10	Carcass, fillet with skin		
Silverside	9	Whole body		
Atlantic menhaden	6	Whole body		
Largemouth bass	6	Carcass, fillet with skin		
Smallmouth bass	6	Carcass, fillet with skin		
Polychaeta	5	Not available		
Bluefish	3	Whole body, skinless fillet		
Gizzard shad	3	Whole body		
Juvenile striped bass	3	Whole body		
Northern pike	2	Carcass, fillet with skin		
Striped Bass	2	Fillet		
Macoma nasuta	1	Not available		
Nereis virens	1	Not available		
Pumpkinseed sunfish	1	Whole body		
Silver Shiner	1	Whole body		
Spottail Shiner	1	Whole body		

Notes:
1. Samples from year 1995, 2009 CPG, 2010 CPG and CARP 1999-2000 datasets were included in the sample count.
2. Samples from 2009 CPG, 2010 CPG and CARP 1999-2000 datasets were included in the sample count.
3. Sample count represents the maximum count of any parameters was analyzed.

Table 2-2: Evaluated Contaminants in Data Evaluation Report No.6

Chlorinated Organics	PAHs	Metals
2,3,7,8-TCDD[1]	*Total PAHs*[1]	Copper[3]
Total PCB[1] *(sum of Aroclors)*	*High Molecular Weight PAH (HMW PAH)* [1]	Lead[2,3]
Total DDx[1] *(sum of 4,4'-DDT, 4,4'-DDD and 4,4'-DDE)*	*Low Molecular Weight PAH (LMWPAH)* [1]	*Mercury*[1]
Total Chlordane (sum of alpha and gamma forms)		
Dieldrin		

Notes: 1. Italicized font indicates available low concentration data from REMAP NY/NJ Harbor for sediment and from CARP for biota.
2. Lead low concentration available for blue crab only.
3. Copper and Lead low concentration data are not available for American eel.

Table 2-3: Summary Statistics for Blue Crab Samples from the FFS Study Area (RM1-RM7), Various Tissue Types

Contaminants	Sample Count	Minimum	Maximum	Mean	Median	Standard Deviation	Standard Error	Number of Nondetects	Detection Limit Range
2,3,7,8-TCDD (pg/g)	132	3.8	674	90	51	119	10	0	N/A
Total PCB (ug/kg)	135	16	19,710	1,268	320	2,466	212	23	67- 160
Dieldrin (ug/kg)	135	0.70	50	9.1	< 7	12	1.0	62	1.9 - 66
Total Chlordane (ug/kg)	135	0.10	202	12	< 5.8	24	2.1	59	0.58 - 100
Total DDx (ug/kg)	135	1.5	2,563	194	60	360	31	14	2.9 - 15
LMW PAH (ug/kg)	131	1.2	835	61	31	108	9.4	2	2.3 - 3.4
HMW PAH (ug/kg)	131	2.8	700	84	44	118	10	6	15 - 250
Total PAH (ug/kg)	131	3.2	1,535	144	74	211	18	0	N/A
Copper (mg/kg)	121	8.4	79	27	22	16	1.5	0	N/A
Lead (mg/kg)	127	0.03	2.4	0.40	0.29	0.39	0.03	10	0.11 - 0.42
Mercury (mg/kg)	135	0.03	0.32	0.11	0.09	0.07	0.01	3	0.09 - 0.10

Notes:
1. Blue crab tissue samples include: muscle, muscle + hepatopancreas, hepatopancreas, and carcass.
2. Table includes sample data from years 1995, 1999, 2000 and 2009.
3. N/A = Not applicable, all samples were detected.
4. Detection limit range is based on detection limits of non-detect samples only.
5. Median values labelled with "<" are non-detect values.

Table 2-4: Summary Statistics for Mummichog Samples from the FFS Study Area (RM1-RM7), Whole Body Samples

Contaminants	Sample Count	Minimum	Maximum	Mean	Median	Standard Deviation	Standard Error	Number of Non-detects	Detection Limit Range
2,3,7,8-TCDD (pg/g)	75	2.0	828	68	50	110	13	1	4 - 4
Total PCB (ug/kg)	73	116	1,160	549	556	224	26	0	N/A
Dieldrin (ug/kg)	74	1.7	13	3.8	< 6	2.8	0.33	51	3.3 - 9
Total Chlordane (ug/kg)	74	2.5	33	8.8	< 10	8.2	0.96	48	5 - 30
Total DDx (ug/kg)	74	7.5	365	63	49	56	6.5	2	15 - 15
LMW PAH (ug/kg)	75	9.5	329	69	49	61	7.1	0	N/A
HMW PAH (ug/kg)	75	4.2	455	41	27	61	7.1	1	250 - 250
Total PAH (ug/kg)	75	12	605	108	83	93	11	0	N/A
Copper (mg/kg)	71	1.9	7.2	3.5	3.3	1.0	0.12	0	N/A
Lead (mg/kg)	44	0.13	3.9	0.84	0.53	0.82	0.12	5	0.25 - 0.26
Mercury (mg/kg)	75	0.019	0.15	0.042	0.036	0.020	0.0023	4	0.09 - 0.10

Notes:
1. Mummichog tissue samples include whole body only.
2. Table includes sample data from years 1995, 1999, 2000 and 2010.
3. N/A = Not applicable, all samples were detected.
4. Detection limit range is based on detection limits of non-detect samples only.
5. Median values labelled with "<" are non-detect values.

Table 2-5: Summary Statistics for White Perch Samples from the FFS Study Area (RM1-RM7), Various Tissue Types

Contaminants	Sample Count	Minimum	Maximum	Mean	Median	Standard Deviation	Standard Error	Number of Nondetects	Detection Limit Range
2,3,7,8-TCDD (pg/g)	69	22	467	168	160	102	12	0	N/A
Total PCB (ug/kg)	77	191	10,490	2,912	2,855	1,907	217	0	N/A
Dieldrin (ug/kg)	77	0.30	80	19	14	17	1.9	26	0.6-66
Total Chlordane (ug/kg)	77	2.5	389	68	52	61	6.9	27	6-250
Total DDx (ug/kg)	77	22	960	257	219	184	21	0	N/A
LMW PAH (ug/kg)	69	17	544	144	125	89	11	0	N/A
HMW PAH (ug/kg)	69	11	333	83	56	68	8.2	0	N/A
Total PAH (ug/kg)	69	28	724	227	185	143	17	0	N/A
Copper (mg/kg)	47	0.31	51	10	6.8	13	1.8	0	N/A
Lead (mg/kg)	38	0.01	0.51	0.22	0.22	0.19	0.03	5	0.11-0.11
Mercury (mg/kg)	87	0.05	0.93	0.27	0.24	0.15	0.02	0	N/A

Notes:
1. White perch tissue samples include: carcass, skinless fillet, fillet with skin, whole body - hepatopancreas&viscera and whole body.
2. Table includes sample data from years 1999, 2000, 2009 and 2010.
3. N/A = Not applicable, all samples were detected.
4. Detection limit range is based on detection limits of non-detect samples only.

Table 2-6: Summary Statistics for American Eel Samples from the FFS Study Area (RM1-RM7), Various Tissue Types

Contaminants	Sample Count	Minimum	Maximum	Mean	Median	Standard Deviation	Standard Error	Number of Nondetects	Detection Limit Range
2,3,7,8-TCDD (pg/g)	45	4.5	70	21	16	15	2.3	0	N/A
Total PCB (ug/kg)	48	320	28,335	2,685	1,585	4,277	617	0	N/A
Dieldrin (ug/kg)	48	1.7	140	31	20	27	3.9	13	3.3-84
Total Chlordane (ug/kg)	48	2.5	526	55	36	80	12	13	5-110
Total DDx (ug/kg)	48	45	2,466	389	252	427	62	0	N/A
LMW PAH (ug/kg)	43	9.1	285	58	41	52	7.9	0	N/A
HMW PAH (ug/kg)	43	3.1	44	16	14	8.5	1.3	0	N/A
Total PAH (ug/kg)	43	13	297	74	56	55	8.4	0	N/A
Copper (mg/kg)	39	0.15	16	1.2	0.65	2.5	0.40	0	N/A
Lead (mg/kg)	28	0.02	1.6	0.28	0.26	0.32	0.06	6	0.8-0.82
Mercury (mg/kg)	48	0.07	0.72	0.36	0.34	0.15	0.02	0	N/A

Notes:

1. American eel tissue samples include: carcass, skinless fillet, fillet with skin, whole body - hepatopancreas&viscera and whole body.
2. Table includes sample data from years 1999, 2000, 2001 and 2009.
3. N/A = Not applicable, all samples were detected.
4. Detection limit range is based on detection limits of non-detect samples only.

Table 3-1. Tissue and Sediment Datasets Used in the Regression, BSAF and BAF Calculations

Species with (Tissue Type) or Sediment	Contaminants	Lower Passaic River Tissue data[1] (RM0-RM11) and Sediment data[2] (RM0-RM13)			NY/NJ Harbor Tissue data[3] (CARP) and Sediment data[4] (CARP, REMAP)		
		Sample Count[8]	Number of Nondetects	Data Source	Sample Count	Number of Nondetects	Data Source
American Eel (Whole Body from Lower Passaic River and (whole body - head&viscera) from NY/NJ Harbor)	2,3,7,8-TCDD	21	0	2000 TSI and 2009 CPG	5	1	1999 CARP
	Total PCB	21	0		6	0	1999 CARP
	Total DDx	21	0		6	0	2001 CARP
	HMW PAH	20	0		4	0	1999-2000 CARP
	LMW PAH	20	0		4	0	
	Total PAH	20	0		4	0	
	Copper	21	0		See Notes 6 and 7		
	Lead	15	0				
	Mercury	21	0		6	0	1999 CARP
	Dieldrin	15	0	2009 CPG	See Note 5		
	Total Chlordane	15	0				
Blue Crab (Muscle/hepatopancreas and all edible tissue)	2,3,7,8-TCDD	53	0	1999 CARP, 1999-2000 TSI and 2009 CPG	15	1	1999 CARP
	Total PCB	56	1		26	0	
	Total DDx	56	0		26	0	
	HMW PAH	52	0		15	11	
	LMW PAH	52	1		15	5	
	Total PAH	52	0		15	4	
	Copper	70	0		See Note 6		
	Lead	78	1		22	1	1999 CARP
	Mercury	78	0		26	0	
	Dieldrin	29	1	2009 CPG	See Note 5		
	Total Chlordane	29	1				
Mummichog (Whole Body)	2,3,7,8-TCDD	40	1	1999-2000 CARP, 1999-2000 TSI and 2010 CPG	4	1	1999-2000 CARP
	Total PCB	38	0		2	0	1999 CARP
	Total DDx	43	0		2	0	2001 CARP
	HMW PAH	42	1		4	0	1999-2000 CARP
	LMW PAH	42	0		4	0	
	Total PAH	42	0		4	0	
	Copper	37	0		See Notes 6 and 7		
	Lead	29	0				
	Mercury	41	0		4	0	1999-2000 CARP
	Dieldrin	21	0	2010 CPG	See Note 5		
	Total Chlordane	21	0				
White Perch (Whole body - head&viscera and fillet with skin)	2,3,7,8-TCDD	38	0	1999-2000 TSI and 2009 CPG	29	1	1999-2000 CARP
	Total PCB	44	0		36	0	1999-2000 CARP
	Total DDx	44	0		36	0	1999-2001 CARP
	HMW PAH	38	0		29	0	1999-2000 CARP
	LMW PAH	38	0		29	0	
	Total PAH	38	0		29	0	
	Copper	16	0		See Notes 6 and 7		
	Lead	16	0				
	Mercury	54	0		46	0	1999-2000 CARP
	Dieldrin	44	2		See Note 5		
	Total Chlordane	44	3				
Sediment (0 to 6 in)	2,3,7,8-TCDD	250	1	1999-2000 TSI, 2008 EPA and 2008-2010 CPG	87	2	1999-2000 CARP and REMAP 1998&2003
	Total PCB	241	2		53	4	
	Total DDx	250	0		77	13	
	HMW PAH	251	0		97	8	
	LMW PAH	251	0		97	16	
	Total PAH	251	0		97	8	
	Copper	258	0		103	0	
	Lead	257	0		105	0	
	Mercury	258	6		97	0	
	Dieldrin	213	3	2008 EPA and 2008-2010 CPG	See Note 5		
	Total Chlordane	212	0				

Notes:

1. Tissue samples were obtained from RM0 to RM11 of the Lower Passaic River.
2. Sediment samples represent locations from RM0 to RM13 of the Lower Passaic River.
3. Tissue samples were obtained from the NY/NJ Harbor as given in the 1999-2001 CARP datasets. Tissue samples represent only those locations where sediment samples were available in the same area. See Figure 3-1.
4. Sediment samples represent locations from the NY/NJ Harbor, as given in the 1999-2000 CARP, REMAP 1998 and REMAP 2003 datasets. Sediment samples represent only those locations where tissue samples were available in the same area. See Figure 3-1.
5. Only Lower Passaic River datasets were used in the dieldrin and total chlordane BSAF calculations. The large number of non-detect results for the NY/NJ harbor datasets prevented their use in the calculations. See text for discussion.
6. No copper data were available from NY/NJ harbor for the above four species.
7. No lead data were available from NY/NJ harbor except blue crab.
8. Sample count per contaminant will not match those given in Table 2-1 due to differences in the spatial extent and tissue types represented in the two tables.

Table 3-2: Summary Statistics for Sediment Samples from the NY/NJ Harbor used in the Regression, BSAF and BAF Calculations

Contaminants	Sample Count	Minimum	Maximum	Mean	Median	Standard Deviation	Standard Error	Number of Nondetects	Detection Limit Range
2,3,7,8-TCDD (pg/g)	87	0.08	35	5.3	3.4	6.4	0.69	2	0.52-3.6
Total PCB (ug/kg)	53	0.66	3,153	264	103	483	66	4	2.2
Total DDx (ug/kg)	77	0.25	401	20	7.0	51	6.0	13	0.25
LMW PAH (ug/kg)	97	5.0	49,610	2,100	501	7,190	750	16	5
HMW PAH (ug/kg)	97	5.0	106,900	5,670	2,030	14,600	1,490	8	5
Total PAH (ug/kg)	97	5.0	156,510	7,690	2,460	21,500	2,180	8	5
Copper (mg/kg)	103	1.9	365	68	60	68	6.7	0	N/A
Lead (mg/kg)	105	4.0	496	86	76	83	8.1	0	N/A
Mercury (mg/kg)	97	0.0085	7.0	0.90	0.64	1.00	0.10	0	N/A

Notes:
1. N/A = Not applicable, all samples were detected.
2. Detection limit range is based on detection limits of non-detect samples only.
3. Table includes NY/NJ Harbor data from 1999-2000 CARP, REMAP 1998 and REMAP 2003.

Table 3-3: Organic Parameters Coefficients Table

Model 1

$$C_f = e^{\wedge}\left[\beta_0 + \beta_1 * \ln(C_s/f_{OC}) + \beta_2 * \ln(f_L)\right]$$

Model 2

$$C_f = \mathrm{BSAF} * (C_s/f_{OC}) * f_L$$

Where: C_f = Tissue concentration
C_s = Sediment concentration
f_{oc} = Fraction of Total Organic Carbon in Sediment (unitless)
f_L = Lipid content in tissue(unitless)

Parameter	Species	Model Type	β_0	β_1	β_2	BSAF			Units		R^2
						Factor	Std Dev	Std Error	Tissue	Sediment	
2,3,7,8-TCDD	American Eel	1	0.09158	0.63439	1.18168				pg/g	pg/g	0.850
2,3,7,8-TCDD	Blue Crab	1	-2.54116	0.93792	0.54587				pg/g	pg/g	0.923
2,3,7,8-TCDD	Mummichog	1	1.59216	0.70923	1.25932				pg/g	pg/g	0.698
2,3,7,8-TCDD	White Perch	1	-0.00391	0.95369	1.34306				pg/g	pg/g	0.911
Total PCB	American Eel	2				0.9914	0.5566	0.1071	ug/kg	ug/kg	
Total PCB	Blue Crab	1	3.27274	0.50183	0.55885				ug/kg	ug/kg	0.302
Total PCB	Mummichog	1	-2.42699	0.94874	0.30150				ug/kg	ug/kg	0.374
Total PCB	White Perch	2				0.9176	0.2889	0.0722	ug/kg	ug/kg	
Dieldrin	American Eel	1	-2.32814	1.55071	0.84101				ug/kg	ug/kg	0.572
Dieldrin	Blue Crab	1	0.24536	0.35411	0.09025				ug/kg	ug/kg	0.134
Dieldrin	Mummichog	1	9.66352	0.06595	2.04146				ug/kg	ug/kg	0.636
Dieldrin	White Perch	1	2.78549	0.34235	0.57399				ug/kg	ug/kg	0.112
Total Chlordane	American Eel	1	3.44662	0.34651	0.65800				ug/kg	ug/kg	0.532
Total Chlordane	Blue Crab	1	4.55313	0.15523	0.98158				ug/kg	ug/kg	0.571
Total Chlordane	Mummichog	1	4.44414	0.76803	1.71386				ug/kg	ug/kg	0.831
Total Chlordane	White Perch	1	4.74107	0.42766	1.13363				ug/kg	ug/kg	0.730
Total DDx	American Eel	1	5.22982	0.29569	0.77243				ug/kg	ug/kg	0.624
Total DDx	Blue Crab	1	-0.46665	0.65774	0.16833				ug/kg	ug/kg	0.390
Total DDx	Mummichog	1	3.73575	0.35613	0.72683				ug/kg	ug/kg	0.238
Total DDx	White Perch	1	6.70305	0.34445	1.35177				ug/kg	ug/kg	0.564
HMW PAH	American Eel	1	-3.38267	0.65048	1.06779				ug/kg	ug/kg	0.561
HMW PAH	Blue Crab	1	-4.58837	0.67763	0.40568				ug/kg	ug/kg	0.161
HMW PAH	Mummichog	1	-9.73635	0.63814	-1.31243				ug/kg	ug/kg	0.190
HMW PAH	White Perch	1	-8.68349	1.02374	0.55762				ug/kg	ug/kg	0.790
LMW PAH	American Eel	1	-3.54429	0.69343	0.28305				ug/kg	ug/kg	0.270
LMW PAH	Blue Crab	1	-2.92707	0.48874	0.03414				ug/kg	ug/kg	0.128
LMW PAH	Mummichog	1	2.51498	0.33456	0.62366				ug/kg	ug/kg	0.105
LMW PAH	White Perch	1	-2.90347	0.83321	0.88768				ug/kg	ug/kg	0.789
Total PAH	American Eel	1	-3.95028	0.67295	0.37867				ug/kg	ug/kg	0.429
Total PAH	Blue Crab	1	-4.52659	0.66322	0.24278				ug/kg	ug/kg	0.183
Total PAH	Mummichog	1	-1.47361	0.44458	-0.04640				ug/kg	ug/kg	0.080
Total PAH	White Perch	1	-3.94124	0.82210	0.83788				ug/kg	ug/kg	0.845

Note:

1. R^2 is the correlation coefficient between observed values and predicted values; R^2 is only determined for regression analysis (model 1).

Table 3-4: Inorganic Parameters Coefficients Table

Model 1

$$C_f = e^{\wedge}\left[\beta_0 + \beta_1 * \ln(C_s / f_{\text{iron}})\right]$$

Model 2

$$C_f = \text{BAF} * (C_s / f_{\text{iron}})$$

Where: C_f = Tissue concentration
C_s = Sediment concentration
f_{iron} = Concentration of Iron in the sediment, expressed as a fraction (unitless)

Parameter	Species	Model Type	β_0	β_1	BAF			Units		R^2
					Factor	Std Dev	Std Error	Tissue	Sediment	
Copper	American Eel	2			1.476E-04	6.265E-04	1.367E-04	mg/kg	mg/kg	
Copper	Blue Crab	1	-7.682	1.242				mg/kg	mg/kg	0.161
Copper	Mummichog	2			5.298E-04	1.515E-04	2.491E-05	mg/kg	mg/kg	
Copper	White Perch	2			6.076E-05	1.047E-05	2.618E-06	mg/kg	mg/kg	
Lead	American Eel	1	-7.921	0.755				mg/kg	mg/kg	-0.0754
Lead	Blue Crab	1	-8.552	0.755				mg/kg	mg/kg	0.115
Lead	Mummichog	1	-7.136	0.755				mg/kg	mg/kg	0.305
Lead	White Perch	1	-11.63	0.755				mg/kg	mg/kg	0.152
Mercury	American Eel	1	-3.079	0.375				mg/kg	mg/kg	-0.0346
Mercury	Blue Crab	1	-3.911	0.375				mg/kg	mg/kg	0.206
Mercury	Mummichog	1	-4.810	0.375				mg/kg	mg/kg	0.077
Mercury	White Perch	1	-2.839	0.375				mg/kg	mg/kg	0.057

Notes:

1. American eel uses a median BAF for copper while a mean BAF is used for copper for mummichog and white perch.
2. R^2 is the correlation coefficient between observed values and predicted values; R^2 is only determined for regression analysis (model 1).

Table 3-5: Regression-based Confidence Limits for Organic Parameters

Species	Parameter	Unit	TOC Normalized Sediment Conc.	Nominal Sediment Conc.	Tissue Concentration	95% Confidence Limits on Tissue	
						Lower	Upper
American Eel	2,3,7,8-TCDD	pg/g	24	1.1	0.29	-54%	117%
		pg/g	35	1.6	0.37	-52%	107%
		pg/g	51	2.4	0.46	-49%	98%
		pg/g	74	3.4	0.59	-47%	89%
		pg/g	107	5.0	0.74	-44%	80%
		pg/g	155	7.2	0.94	-42%	72%
		pg/g	225	10	1.19	-39%	65%
		pg/g	326	15	1.51	-37%	58%
		pg/g	472	22	1.91	-34%	51%
		pg/g	685	32	2.42	-31%	45%
		pg/g	993	46	3.06	-28%	40%
		pg/g	1,440	67	3.87	-26%	35%
		pg/g	2,089	97	4.90	-24%	31%
		pg/g	3,029	141	6.21	-22%	28%
		pg/g	4,393	205	7.86	-21%	26%
		pg/g	6,371	297	9.95	-20%	25%
		pg/g	9,239	431	12.6	-21%	26%
		pg/g	13,398	625	15.9	-22%	28%
		pg/g	19,430	906	20.2	-24%	31%
		pg/g	28,178	1,314	25.5	-26%	36%
		pg/g	40,863	1,906	32.3	-29%	40%
Blue Crab	2,3,7,8-TCDD	pg/g	26	1.2	0.18	-34%	51%
		pg/g	37	1.7	0.26	-32%	47%
		pg/g	54	2.5	0.37	-30%	43%
		pg/g	78	3.7	0.53	-28%	40%
		pg/g	114	5.3	0.75	-27%	36%
		pg/g	165	7.7	1.06	-25%	33%
		pg/g	239	11	1.50	-23%	30%
		pg/g	347	16	2.12	-21%	27%
		pg/g	503	23	3.01	-19%	24%
		pg/g	729	34	4.26	-18%	22%
		pg/g	1,057	49	6.04	-16%	19%
		pg/g	1,533	72	8.56	-15%	18%
		pg/g	2,223	104	12.1	-14%	16%
		pg/g	3,224	150	17.2	-13%	15%
		pg/g	4,676	218	24.4	-13%	15%
		pg/g	6,781	316	34.5	-13%	15%
		pg/g	9,834	459	48.9	-14%	16%
		pg/g	14,261	665	69.3	-15%	18%
		pg/g	20,681	965	98.3	-16%	20%
		pg/g	29,992	1,399	139	-18%	22%
		pg/g	43,494	2,029	197	-20%	25%
Mummichog	2,3,7,8-TCDD	pg/g	27	1.3	0.48	-55%	124%
		pg/g	39	1.8	0.63	-53%	113%
		pg/g	57	2.6	0.82	-51%	103%
		pg/g	82	3.8	1.06	-48%	93%
		pg/g	119	5.5	1.38	-46%	84%
		pg/g	173	8.0	1.80	-43%	75%
		pg/g	250	12	2.34	-40%	67%
		pg/g	363	17	3.05	-37%	59%
		pg/g	526	25	3.97	-34%	52%
		pg/g	763	36	5.17	-31%	45%
		pg/g	1,107	52	6.73	-28%	39%
		pg/g	1,605	75	8.76	-25%	34%
		pg/g	2,327	109	11.4	-22%	28%
		pg/g	3,375	157	14.8	-20%	24%
		pg/g	4,895	228	19.3	-17%	21%
		pg/g	7,098	331	25.1	-16%	19%
		pg/g	10,294	480	32.7	-16%	19%
		pg/g	14,928	696	42.6	-17%	21%
		pg/g	21,648	1,010	55.4	-19%	24%
		pg/g	31,394	1,464	72.2	-22%	28%
		pg/g	45,527	2,123	93.9	-25%	33%

Table 3-5: Regression-based Confidence Limits for Organic Parameters

Species	Parameter	Unit	TOC Normalized Sediment Conc.	Nominal Sediment Conc.	Tissue Concentration	95% Confidence Limits on Tissue	
						Lower	Upper
White Perch	2,3,7,8-TCDD	pg/g	28	1.3	0.32	-29%	41%
		pg/g	40	1.9	0.46	-28%	38%
		pg/g	58	2.7	0.65	-26%	35%
		pg/g	84	3.9	0.93	-24%	32%
		pg/g	122	5.7	1.32	-22%	29%
		pg/g	178	8.3	1.88	-21%	26%
		pg/g	258	12	2.68	-19%	24%
		pg/g	373	17	3.82	-18%	21%
		pg/g	542	25	5.44	-16%	19%
		pg/g	785	37	7.76	-15%	18%
		pg/g	1,139	53	11.1	-14%	16%
		pg/g	1,652	77	15.8	-14%	16%
		pg/g	2,395	112	22.5	-13%	15%
		pg/g	3,474	162	32.0	-14%	16%
		pg/g	5,038	235	45.7	-14%	17%
		pg/g	7,306	341	65.1	-15%	18%
		pg/g	10,595	494	92.8	-16%	20%
		pg/g	15,365	717	132	-18%	22%
		pg/g	22,281	1,039	189	-19%	24%
		pg/g	32,312	1,507	269	-21%	27%
		pg/g	46,859	2,185	383	-23%	29%
American Eel	Dieldrin	ug/kg	26	1.2	1.50	-65%	188%
		ug/kg	30	1.4	1.81	-63%	168%
		ug/kg	34	1.6	2.19	-60%	150%
		ug/kg	38	1.8	2.64	-57%	133%
		ug/kg	43	2.0	3.19	-54%	117%
		ug/kg	49	2.3	3.85	-51%	103%
		ug/kg	55	2.6	4.65	-47%	90%
		ug/kg	62	2.9	5.62	-44%	78%
		ug/kg	70	3.3	6.78	-40%	68%
		ug/kg	79	3.7	8.19	-37%	59%
		ug/kg	89	4.2	9.89	-34%	51%
		ug/kg	101	4.7	11.9	-31%	44%
		ug/kg	114	5.3	14.4	-29%	40%
		ug/kg	128	6.0	17.4	-27%	38%
		ug/kg	145	6.8	21.0	-27%	38%
		ug/kg	164	7.6	25.4	-29%	40%
		ug/kg	185	8.6	30.7	-31%	45%
		ug/kg	209	9.7	37.1	-34%	51%
		ug/kg	236	11	44.8	-37%	59%
		ug/kg	267	12	54.0	-41%	68%
		ug/kg	301	14	65.3	-44%	79%
Blue Crab	Dieldrin	ug/kg	24	1.1	2.76	-33%	48%
		ug/kg	27	1.3	2.88	-31%	45%
		ug/kg	30	1.4	3.01	-29%	42%
		ug/kg	34	1.6	3.14	-28%	38%
		ug/kg	39	1.8	3.28	-26%	35%
		ug/kg	44	2.0	3.42	-25%	33%
		ug/kg	50	2.3	3.57	-23%	30%
		ug/kg	56	2.6	3.73	-22%	28%
		ug/kg	63	2.9	3.89	-21%	26%
		ug/kg	71	3.3	4.07	-19%	24%
		ug/kg	81	3.8	4.24	-19%	23%
		ug/kg	91	4.2	4.43	-18%	22%
		ug/kg	103	4.8	4.63	-18%	22%
		ug/kg	116	5.4	4.83	-18%	22%
		ug/kg	131	6.1	5.04	-18%	22%
		ug/kg	148	6.9	5.26	-19%	23%
		ug/kg	167	7.8	5.50	-20%	25%
		ug/kg	189	8.8	5.74	-21%	26%
		ug/kg	213	9.9	5.99	-22%	29%
		ug/kg	241	11	6.25	-24%	31%
		ug/kg	272	13	6.53	-25%	34%

Table 3-5: Regression-based Confidence Limits for Organic Parameters

Species	Parameter	Unit	TOC Normalized Sediment Conc.	Nominal Sediment Conc.	Tissue Concentration	95% Confidence Limits on Tissue	
						Lower	Upper
Mummichog	Dieldrin	ug/kg	21	0.97	6.66	-85%	552%
		ug/kg	23	1.1	6.71	-83%	486%
		ug/kg	26	1.2	6.77	-81%	427%
		ug/kg	30	1.4	6.82	-79%	374%
		ug/kg	34	1.6	6.88	-77%	326%
		ug/kg	38	1.8	6.93	-74%	284%
		ug/kg	43	2.0	6.99	-71%	245%
		ug/kg	49	2.3	7.04	-68%	211%
		ug/kg	55	2.6	7.10	-64%	180%
		ug/kg	62	2.9	7.16	-60%	153%
		ug/kg	70	3.3	7.22	-56%	129%
		ug/kg	79	3.7	7.27	-52%	107%
		ug/kg	89	4.2	7.33	-47%	88%
		ug/kg	101	4.7	7.39	-42%	71%
		ug/kg	114	5.3	7.45	-36%	57%
		ug/kg	129	6.0	7.51	-32%	46%
		ug/kg	146	6.8	7.57	-28%	39%
		ug/kg	164	7.7	7.63	-26%	35%
		ug/kg	186	8.7	7.69	-27%	37%
		ug/kg	210	9.8	7.76	-31%	44%
		ug/kg	237	11	7.82	-35%	54%
White Perch	Dieldrin	ug/kg	30	1.4	8.05	-46%	84%
		ug/kg	34	1.6	8.39	-43%	75%
		ug/kg	38	1.8	8.75	-40%	65%
		ug/kg	43	2.0	9.12	-36%	57%
		ug/kg	49	2.3	9.51	-33%	49%
		ug/kg	55	2.6	9.91	-30%	42%
		ug/kg	62	2.9	10.3	-26%	35%
		ug/kg	70	3.3	10.8	-23%	29%
		ug/kg	79	3.7	11.2	-20%	25%
		ug/kg	90	4.2	11.7	-17%	21%
		ug/kg	101	4.7	12.2	-16%	19%
		ug/kg	114	5.3	12.7	-16%	19%
		ug/kg	129	6.0	13.3	-18%	22%
		ug/kg	146	6.8	13.8	-20%	26%
		ug/kg	165	7.7	14.4	-24%	31%
		ug/kg	186	8.7	15.0	-27%	37%
		ug/kg	210	9.8	15.7	-30%	44%
		ug/kg	237	11	16.3	-34%	51%
		ug/kg	268	12	17.0	-37%	59%
		ug/kg	302	14	17.8	-40%	68%
		ug/kg	341	16	18.5	-43%	77%
American Eel	HMW PAH	ug/kg	719	34	0.12	-99%	7017%
		ug/kg	1,257	59	0.17	-98%	4934%
		ug/kg	2,199	103	0.25	-97%	3463%
		ug/kg	3,847	179	0.36	-96%	2423%
		ug/kg	6,729	314	0.52	-94%	1688%
		ug/kg	11,771	549	0.74	-92%	1168%
		ug/kg	20,589	960	1.07	-89%	801%
		ug/kg	36,015	1,680	1.54	-84%	542%
		ug/kg	62,998	2,938	2.21	-78%	359%
		ug/kg	110,196	5,140	3.18	-70%	230%
		ug/kg	192,755	8,990	4.58	-59%	142%
		ug/kg	337,169	15,725	6.59	-46%	84%
		ug/kg	589,779	27,507	9.48	-37%	58%
		ug/kg	1,031,645	48,116	13.6	-41%	71%
		ug/kg	1,804,562	84,164	19.6	-54%	118%
Blue Crab	HMW PAH	ug/kg	787	37	0.19	-81%	435%
		ug/kg	1,377	64	0.27	-79%	366%
		ug/kg	2,409	112	0.40	-75%	306%
		ug/kg	4,215	197	0.58	-72%	254%
		ug/kg	7,372	344	0.85	-68%	209%
		ug/kg	12,895	601	1.24	-63%	170%
		ug/kg	22,556	1,052	1.81	-58%	136%
		ug/kg	39,456	1,840	2.65	-52%	107%
		ug/kg	69,017	3,219	3.87	-45%	82%
		ug/kg	120,724	5,631	5.65	-38%	61%

Table 3-5: Regression-based Confidence Limits for Organic Parameters

Species	Parameter	Unit	TOC Normalized Sediment Conc.	Nominal Sediment Conc.	Tissue Concentration	95% Confidence Limits on Tissue	
						Lower	Upper
		ug/kg	211,172	9,849	8.25	-31%	44%
		ug/kg	369,384	17,228	12.0	-24%	32%
		ug/kg	646,129	30,135	17.6	-22%	29%
		ug/kg	1,130,214	52,713	25.7	-25%	34%
		ug/kg	1,976,978	92,206	37.5	-32%	47%
Mummichog	HMW PAH	ug/kg	710	33	0.51	-97%	3268%
		ug/kg	1,243	58	0.73	-96%	2455%
		ug/kg	2,174	101	1.04	-95%	1839%
		ug/kg	3,802	177	1.49	-93%	1371%
		ug/kg	6,650	310	2.13	-91%	1017%
		ug/kg	11,633	543	3.04	-88%	749%
		ug/kg	20,349	949	4.34	-85%	545%
		ug/kg	35,594	1,660	6.20	-80%	391%
		ug/kg	62,261	2,904	8.86	-73%	275%
		ug/kg	108,908	5,079	12.7	-65%	187%
		ug/kg	190,503	8,885	18.1	-55%	121%
		ug/kg	333,229	15,542	25.9	-42%	74%
		ug/kg	582,887	27,186	36.9	-31%	44%
		ug/kg	1,019,590	47,553	52.8	-29%	40%
		ug/kg	1,783,475	83,181	75.4	-39%	65%
White Perch	HMW PAH	ug/kg	843	39	0.03	-80%	410%
		ug/kg	1,474	69	0.05	-77%	341%
		ug/kg	2,579	120	0.09	-74%	281%
		ug/kg	4,511	210	0.16	-70%	230%
		ug/kg	7,891	368	0.28	-65%	186%
		ug/kg	13,802	644	0.50	-60%	148%
		ug/kg	24,143	1,126	0.88	-54%	115%
		ug/kg	42,231	1,970	1.56	-47%	88%
		ug/kg	73,871	3,445	2.77	-39%	65%
		ug/kg	129,216	6,027	4.91	-32%	47%
		ug/kg	226,026	10,542	8.70	-26%	35%
		ug/kg	395,366	18,440	15.4	-24%	32%
		ug/kg	691,578	32,255	27.3	-28%	39%
		ug/kg	1,209,713	56,421	48.4	-35%	53%
		ug/kg	2,116,038	98,691	85.9	-42%	73%
American Eel	LMW PAH	ug/kg	5,183	242	4.90	-87%	657%
		ug/kg	8,425	393	6.86	-82%	467%
		ug/kg	13,693	639	9.60	-77%	326%
		ug/kg	22,257	1,038	13.4	-69%	222%
		ug/kg	36,175	1,687	18.8	-59%	144%
		ug/kg	58,797	2,742	26.4	-47%	89%
		ug/kg	95,565	4,457	36.9	-35%	53%
		ug/kg	155,326	7,244	51.7	-30%	43%
		ug/kg	252,459	11,775	72.4	-39%	65%
		ug/kg	410,335	19,138	101	-52%	109%
Blue Crab	LMW PAH	ug/kg	5,689	265	3.20	-49%	97%
		ug/kg	9,246	431	4.06	-44%	80%
		ug/kg	15,028	701	5.14	-39%	64%
		ug/kg	24,426	1,139	6.52	-33%	50%
		ug/kg	39,700	1,852	8.27	-27%	38%
		ug/kg	64,527	3,010	10.5	-22%	28%
		ug/kg	104,879	4,892	13.3	-18%	23%
		ug/kg	170,465	7,950	16.9	-18%	23%
		ug/kg	277,064	12,922	21.4	-22%	28%
		ug/kg	450,326	21,003	27.1	-27%	38%
Mummichog	LMW PAH	ug/kg	5,115	239	21.3	-79%	384%
		ug/kg	8,314	388	25.0	-74%	290%
		ug/kg	13,514	630	29.4	-68%	215%
		ug/kg	21,964	1,024	34.6	-61%	155%
		ug/kg	35,700	1,665	40.7	-52%	107%
		ug/kg	58,024	2,706	47.9	-41%	70%
		ug/kg	94,310	4,399	56.4	-30%	42%
		ug/kg	153,286	7,149	66.3	-22%	29%
		ug/kg	249,144	11,620	78.0	-27%	37%
		ug/kg	404,946	18,887	91.8	-38%	61%
White Perch	LMW PAH	ug/kg	6,078	283	4.62	-49%	95%
		ug/kg	9,879	461	6.93	-43%	75%

Table 3-5: Regression-based Confidence Limits for Organic Parameters

Species	Parameter	Unit	TOC Normalized Sediment Conc.	Nominal Sediment Conc.	Tissue Concentration	95% Confidence Limits on Tissue	
						Lower	Upper
		ug/kg	16,057	749	10.4	-37%	58%
		ug/kg	26,098	1,217	15.6	-30%	43%
		ug/kg	42,419	1,978	23.3	-24%	32%
		ug/kg	68,945	3,216	35.0	-20%	25%
		ug/kg	112,060	5,226	52.4	-20%	25%
		ug/kg	182,136	8,495	78.6	-24%	32%
		ug/kg	296,035	13,807	118	-30%	43%
		ug/kg	481,160	22,441	176	-36%	57%
American Eel	Total Chlordane	ug/kg	302	14	35.9	-60%	148%
		ug/kg	370	17	38.5	-54%	117%
		ug/kg	453	21	41.3	-48%	91%
		ug/kg	555	26	44.3	-40%	68%
		ug/kg	680	32	47.5	-32%	48%
		ug/kg	832	39	50.9	-24%	32%
		ug/kg	1,019	48	54.6	-18%	22%
		ug/kg	1,248	58	58.6	-18%	21%
Blue Crab	Total Chlordane	ug/kg	306	14	3.91	-46%	85%
		ug/kg	375	17	4.04	-41%	69%
		ug/kg	459	21	4.17	-35%	54%
		ug/kg	562	26	4.30	-29%	41%
		ug/kg	688	32	4.44	-23%	29%
		ug/kg	842	39	4.58	-17%	20%
		ug/kg	1,032	48	4.72	-13%	15%
		ug/kg	1,263	59	4.88	-14%	16%
Mummichog	Total Chlordane	ug/kg	298	14	8.09	-61%	157%
		ug/kg	365	17	9.46	-55%	123%
		ug/kg	447	21	11.0	-48%	93%
		ug/kg	548	26	12.9	-41%	68%
		ug/kg	671	31	15.1	-32%	47%
		ug/kg	821	38	17.6	-23%	30%
		ug/kg	1,006	47	20.6	-16%	18%
		ug/kg	1,231	57	24.0	-16%	19%
White Perch	Total Chlordane	ug/kg	292	14	31.6	-55%	124%
		ug/kg	357	17	34.5	-49%	98%
		ug/kg	437	20	37.6	-43%	74%
		ug/kg	535	25	41.0	-35%	54%
		ug/kg	656	31	44.7	-27%	36%
		ug/kg	803	37	48.7	-18%	21%
		ug/kg	983	46	53.2	-11%	12%
		ug/kg	1,204	56	58.0	-14%	16%
American Eel	Total DDx	ug/kg	126	5.9	88.1	-71%	244%
		ug/kg	176	8.2	97.1	-67%	203%
		ug/kg	244	11	107	-63%	167%
		ug/kg	339	16	118	-58%	135%
		ug/kg	471	22	130	-52%	108%
		ug/kg	655	31	143	-46%	84%
		ug/kg	910	42	158	-39%	64%
		ug/kg	1,265	59	174	-32%	47%
		ug/kg	1,759	82	192	-25%	34%
		ug/kg	2,445	114	211	-21%	27%
		ug/kg	3,398	158	233	-22%	28%
		ug/kg	4,722	220	257	-27%	37%
		ug/kg	6,563	306	283	-34%	51%
		ug/kg	9,122	425	312	-41%	69%
		ug/kg	12,679	591	344	-47%	90%
		ug/kg	17,622	822	379	-54%	115%
Blue Crab	Total DDx	ug/kg	133	6.2	8.13	-38%	61%
		ug/kg	185	8.6	10.1	-35%	53%
		ug/kg	257	12	12.5	-31%	45%
		ug/kg	358	17	15.6	-28%	38%
		ug/kg	497	23	19.3	-24%	32%
		ug/kg	691	32	24.0	-21%	26%
		ug/kg	960	45	29.8	-17%	21%
		ug/kg	1,334	62	37.0	-15%	17%
		ug/kg	1,854	86	45.9	-13%	15%
		ug/kg	2,577	120	57.0	-12%	14%
		ug/kg	3,582	167	70.8	-14%	16%

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Table 3-5: Regression-based Confidence Limits for Organic Parameters

Species	Parameter	Unit	TOC Normalized Sediment Conc.	Nominal Sediment Conc.	Tissue Concentration	95% Confidence Limits on Tissue	
						Lower	Upper
		ug/kg	4,979	232	88.0	-17%	20%
		ug/kg	6,920	323	109	-20%	25%
		ug/kg	9,618	449	136	-23%	31%
		ug/kg	13,367	623	168	-27%	37%
		ug/kg	18,579	867	209	-31%	44%
Mummichog	Total DDx	ug/kg	135	6.3	16.0	-58%	141%
		ug/kg	187	8.7	18.0	-55%	120%
		ug/kg	260	12	20.3	-50%	101%
		ug/kg	362	17	22.8	-46%	85%
		ug/kg	503	23	25.6	-41%	69%
		ug/kg	699	33	28.8	-36%	56%
		ug/kg	972	45	32.4	-30%	44%
		ug/kg	1,350	63	36.4	-25%	33%
		ug/kg	1,877	88	41.0	-20%	25%
		ug/kg	2,609	122	46.1	-17%	21%
		ug/kg	3,626	169	51.8	-17%	21%
		ug/kg	5,039	235	58.2	-21%	26%
		ug/kg	7,004	327	65.5	-26%	35%
		ug/kg	9,735	454	73.6	-31%	45%
		ug/kg	13,530	631	82.8	-37%	58%
		ug/kg	18,805	877	93.1	-42%	72%
White Perch	Total DDx	ug/kg	146	6.8	58.1	-37%	59%
		ug/kg	203	9.5	65.1	-34%	51%
		ug/kg	282	13	72.9	-30%	43%
		ug/kg	392	18	81.6	-27%	36%
		ug/kg	545	25	91.4	-23%	30%
		ug/kg	758	35	102	-19%	24%
		ug/kg	1,054	49	115	-16%	19%
		ug/kg	1,464	68	128	-14%	16%
		ug/kg	2,035	95	144	-12%	14%
		ug/kg	2,829	132	161	-13%	15%
		ug/kg	3,932	183	181	-15%	18%
		ug/kg	5,465	255	202	-19%	23%
		ug/kg	7,595	354	226	-22%	28%
		ug/kg	10,557	492	254	-26%	35%
		ug/kg	14,672	684	284	-29%	41%
		ug/kg	20,393	951	318	-33%	49%
American Eel	Total PAH	ug/kg	766	36	0.58	-98%	4957%
		ug/kg	1,353	63	0.85	-97%	3578%
		ug/kg	2,390	111	1.24	-96%	2576%
		ug/kg	4,224	197	1.82	-95%	1848%
		ug/kg	7,464	348	2.67	-93%	1319%
		ug/kg	13,189	615	3.92	-90%	934%
		ug/kg	23,305	1,087	5.75	-87%	655%
		ug/kg	41,180	1,921	8.43	-82%	452%
		ug/kg	72,765	3,394	12.4	-75%	305%
		ug/kg	128,576	5,997	18.1	-67%	199%
		ug/kg	227,196	10,596	26.6	-55%	124%
		ug/kg	401,458	18,724	39.0	-42%	73%
		ug/kg	709,381	33,085	57.3	-33%	49%
		ug/kg	1,253,485	58,462	84.0	-38%	60%
		ug/kg	2,214,924	103,303	123	-50%	101%
Blue Crab	Total PAH	ug/kg	839	39	0.36	-78%	350%
		ug/kg	1,482	69	0.52	-75%	298%
		ug/kg	2,619	122	0.76	-72%	252%
		ug/kg	4,628	216	1.11	-68%	211%
		ug/kg	8,177	381	1.62	-64%	175%
		ug/kg	14,449	674	2.37	-59%	144%
		ug/kg	25,531	1,191	3.46	-54%	116%
		ug/kg	45,114	2,104	5.04	-48%	92%
		ug/kg	79,717	3,718	7.35	-41%	71%
		ug/kg	140,861	6,570	10.7	-35%	53%
		ug/kg	248,903	11,609	15.6	-28%	38%
		ug/kg	439,815	20,513	22.8	-22%	28%
		ug/kg	777,159	36,246	33.3	-20%	24%
		ug/kg	1,373,249	64,048	48.6	-23%	29%
		ug/kg	2,426,548	113,173	70.9	-29%	40%

Table 3-5: Regression-based Confidence Limits for Organic Parameters

Species	Parameter	Unit	TOC Normalized Sediment Conc.	Nominal Sediment Conc.	Tissue Concentration	95% Confidence Limits on Tissue	
						Lower	Upper
Mummichog	Total PAH	ug/kg	756	35	5.18	-96%	2382%
		ug/kg	1,335	62	6.67	-95%	1827%
		ug/kg	2,359	110	8.60	-93%	1397%
		ug/kg	4,169	194	11.1	-91%	1063%
		ug/kg	7,366	344	14.3	-89%	803%
		ug/kg	13,016	607	18.4	-86%	602%
		ug/kg	22,999	1,073	23.7	-82%	446%
		ug/kg	40,639	1,895	30.5	-77%	326%
		ug/kg	71,809	3,349	39.2	-70%	232%
		ug/kg	126,888	5,918	50.6	-62%	160%
		ug/kg	224,212	10,457	65.1	-51%	105%
		ug/kg	396,186	18,478	83.9	-39%	64%
		ug/kg	700,065	32,651	108	-27%	37%
		ug/kg	1,237,023	57,694	139	-26%	35%
		ug/kg	2,185,835	101,947	179	-36%	57%
White Perch	Total PAH	ug/kg	898	42	0.36	-77%	341%
		ug/kg	1,586	74	0.58	-74%	287%
		ug/kg	2,803	131	0.92	-70%	239%
		ug/kg	4,953	231	1.47	-66%	197%
		ug/kg	8,752	408	2.35	-62%	161%
		ug/kg	15,465	721	3.75	-56%	129%
		ug/kg	27,327	1,275	5.99	-50%	102%
		ug/kg	48,287	2,252	9.57	-44%	78%
		ug/kg	85,324	3,980	15.3	-37%	58%
		ug/kg	150,769	7,032	24.4	-30%	42%
		ug/kg	266,411	12,425	39.0	-24%	31%
		ug/kg	470,752	21,956	62.2	-21%	27%
		ug/kg	831,824	38,796	99.4	-25%	33%
		ug/kg	1,469,843	68,553	159	-31%	45%
		ug/kg	2,597,230	121,134	253	-38%	62%
Blue Crab	Total PCB	ug/kg	992	46	95.5	-39%	64%
		ug/kg	1,475	69	117	-35%	55%
		ug/kg	2,192	102	142	-31%	46%
		ug/kg	3,257	152	173	-27%	38%
		ug/kg	4,841	226	212	-23%	30%
		ug/kg	7,196	336	258	-19%	24%
		ug/kg	10,695	499	315	-15%	18%
		ug/kg	15,895	741	384	-13%	15%
		ug/kg	23,625	1,102	469	-13%	15%
		ug/kg	35,113	1,638	572	-15%	18%
		ug/kg	52,188	2,434	698	-18%	23%
		ug/kg	77,567	3,618	851	-22%	29%
Mummichog	Total PCB	ug/kg	968	45	19.7	-85%	548%
		ug/kg	1,438	67	28.7	-81%	425%
		ug/kg	2,138	100	41.8	-76%	325%
		ug/kg	3,178	148	60.9	-71%	244%
		ug/kg	4,723	220	88.6	-64%	179%
		ug/kg	7,019	327	129	-56%	127%
		ug/kg	10,433	487	188	-46%	85%
		ug/kg	15,506	723	274	-34%	52%
		ug/kg	23,046	1,075	399	-22%	28%
		ug/kg	34,253	1,598	581	-18%	22%
		ug/kg	50,909	2,374	846	-28%	39%
		ug/kg	75,665	3,529	1,232	-40%	68%

Table 3-6: Regression-based Confidence Limits for Inorganic Parameters

Species	Parameter	Iron Normalized Sediment Conc. (mg/kg)	Nominal Sediment Conc. (mg/kg)	Tissue Concentration (ug/kg)	95% Confidence Limits on Tissue	
					Lower	Upper
American Eel	Lead	1,082	27	71	-55%	124%
		1,714	43	100	-50%	99%
		2,714	68	142	-44%	78%
		4,297	108	201	-38%	63%
		6,804	171	284	-35%	54%
		10,774	270	402	-34%	52%
Blue Crab	Lead	1,082	27	38	-45%	83%
		1,714	43	53	-37%	59%
		2,714	68	76	-28%	39%
		4,297	108	107	-19%	24%
		6,804	171	151	-15%	18%
		10,774	270	214	-20%	25%
Mummichog	Lead	1,082	27	155	-52%	107%
		1,714	43	220	-45%	82%
		2,714	68	311	-38%	61%
		4,297	108	440	-31%	45%
		6,804	171	623	-27%	36%
		10,774	270	881	-27%	36%
White Perch	Lead	1,082	27	1.7	-55%	124%
		1,714	43	2.5	-49%	98%
		2,714	68	3.5	-43%	77%
		4,297	108	4.9	-38%	61%
		6,804	171	7.0	-34%	52%
		10,774	270	10	-33%	50%
American Eel	Mercury	8.1	0.20	101	-27%	37%
		10	0.26	110	-25%	34%
		13	0.32	120	-24%	31%
		16	0.40	130	-22%	29%
		20	0.51	142	-21%	26%
		25	0.64	155	-19%	24%
		32	0.80	169	-18%	22%
		40	1.0	184	-17%	21%
		50	1.3	200	-17%	20%
		63	1.6	218	-16%	20%
		80	2.0	237	-17%	20%
		100	2.5	258	-17%	20%
Blue Crab	Mercury	8.1	0.20	44	-23%	29%
		10	0.26	48	-21%	26%
		13	0.32	52	-19%	23%
		16	0.40	57	-17%	20%
		20	0.51	62	-15%	17%
		25	0.64	67	-13%	15%
		32	0.80	73	-11%	12%
		40	1.0	80	-10%	11%
		50	1.3	87	-9%	10%
		63	1.6	95	-9%	10%
		80	2.0	103	-9%	10%

Table 3-6: Regression-based Confidence Limits for Inorganic Parameters

Species	Parameter	Iron Normalized Sediment Conc. (mg/kg)	Nominal Sediment Conc. (mg/kg)	Tissue Concentration (ug/kg)	95% Confidence Limits on Tissue	
					Lower	Upper
		100	2.5	112	-11%	12%
Mummichog	Mercury	8.1	0.20	18	-26%	35%
		10	0.26	19	-24%	32%
		13	0.32	21	-22%	29%
		16	0.40	23	-21%	26%
		20	0.51	25	-19%	23%
		25	0.64	27	-17%	21%
		32	0.80	30	-16%	19%
		40	1.0	33	-15%	17%
		50	1.3	35	-14%	16%
		63	1.6	39	-13%	15%
		80	2.0	42	-13%	15%
		100	2.5	46	-13%	15%
White Perch	Mercury	8.1	0.20	128	-22%	28%
		10	0.26	140	-20%	25%
		13	0.32	152	-18%	22%
		16	0.40	166	-16%	19%
		20	0.51	181	-14%	16%
		25	0.64	197	-12%	14%
		32	0.80	214	-11%	12%
		40	1.0	233	-9%	10%
		50	1.3	254	-9%	10%
		63	1.6	277	-9%	10%
		80	2.0	302	-10%	11%
		100	2.5	329	-11%	13%
Blue Crab	Copper	1,842	46	5,227	-54%	118%
		2,851	72	8,994	-39%	64%
		4,414	111	15,476	-19%	23%
		6,834	171	26,628	-10%	11%

Table 3-7: White Perch Whole Body-Fillet Organic Parameters Correction Factor Table

$$C_W = Fillet\ Conc * \overline{\frac{Lipid\ Normalized\ Whole\ Body\ Conc}{Lipid\ Normalized\ Fillet\ Conc}} * \overline{\frac{Whole\ Body\ Lipid\ Content}{Fillet\ Lipid\ Content}}$$

Where: C_W = Whole Body Concentration

$\overline{\frac{Lipid\ Normalized\ Whole\ Body\ Conc}{Lipid\ Normalized\ Fillet\ Conc}}$ = mean ratio of lipid-normalized whole body concentration to lipid-normalized fillet concentration = 1.62

$\overline{\frac{Whole\ Body\ Lipid\ Content}{Fillet\ Lipid\ Content}}$ = mean ratio of whole body lipid fraction to fillet lipid fraction = 2.29

Reduced Equation:

$$C_W = \text{Fillet conc.} * 1.62 * 2.29$$

Parameter	2,3,7,8-TCDD Conc. (pg/g lipid)	Dieldrin Conc.(ug/kg lipid)	Total DDx Conc. (ug/kg lipid)	Total PCB Conc. (ug/kg lipid)	Total Chlordane Conc. (ug/kg lipid)	LMW PAH Conc. (ug/kg lipid)	HMW PAH Conc. (ug/kg lipid)	Lipid (%)	Mean of Whole Body to Fillet Correction Factor	Standard Deviation	Standard Error
Number of Fillet with Skin Samples	11	11	11	11	11	11	11	11			
Number of Whole Body Samples	10	10	10	10	10	10	10	10			
Fillet with Skin Average Conc.	2,235	434	2,319	29,392	1,277	4,212	1,485	2.26			
Whole Body Average Conc.	3,256	607	4,390	51,145	2,108	5,185	2,971	5.19			
Whole Body to Fillet with Skin Correction Factor	1.46	1.40	1.89	1.74	1.65	1.23	2.00	**2.29**	**1.62**	0.28	0.10

Notes:

1. The dataset used for the above calculation was the tissue samples from Year 2009 CPG RM1, RM5 and RM7.
2. The type of fillet samples used in the above calculation was fillet with skin.

Table 3-8: White Perch Whole Body-Fillet Inorganic Parameters Correction Factor Table

$$C_W = \text{Fillet Conc} \times \overline{\frac{\text{Whole Body Conc}}{\text{Fillet Conc}}}$$

Where: C_W = Whole Body Concentration

$\overline{\frac{\text{Whole Body Conc.}}{\text{Fillet Conc.}}}$ = The mean ratio of whole body concentration to fillet concentration per parameter

Parameter	**Copper (mg/kg)**	**Lead (mg/kg)**	**Mercury (ug/kg)**
Number of Fillet with Skin Samples	11	11	11
Number of Whole Body Samples	10	9	10
Fillet with Skin Average Conc.	0.39	0.0088	262
Whole Body Average Conc.	9.50	0.31	165
Whole Body to Fillet with Skin Correction Factor	**24**	**35**	**0.63**

Notes:

1. The dataset used for the above calculation was the tissue samples from Year 2009 CPG RM1, RM5 and RM7.
2. The type of fillet samples used in the above calculation was fillet with skin.

Table 3-9: American Eel Fillet-Whole Body Organic Parameters Correction Factor Table

$$C_F = Whole\ Body\ Conc * \frac{\overline{Lipid\ Normalized\ Fillet\ Conc}}{Lipid\ Normalized\ Whole\ Body\ Conc} * \frac{\overline{Fillet\ Lipid\ Content}}{Whole\ Body\ Lipid\ Content}$$

Where:

C_F = Fillet Concentration

$\frac{\overline{Lipid\ Normalized\ Fillet\ Conc}}{Lipid\ Normalized\ Whole\ Body\ Conc}$ = mean ratio of lipid-normalized fillet concentration to lipid-normalized whole body concentration = 0.93

$\frac{\overline{Fillet\ Lipid\ Content}}{Whole\ Body\ Lipid\ Content}$ = mean ratio of fillet lipid fraction to whole body lipid fraction = 0.65

Reduced Equation:

$$C_F = \text{Whole body conc.} * 0.93 * 0.65$$

Parameter	2,3,7,8-TCDD Conc. (pg/g lipid)	Dieldrin Conc.(ug/kg lipid)	Total DDx Conc. (ug/kg lipid)	Total PCB Conc. (ug/kg lipid)	Total Chlordane Conc. (ug/kg lipid)	LMW PAH Conc. (ug/kg lipid)	HMW PAH Conc. (ug/kg lipid)	Lipid (%)	Mean of Fillet to Whole Body Correction Factor	Standard Deviation	Standard Error
Number of Skinless Fillet Samples	12	12	12	12	12	12	12	12			
Number of Whole Body Samples	7	7	7	7	7	7	7	7			
Skinless Fillet Average Conc.	345	739	4,088	29,887	889	819	310	4.58			
Whole Body Average Conc.	352	641	4,500	42,482	1,031	870	317	7.00			
Skinless Fillet to Whole Body Correction Factor	0.98	1.15	0.91	0.70	0.86	0.94	0.98	**0.65**	**0.93**	0.14	0.051

Notes:

1. The dataset used for the above calculation was the tissue samples from Year 2009 CPG RM5 and RM7.
2. The type of fillet samples used in the above calculation was skinless fillet.

Table 3-10: American Eel Fillet-Whole Body Inorganic Parameters Correction Factor Table

$$C_F = \text{Whole Body Conc} \times \overline{\frac{\text{Fillet Conc.}}{\text{Whole Body Conc.}}}$$

Where: C_F = Fillet Concentration

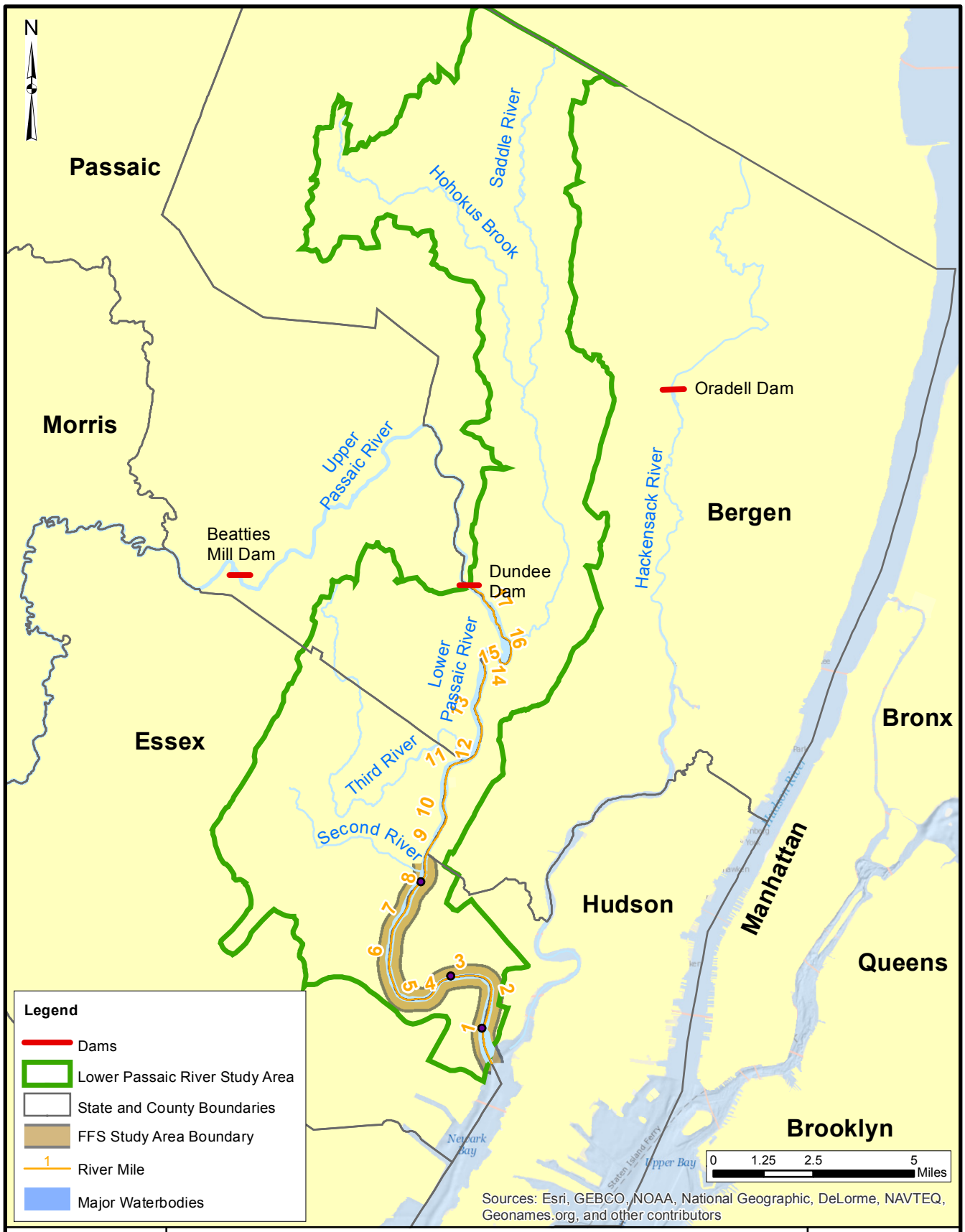
$\overline{\frac{\text{Fillet Conc.}}{\text{Whole Body Conc.}}}$ = The mean ratio of fillet concentration to whole body concentration per parameter

Parameter	**Copper (mg/kg)**	**Lead (mg/kg)**	**Mercury (ug/kg)**
Number of Skinless Fillet Samples	12	12	12
Number of Whole Body Samples	7	2	7
Skinless Fillet Average Conc.	0.23	0.030	429
Whole Body Average Conc.	0.75	0.23	291
Skinless Fillet to Whole Body Correction Factor	**0.30**	**0.13**	**1.48**

Notes:

1. The dataset used for the above calculation was the tissue samples from Year 2009 CPG RM5 and RM7.
2. The type of fillet samples used in the above calculation was skinless fillet.

FIGURES



FFS Study Area Location Map

Lower Eight Miles of the Lower Passaic River

Figure 1-1

2014

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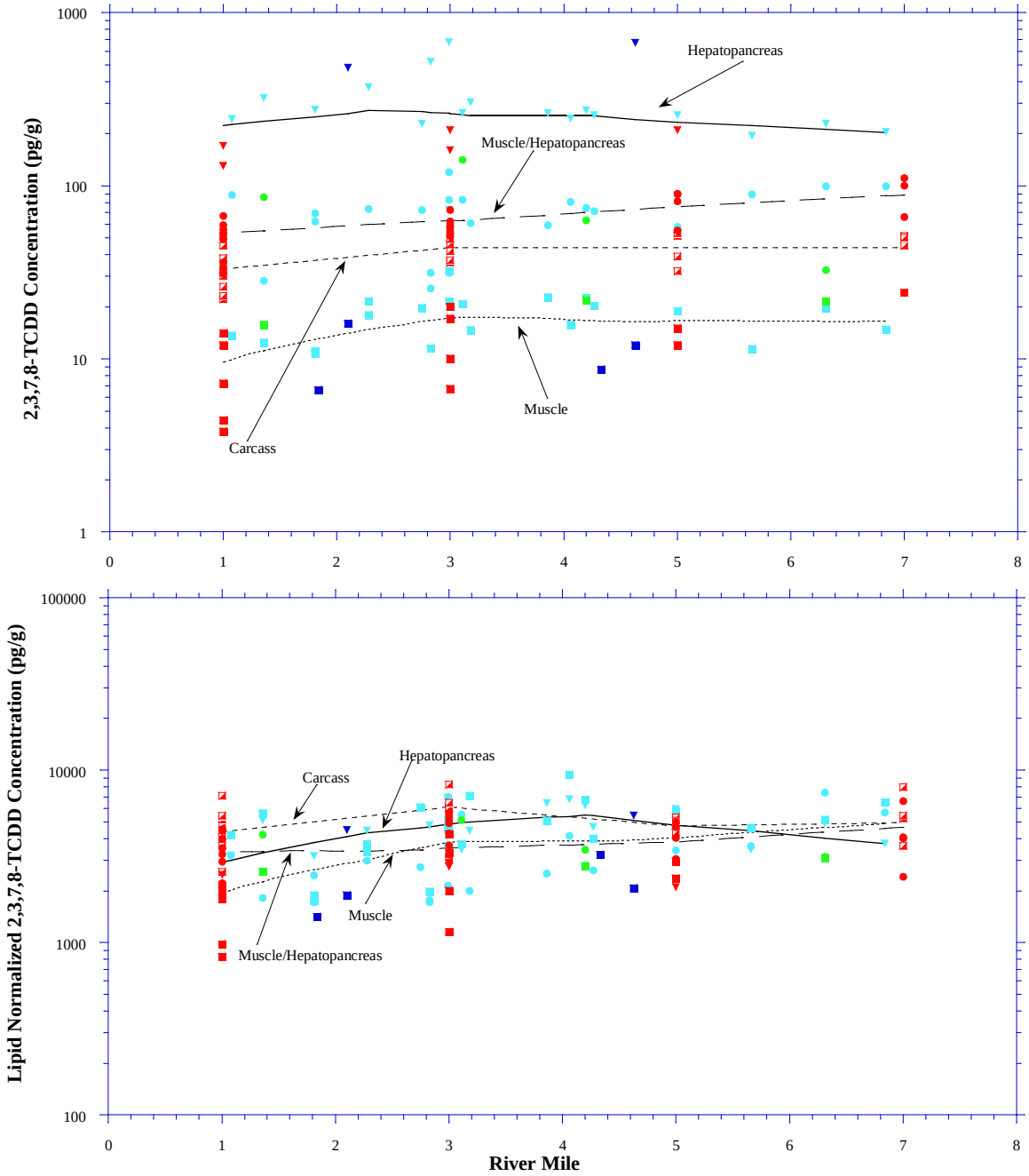
R2-0027559



Legend

Tissue Sampling Year

- 1995
- 1999
- 2000
- 2009

Tissue Type

- Hepatopancreas
- Muscle
- Muscle/ Hepatopancreas
- Carcass

Notes

1. Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.
2. Muscle/Hepatopancreas tissue type includes muscle/hepatopancreas, all edible tissue and whole body – soft tissue.
3. Muscle tissue includes muscle, edible muscle and muscle tissue.

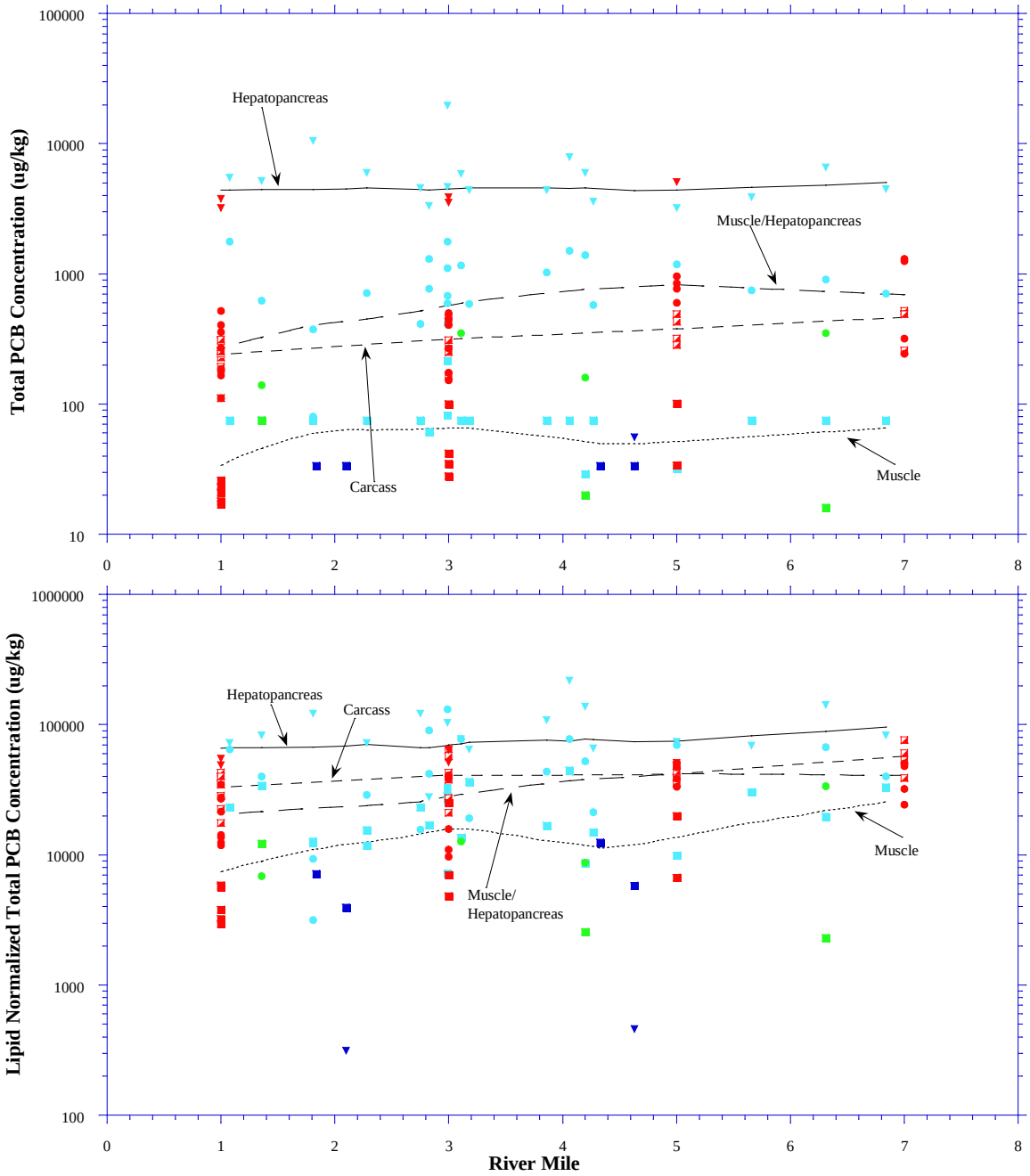
Blue Crab 2,3,7,8-TCDD Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-1a

2014

R2-0027560



Legend

Tissue Sampling Year

- 1995
- 1999
- 2000
- 2009

Tissue Type

- Hepatopancreas
- Muscle
- Muscle/ Hepatopancreas
- Carcass

Notes

1. Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.
2. Muscle/Hepatopancreas tissue type includes muscle/hepatopancreas, all edible tissue and whole body – soft tissue.
3. Muscle tissue includes muscle, edible muscle and muscle tissue.

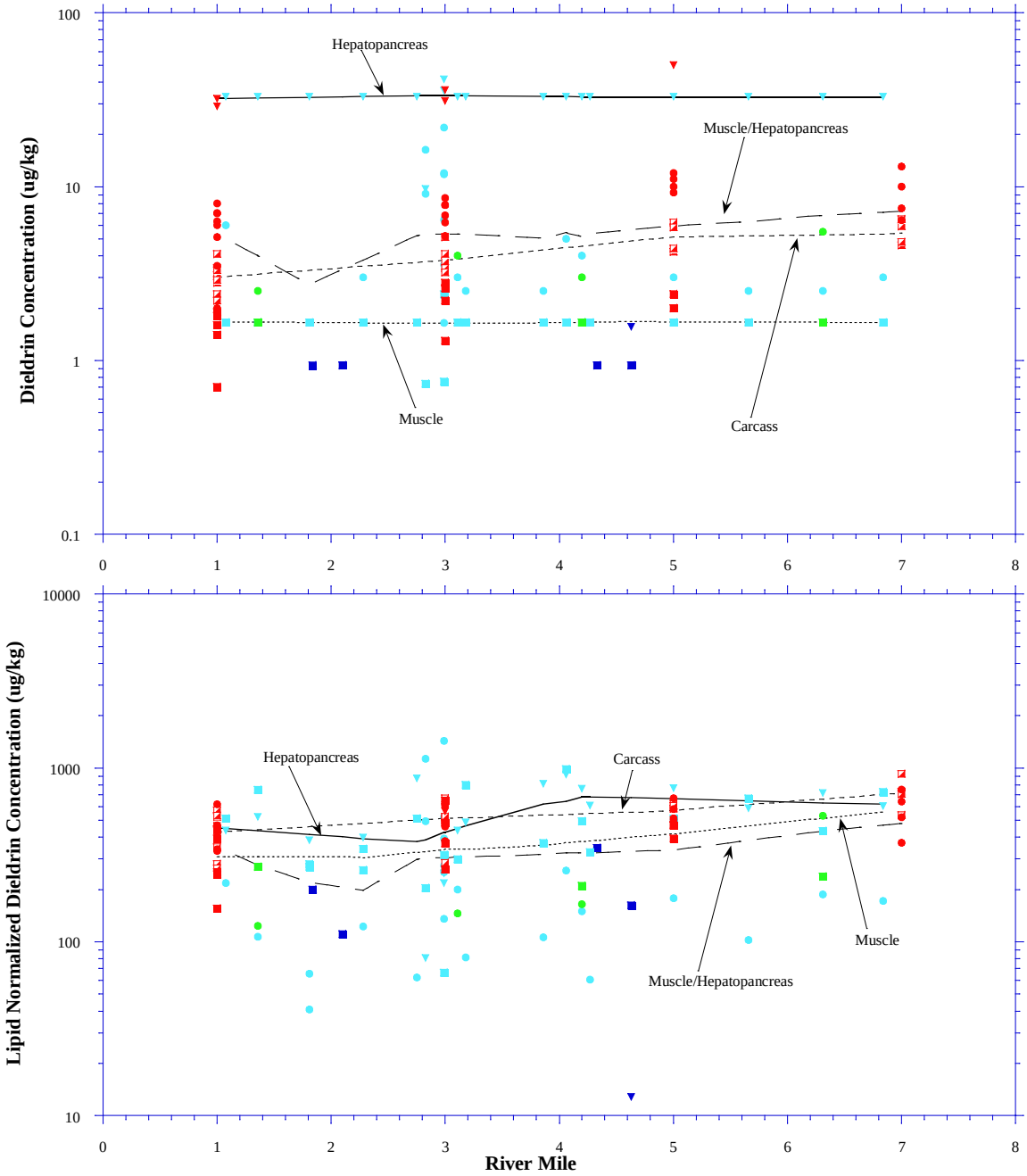
Blue Crab Total PCB Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-1b

2014

R2-0027561



Legend

Tissue Sampling Year

- 1995
- 1999
- 2000
- 2009

Tissue Type

- Hepatopancreas
- Muscle
- Muscle/ Hepatopancreas
- Carcass

Notes

1. Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.
2. Muscle/Hepatopancreas tissue type includes muscle/hepatopancreas, all edible tissue and whole body – soft tissue.
3. Muscle tissue includes muscle, edible muscle and muscle tissue.

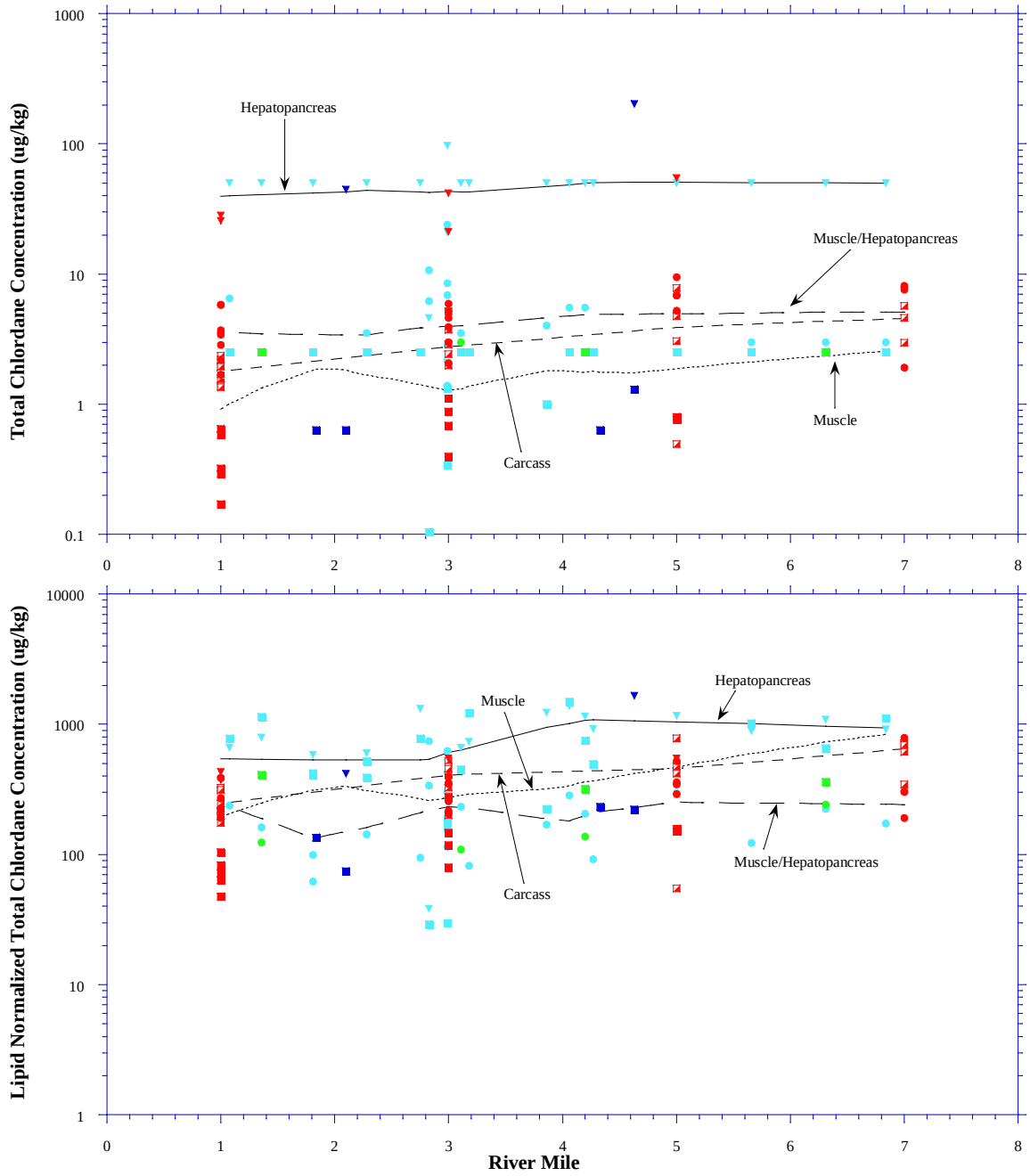
Blue Crab Dieldrin Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-1c

2014

R2-0027562



Legend

Tissue Sampling Year

- 1995
- 1999
- 2000
- 2009

Tissue Type

- Hepatopancreas
- Muscle
- Muscle/ Hepatopancreas
- Carcass

Notes

1. Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.
2. Muscle/Hepatopancreas tissue type includes muscle/hepatopancreas, all edible tissue and whole body – soft tissue.
3. Muscle tissue includes muscle, edible muscle and muscle tissue.

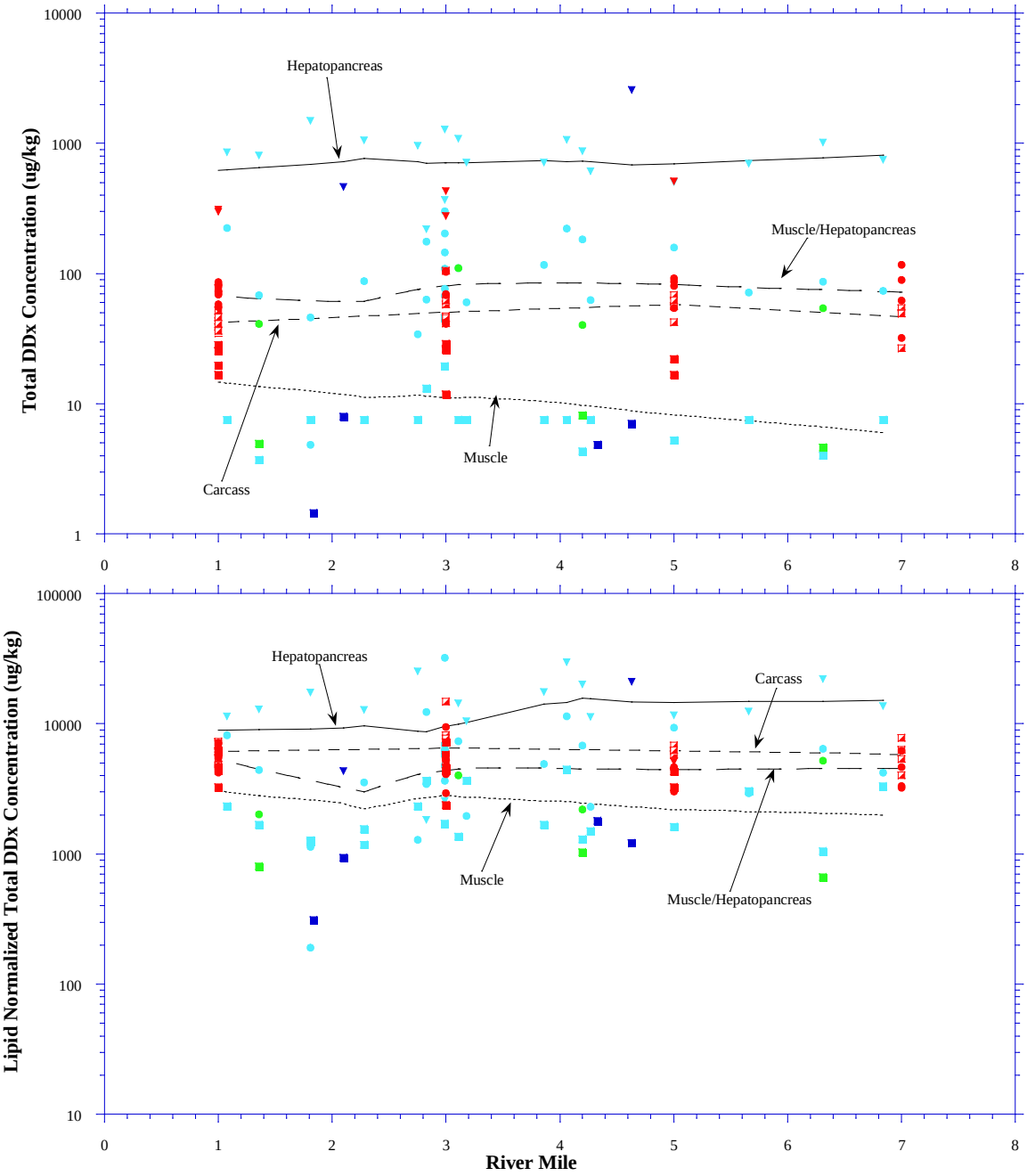
Blue Crab Total Chlordane Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-1d

2014

R2-0027563



Legend

Tissue Sampling Year

- 1995
- 1999
- 2000
- 2009

Tissue Type

- Hepatopancreas
- Muscle
- Muscle/ Hepatopancreas
- Carcass

Notes

1. Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.
2. Muscle/Hepatopancreas tissue type includes muscle/hepatopancreas, all edible tissue and whole body – soft tissue.
3. Muscle tissue includes muscle, edible muscle and muscle tissue.

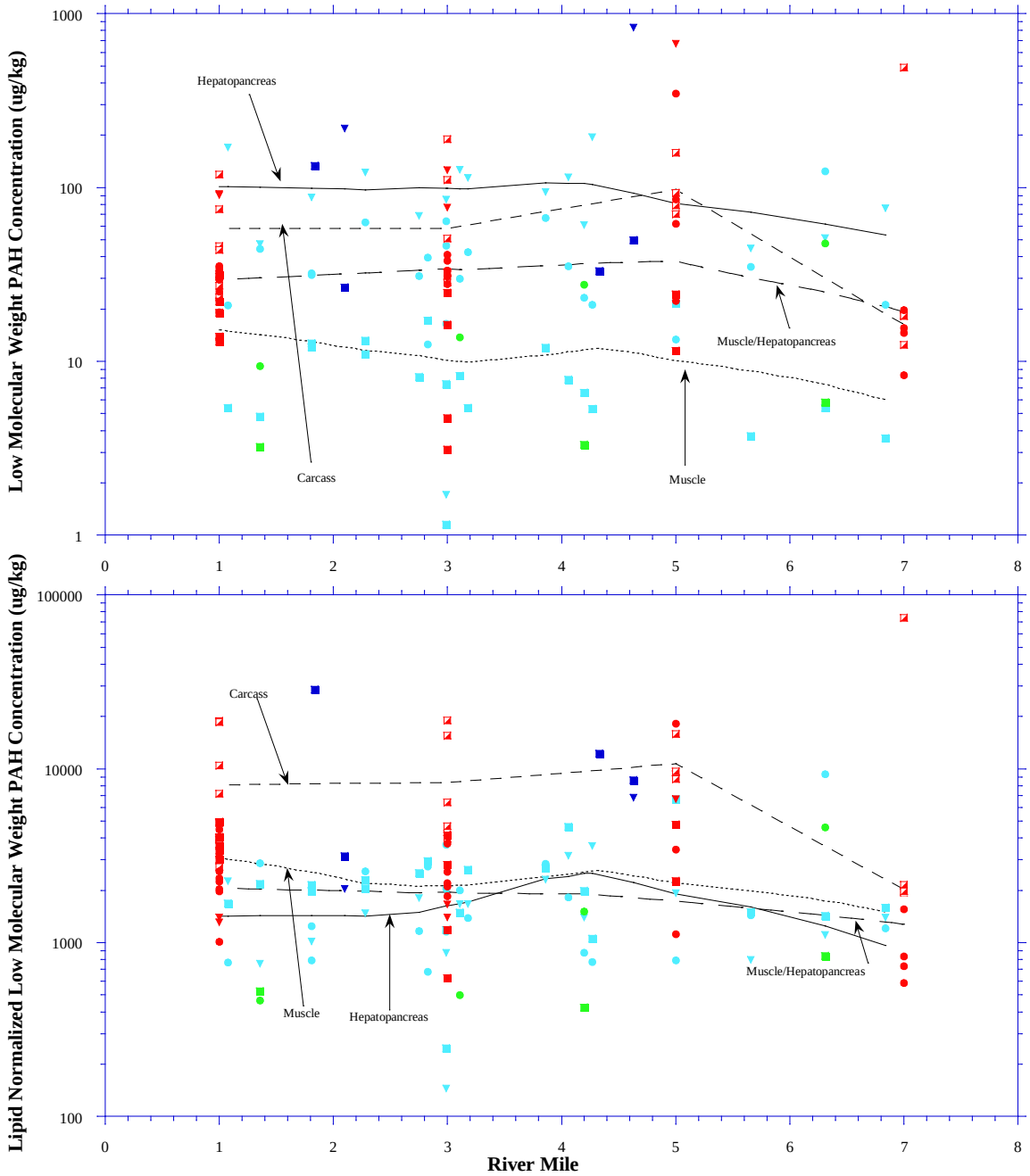
Blue Crab Total DDx Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-1e

2014

R2-0027564



Legend

Tissue Sampling Year		Tissue Type	
1995	●	Hepatopancreas	▼
1999	●	Muscle	■
2000	●	Muscle/ Hepatopancreas	●
2009	●	Carcass	◪

Notes

1. Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.
2. Muscle/Hepatopancreas tissue type includes muscle/hepatopancreas, all edible tissue and whole body – soft tissue.
3. Muscle tissue includes muscle, edible muscle and muscle tissue.

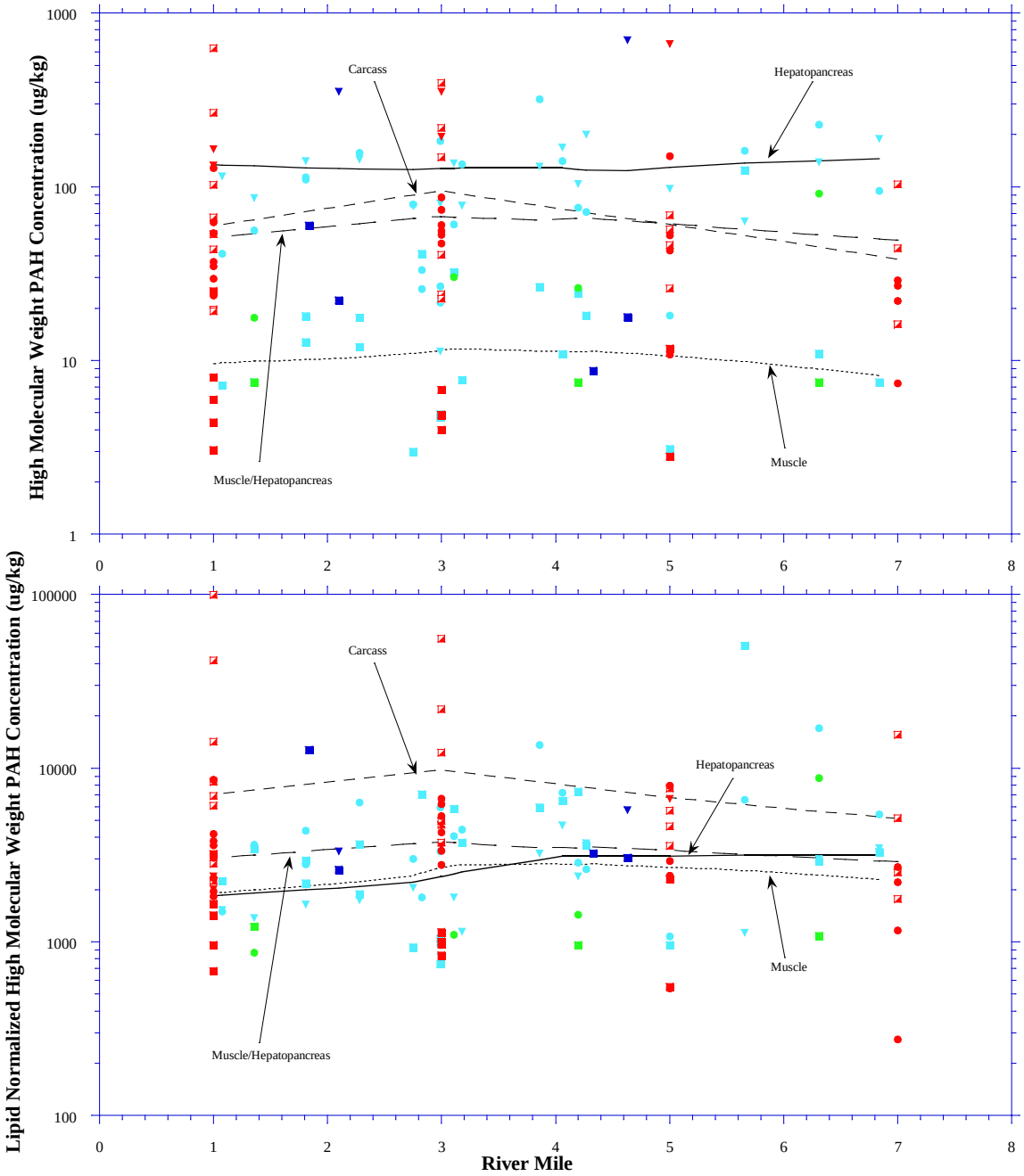
Blue Crab LMW PAH Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-1f

2014

R2-0027565



Legend

Tissue Sampling Year

- 1995
- 1999
- 2000
- 2009

Tissue Type

- Hepatopancreas
- Muscle
- Muscle/ Hepatopancreas
- Carcass

Notes

1. Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.
2. Muscle/Hepatopancreas tissue type includes muscle/hepatopancreas, all edible tissue and whole body – soft tissue.
3. Muscle tissue includes muscle, edible muscle and muscle tissue.

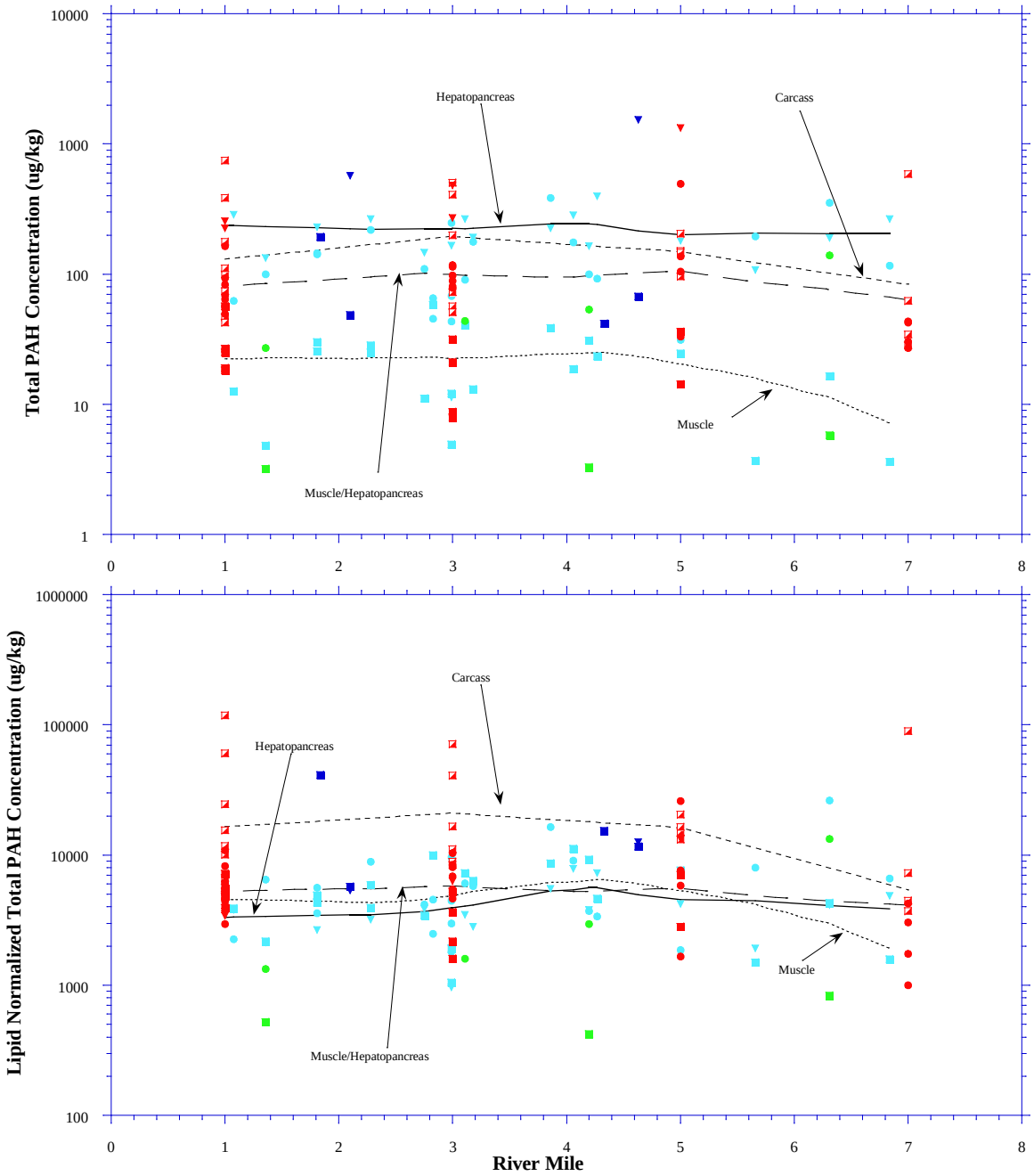
Blue Crab HMW PAH Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-1g

2014

R2-0027566



Legend

Tissue Sampling Year

- 1995
- 1999
- 2000
- 2009

Tissue Type

- Hepatopancreas
- Muscle
- Muscle/ Hepatopancreas
- Carcass

Notes

1. Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.
2. Muscle/Hepatopancreas tissue type includes muscle/hepatopancreas, all edible tissue and whole body – soft tissue.
3. Muscle tissue includes muscle, edible muscle and muscle tissue.

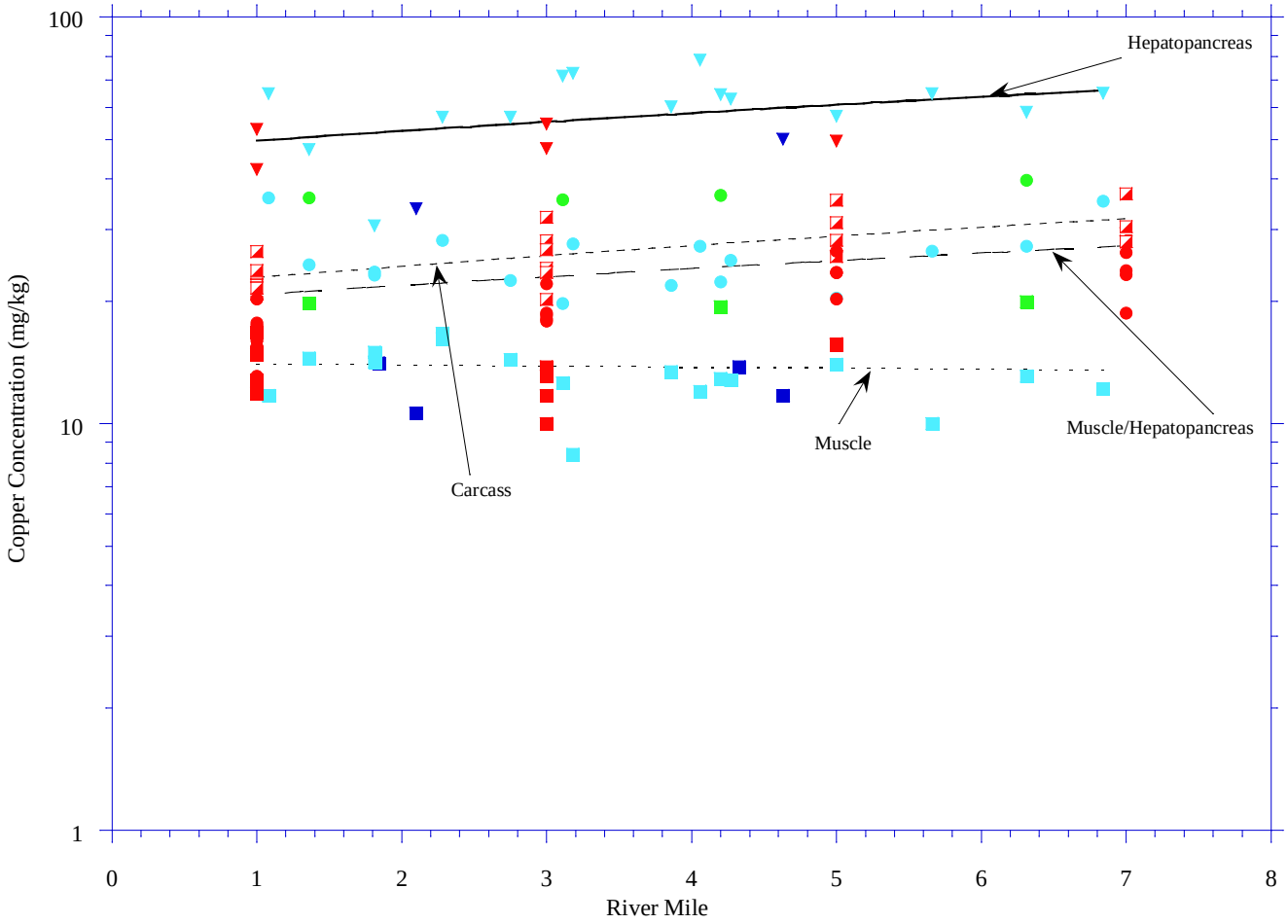
Blue Crab Total PAH Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-1h

2014

R2-0027567



Legend

Tissue Sampling Year

- 1995
- 1999
- 2000
- 2009

Tissue Type

- Hepatopancreas
- Muscle
- Muscle/ Hepatopancreas
- Carcass

Notes:
1) Mucle/Hepatopancreas tissue type includes muscle/hepatopancreas, all edible tissue and whole body - soft tissue.
2) Muscle tissue type includes edible muscle, muscle and muscle tissue.

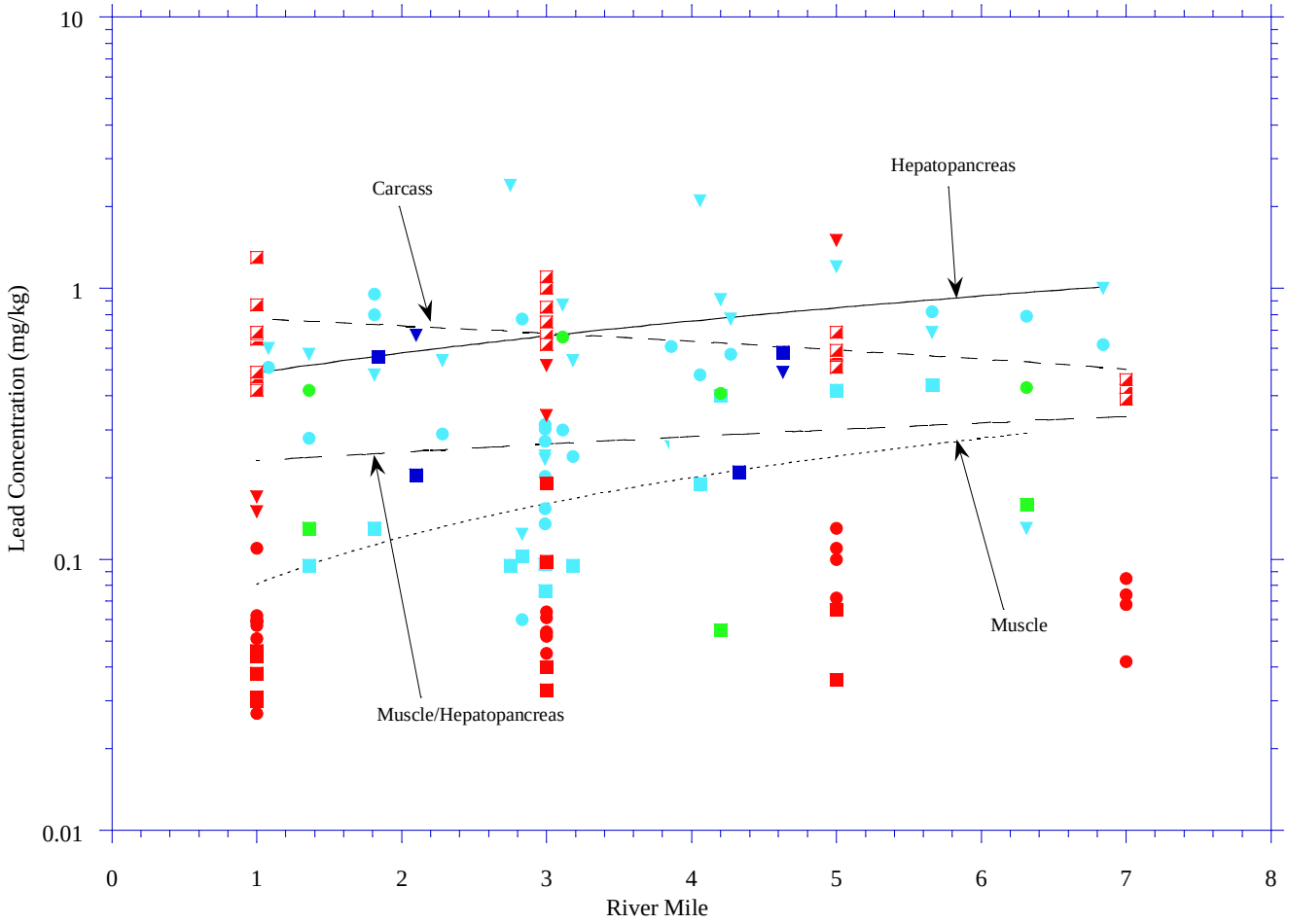
Blue Crab Copper Concentration *vs*. River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-1i

2014

R2-0027568



Legend

Tissue Sampling Year

- 1995
- 1999
- 2000
- 2009

Tissue Type

- Hepatopancreas
- Muscle
- Muscle/ Hepatopancreas
- Carcass

Notes:
1) Mucle/Hepatopancreas tissue type includes muscle/hepatopancreas, all edible tissue and whole body - soft tissue.
2) Muscle tissue type includes edible muscle, muscle and muscle tissue.

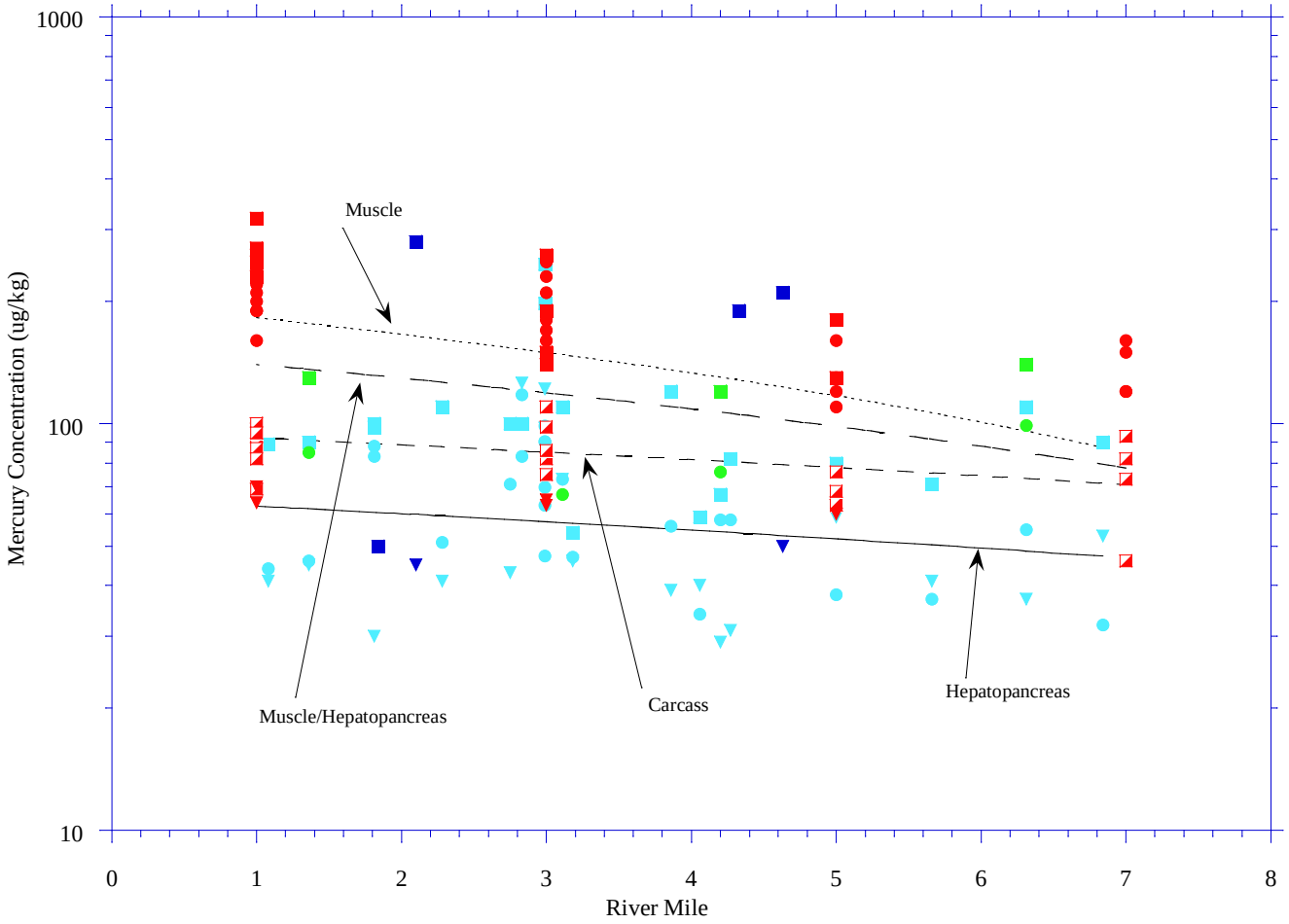
Blue Crab Lead Concentration *vs*. River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-1j

2014

R2-0027569



Legend

Tissue Sampling Year

- 1995
- 1999
- 2000
- 2009

Tissue Type

- Hepatopancreas
- Muscle
- Muscle/ Hepatopancreas
- Carcass

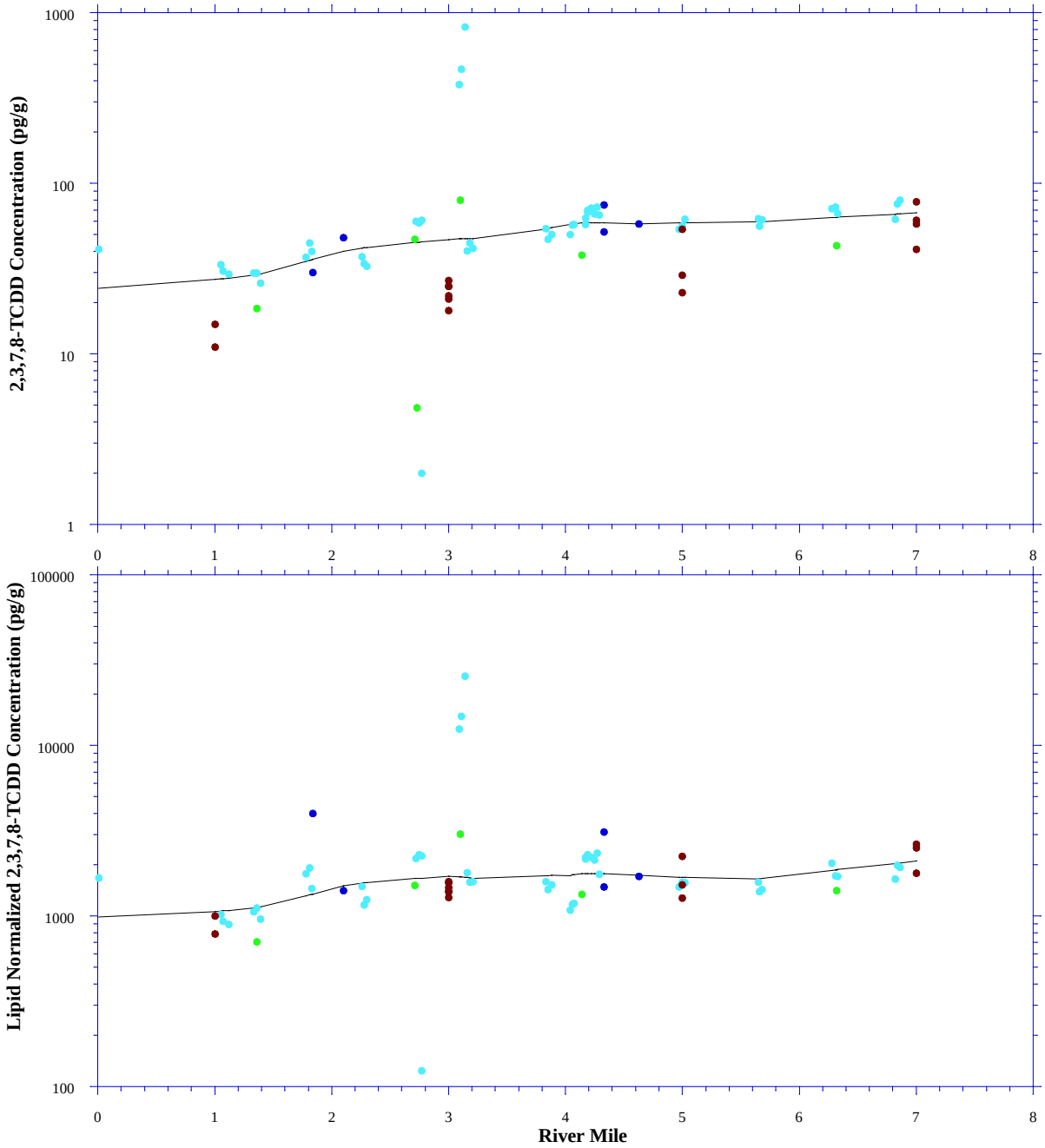
Notes:
1) Mucle/Hepatopancreas tissue type includes muscle/hepatopancreas, all edible tissue and whole body - soft tissue.
2) Muscle tissue type includes edible muscle, muscle and muscle tissue.

Blue Crab Mercury Concentration *vs*. River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-1k

2014



Legend

Tissue Sampling Year
- 1995
- 1999
- 2000
- 2010

Tissue Type
- Whole Body

Note

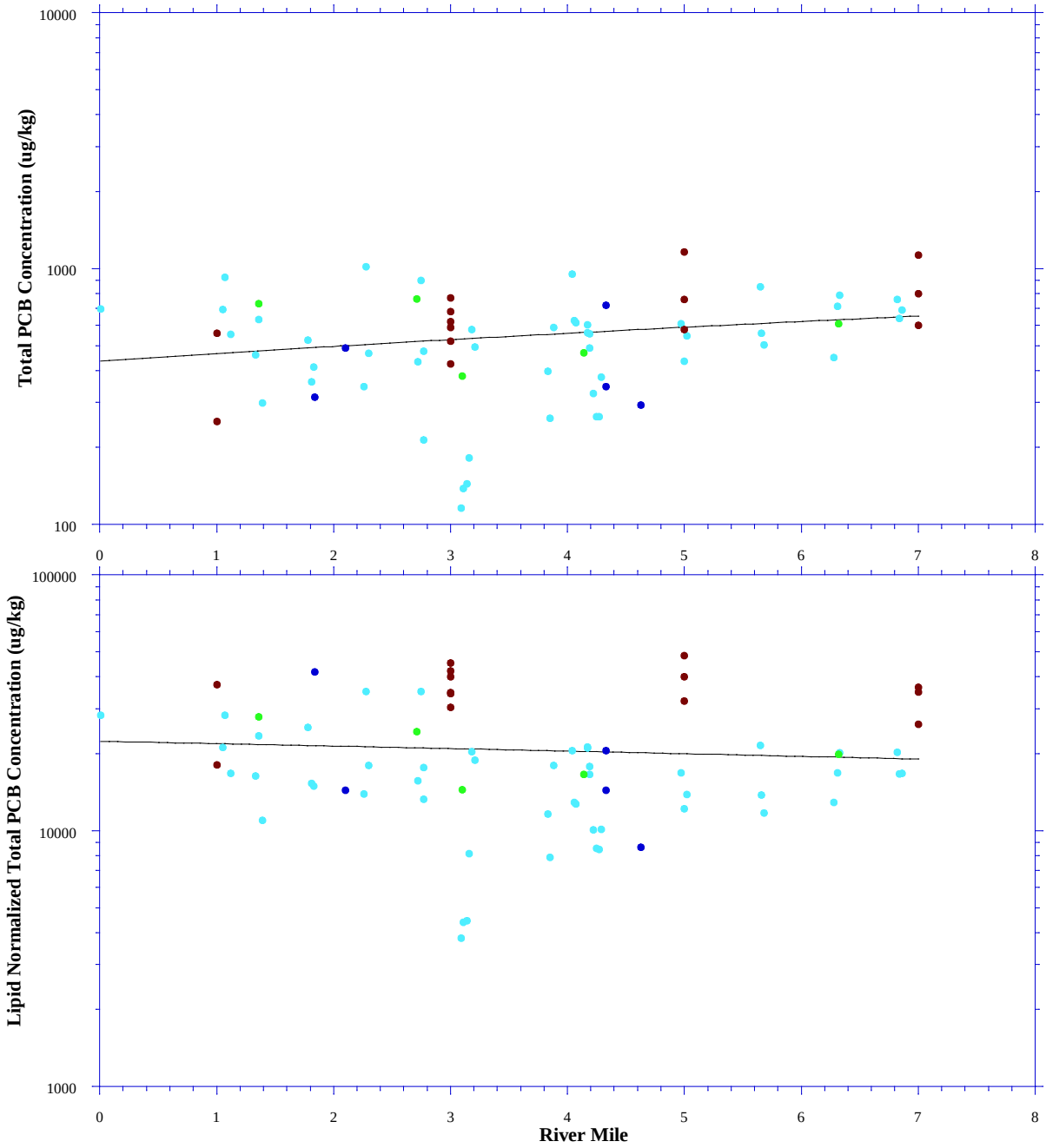
Fit Lines are weighted curves for illustration purpose only.

Mummichog 2,3,7,8-TCDD Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-2a

2014



Legend

Tissue Sampling Year
- 1995
- 1999
- 2000
- 2010

Tissue Type
- Whole Body

Note

Fit Lines are weighted curves for illustration purpose only.

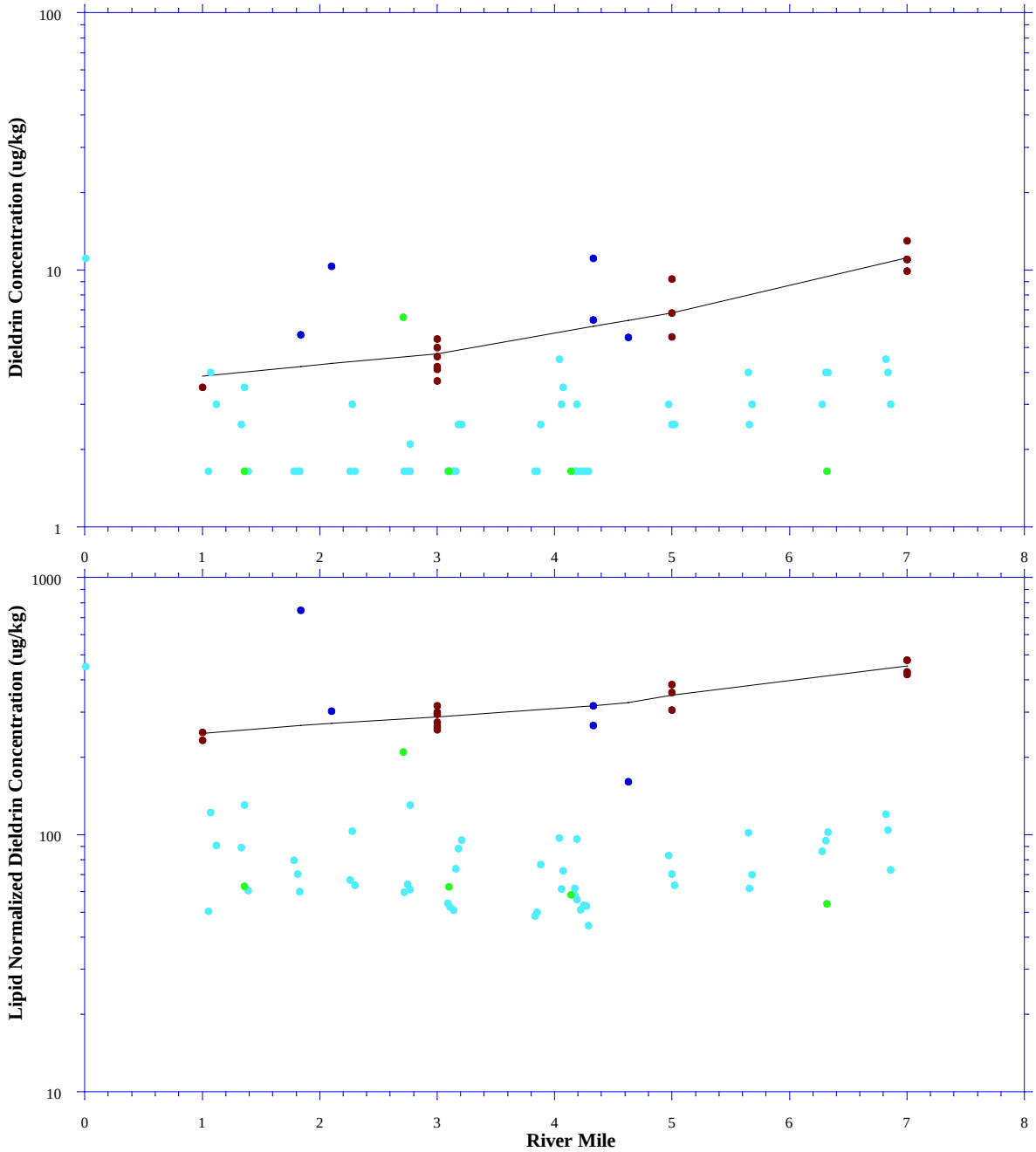
Mummichog Total PCB Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-2b

2014

R2-0027572



Legend

Tissue Sampling Year
- 1995
- 1999
- 2000
- 2010

Tissue Type Whole Body

Notes

1. Fit Lines are weighted curves for illustration purpose only.
2. 1999 and 2000 data was excluded from the fit line because the large number of nondetects presented in the data.

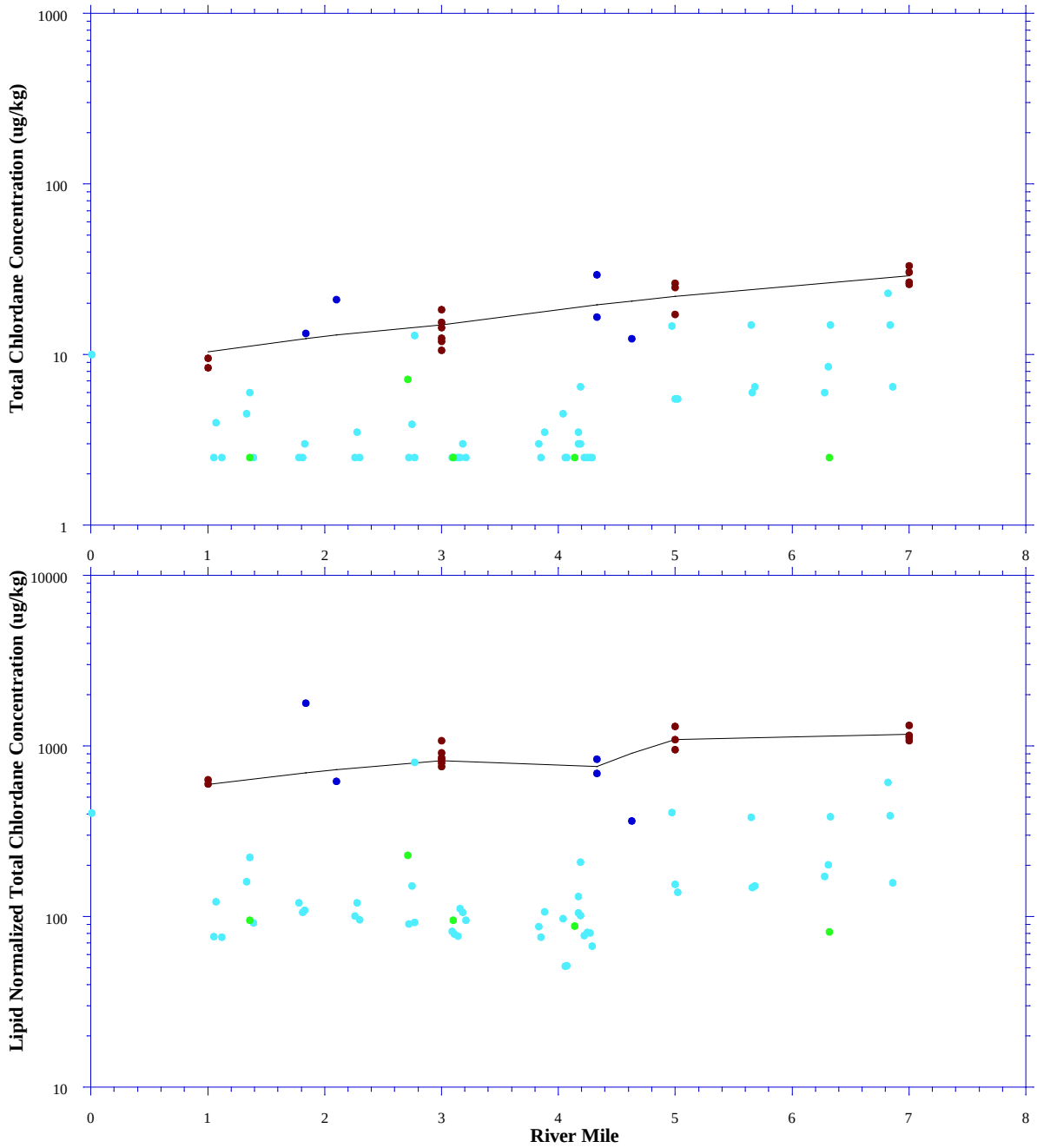
Mummichog Dieldrin Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-2c

2014

R2-0027573



Legend

Tissue Sampling Year
- 1995
- 1999
- 2000
- 2010

Tissue Type Whole Body

Notes

1. Fit Lines are weighted curves for illustration purpose only.
2. 1999 and 2000 data was excluded from the fit line because the large number of nondetects presented in the data.

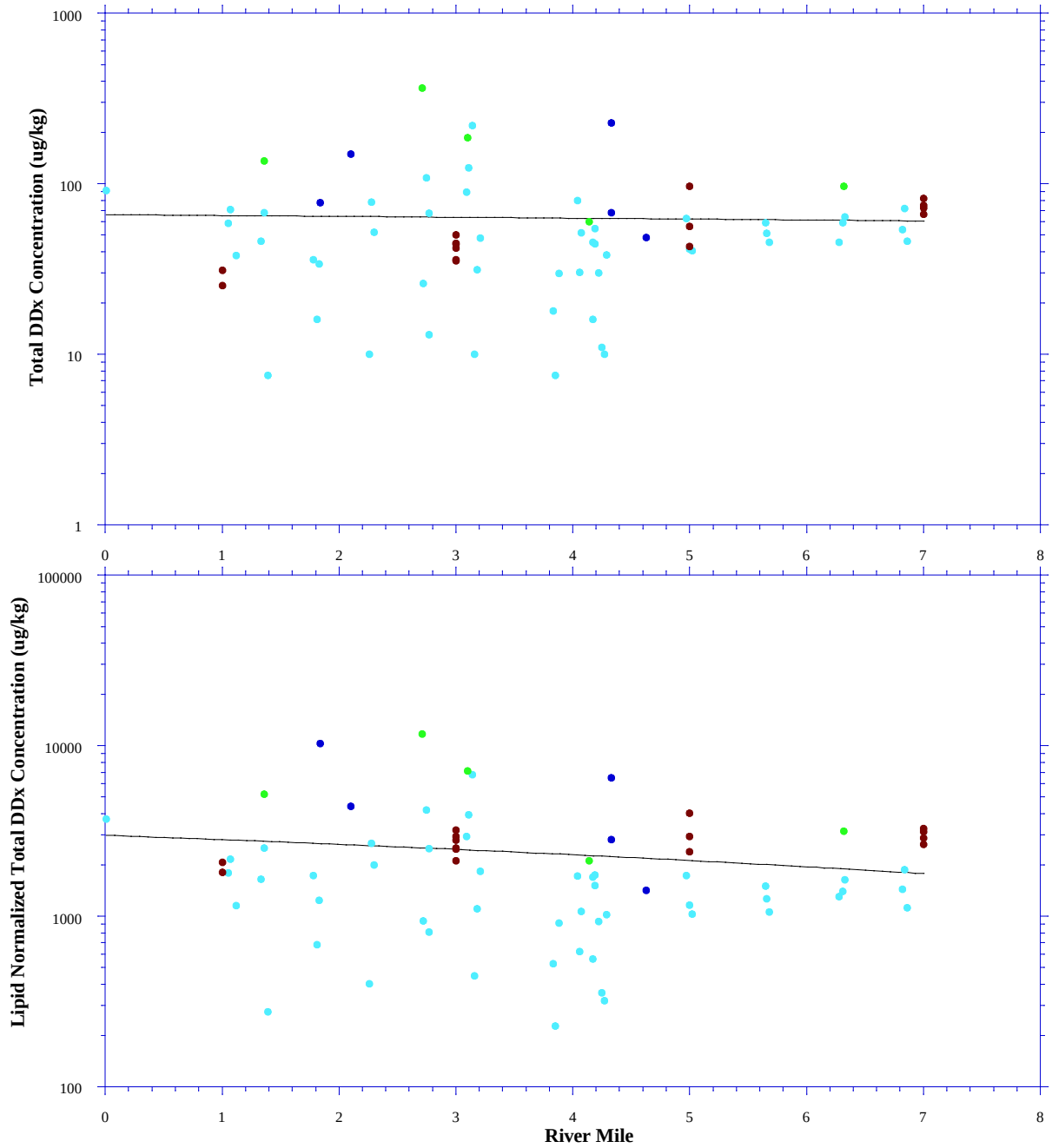
Mummichog Total Chlordane Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-2d

2014

R2-0027574



Legend

Tissue Sampling Year
- 1995
- 1999
- 2000
- 2010

Tissue Type
- Whole Body

Note

Fit Lines are weighted curves for illustration purpose only.

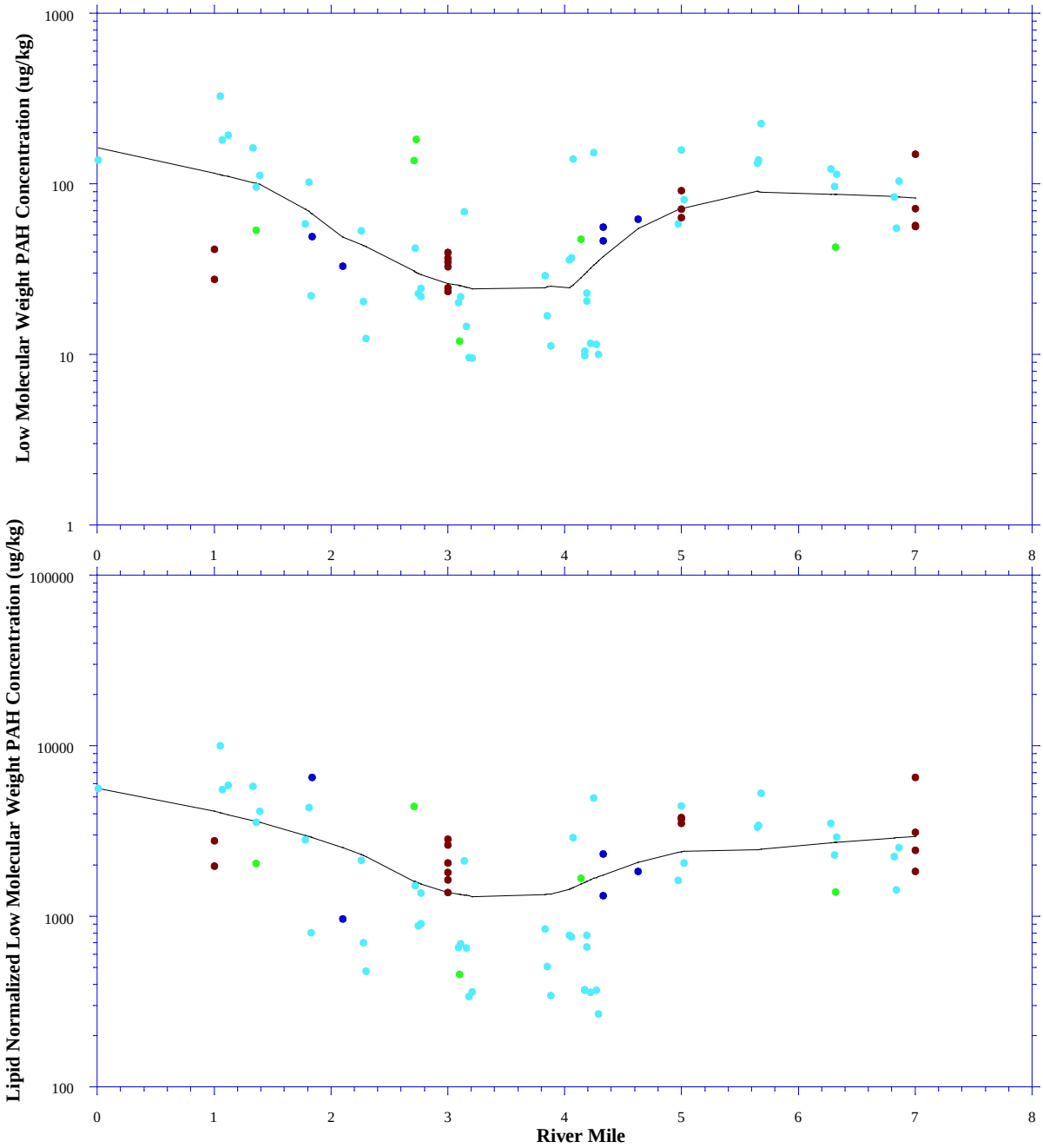
Mummichog Total DDx Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-2e

2014

R2-0027575



Legend

Tissue Sampling Year
- 1995
- 1999
- 2000
- 2010

Tissue Type
- Whole Body

Note

Fit Lines are weighted curves for illustration purpose only.

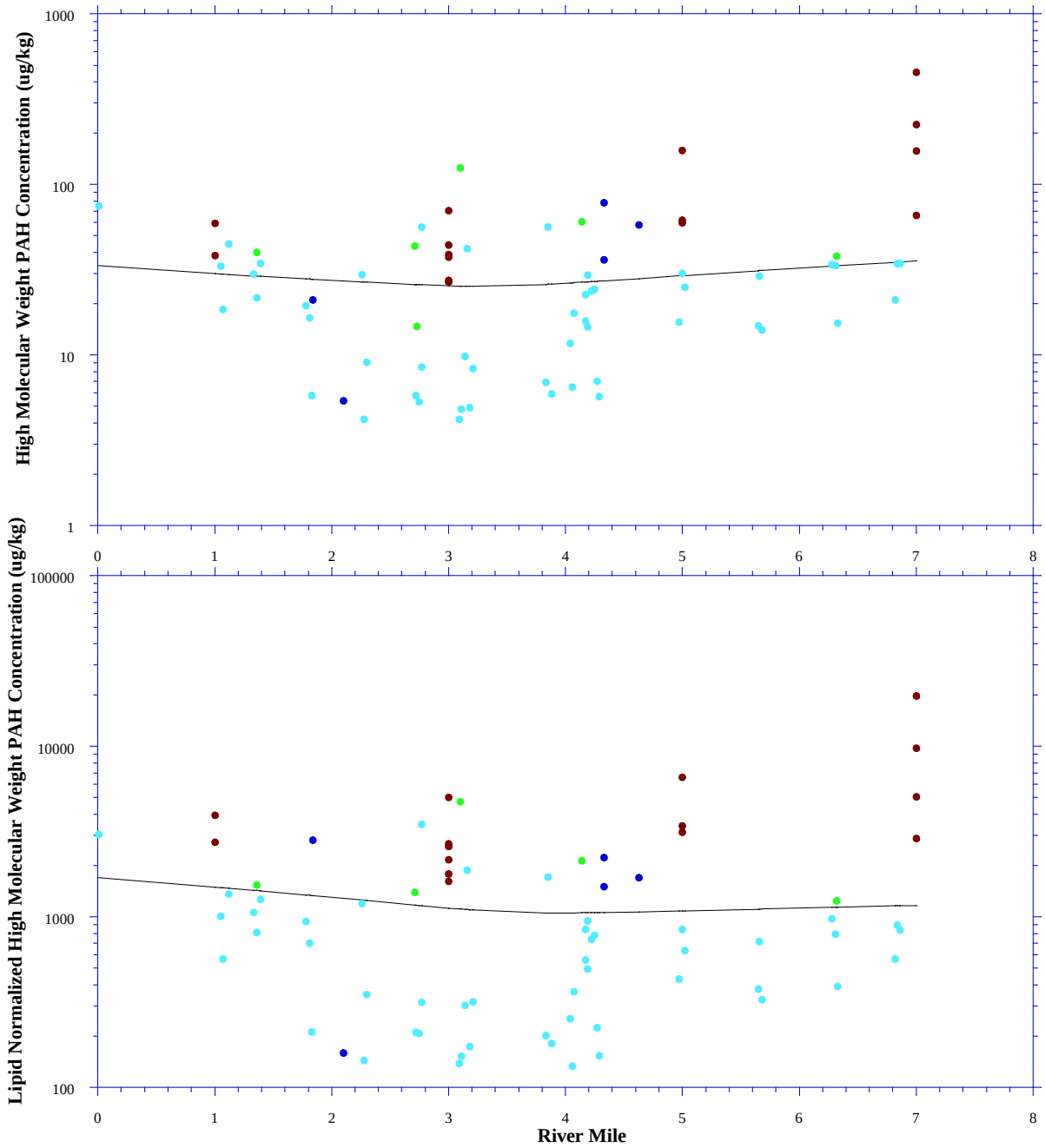
Mummichog LMW PAH Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-2f

2014

R2-0027576



Legend

Tissue Sampling Year
- 1995
- 1999
- 2000
- 2010

Tissue Type
- Whole Body

Note

Fit Lines are weighted curves for illustration purpose only.

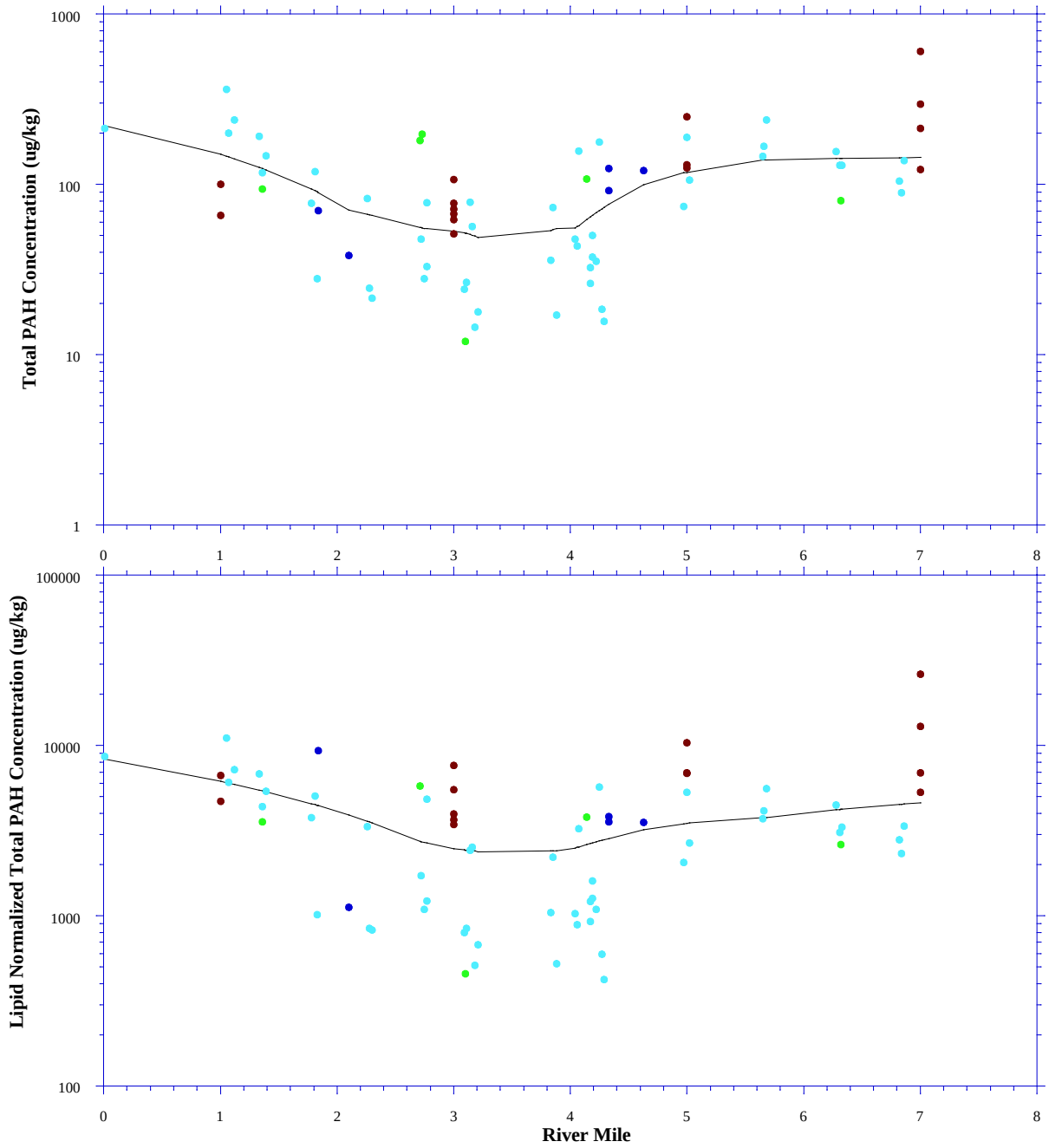
Mummichog HMW PAH Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-2g

2014

R2-0027577



Legend

Tissue Sampling Year
- 1995
- 1999
- 2000
- 2010

Tissue Type
- Whole Body

Note

Fit Lines are weighted curves for illustration purpose only.

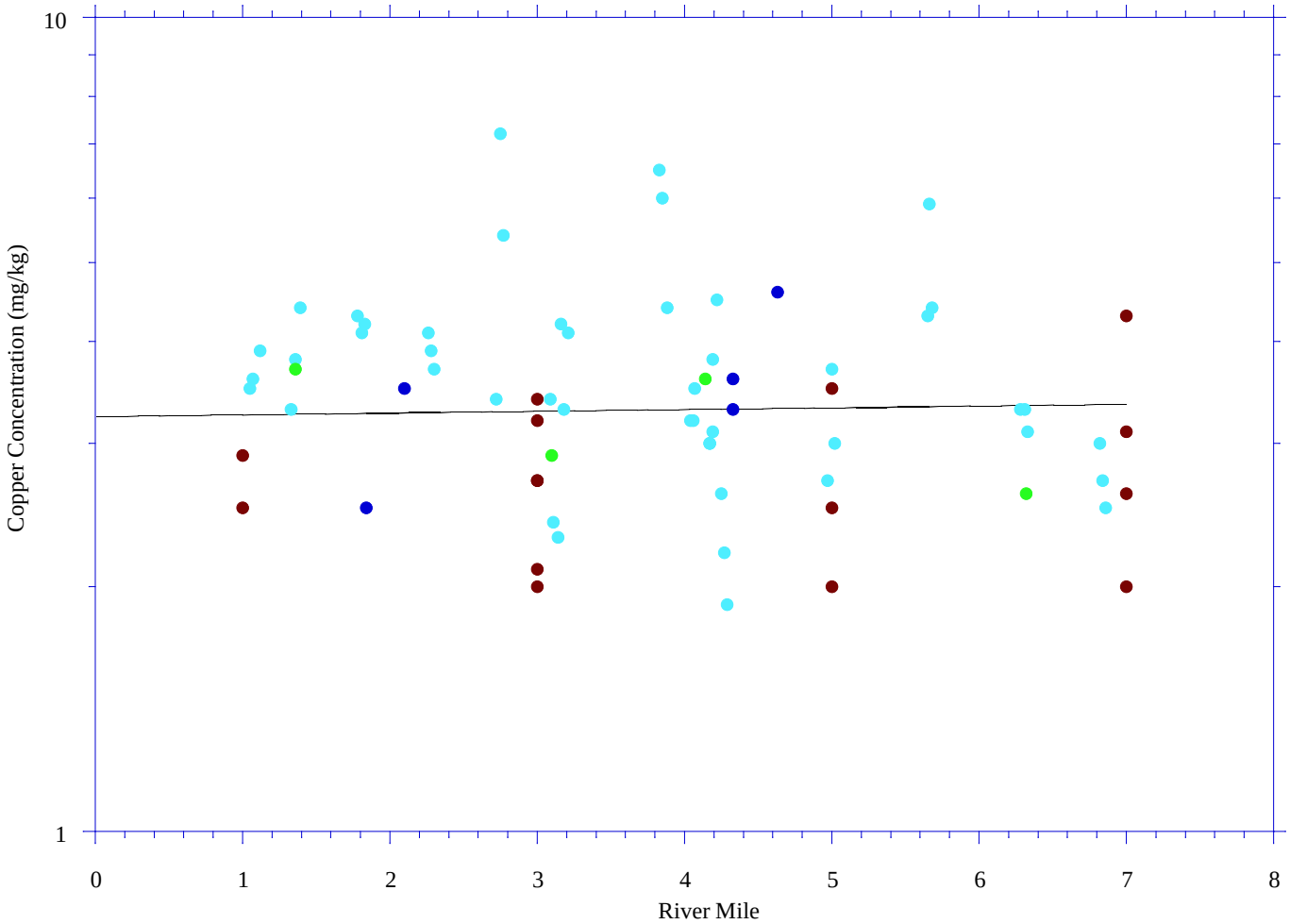
Mummichog Total PAH Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-2h

2014

R2-0027578



Legend

Tissue Sampling Year

- 1995
- 1999
- 2000
- 2010

Tissue Type

- Whole Body

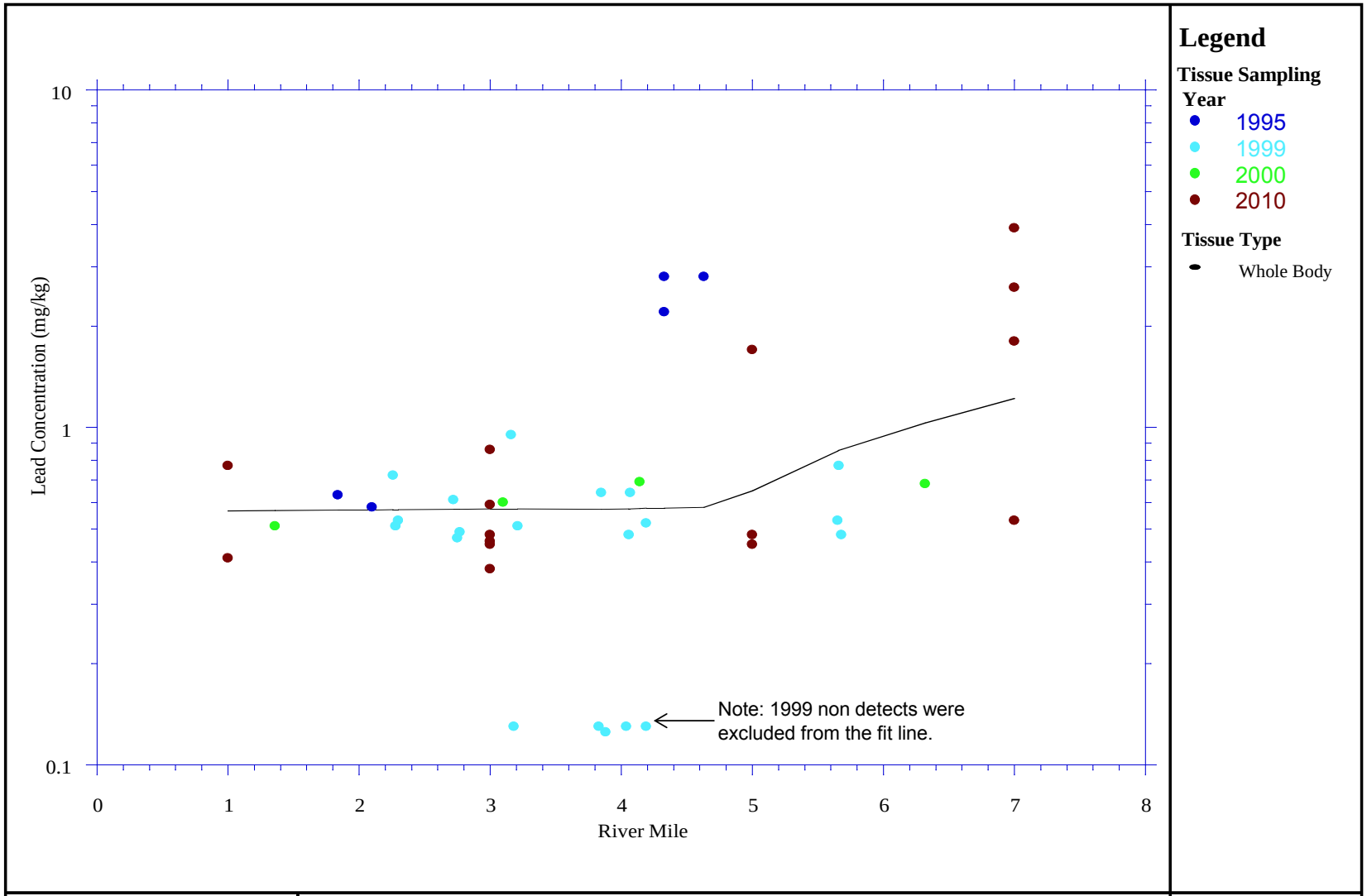
Mummichog Copper Concentration *vs*. River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-2i

2014

R2-0027579



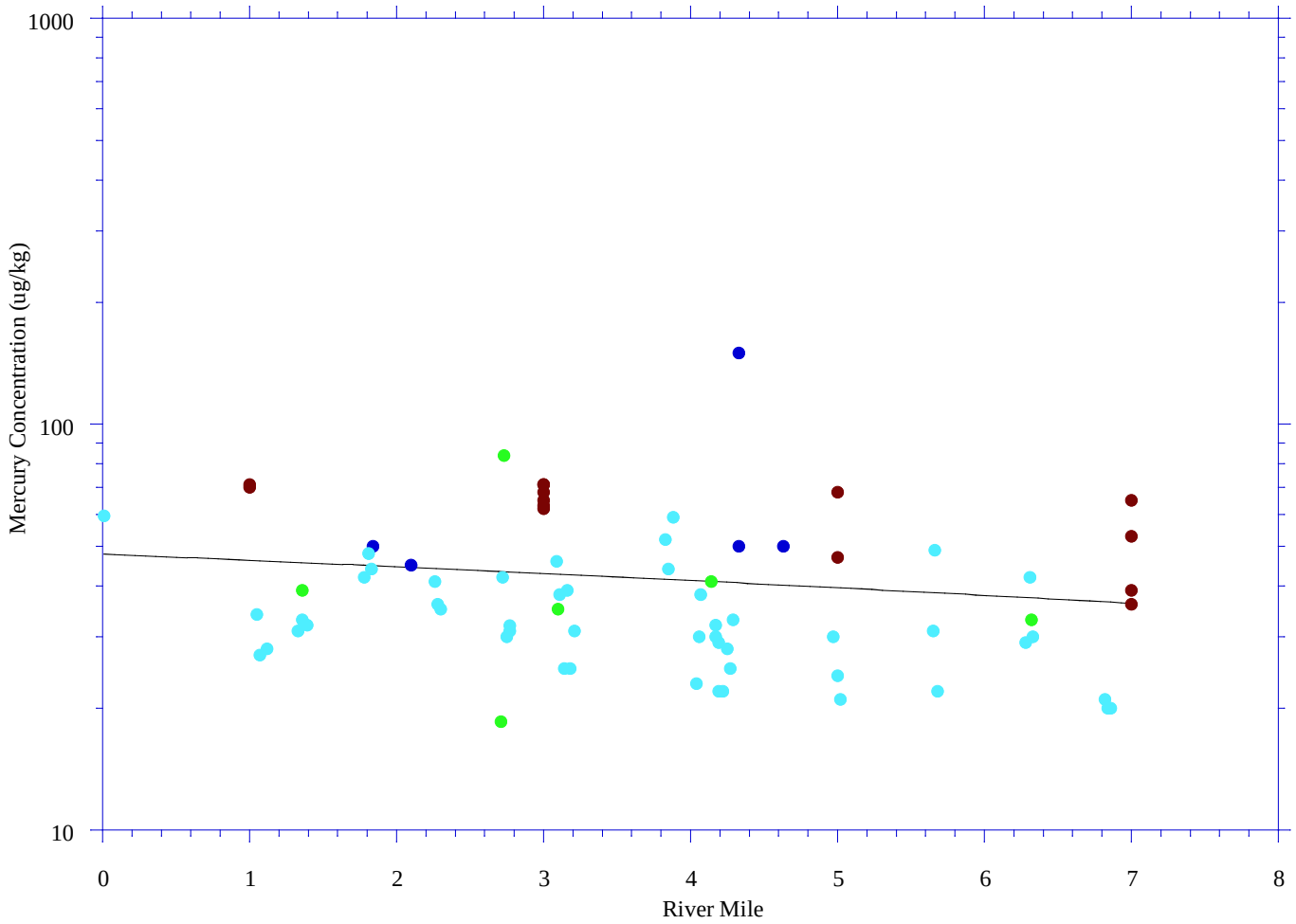
Mummichog Lead Concentration *vs*. River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-2j

2014

R2-0027580



Legend

Tissue Sampling Year

- 1995
- 1999
- 2000
- 2010

Tissue Type

- Whole Body

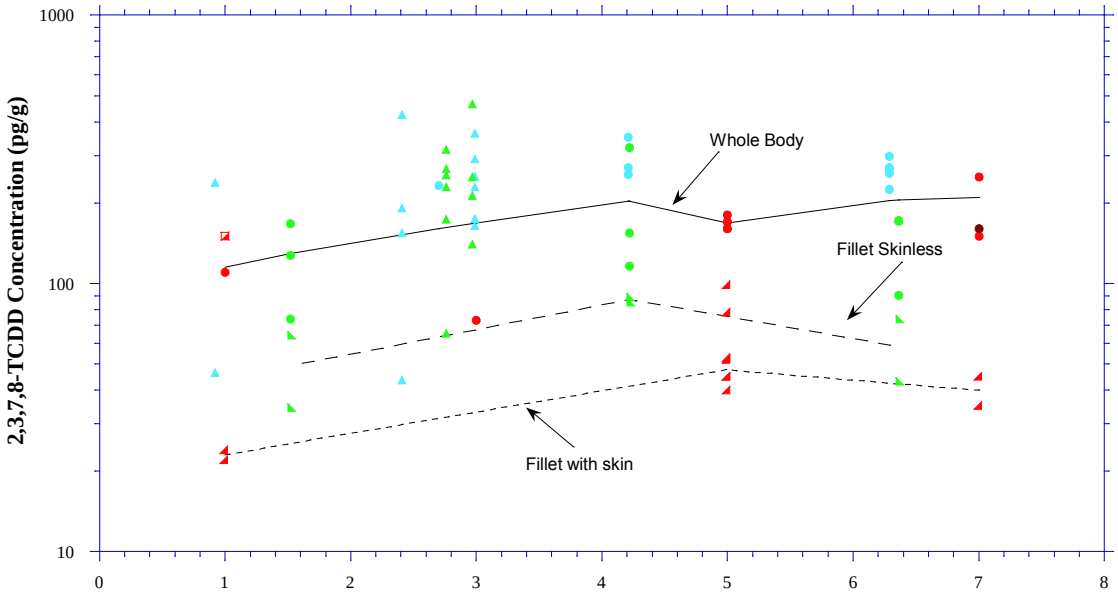
Mummichog Mercury Concentration *vs*. River Mile

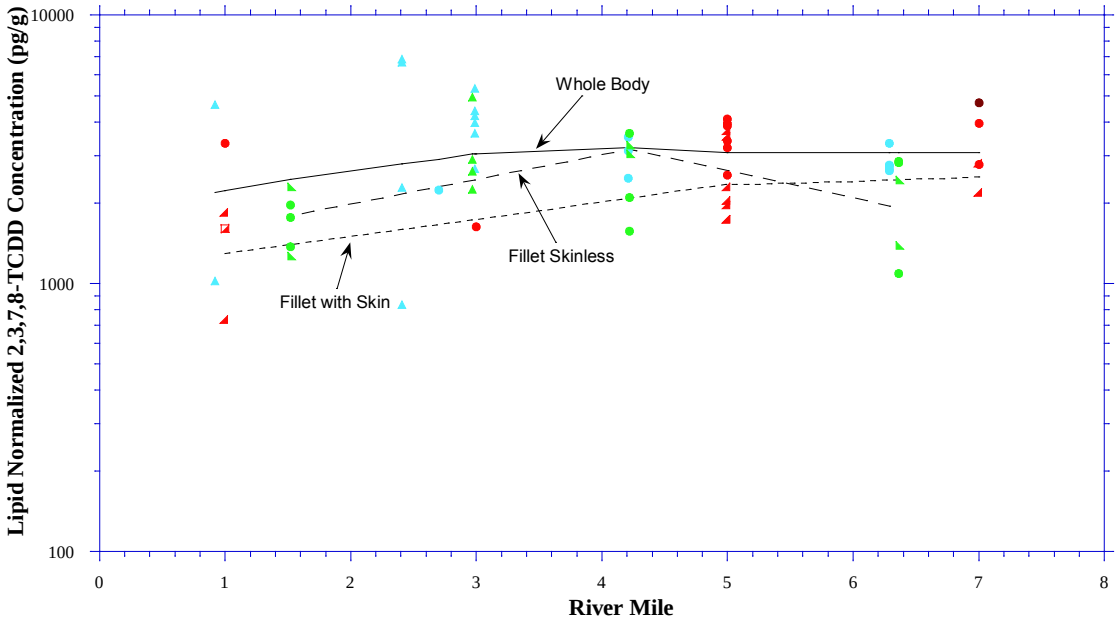
Lower Eight Miles of the Lower Passaic River

Figure 2-2k

2014

R2-0027581





Legend

Tissue Sampling Year

- 1999
- 2000
- 2009
- 2010

Tissue Type

- Whole Body - Head&Viscera
- Whole Body
- Fillet Skinless
- Carcass
- Fillet with Skin

Note

Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.

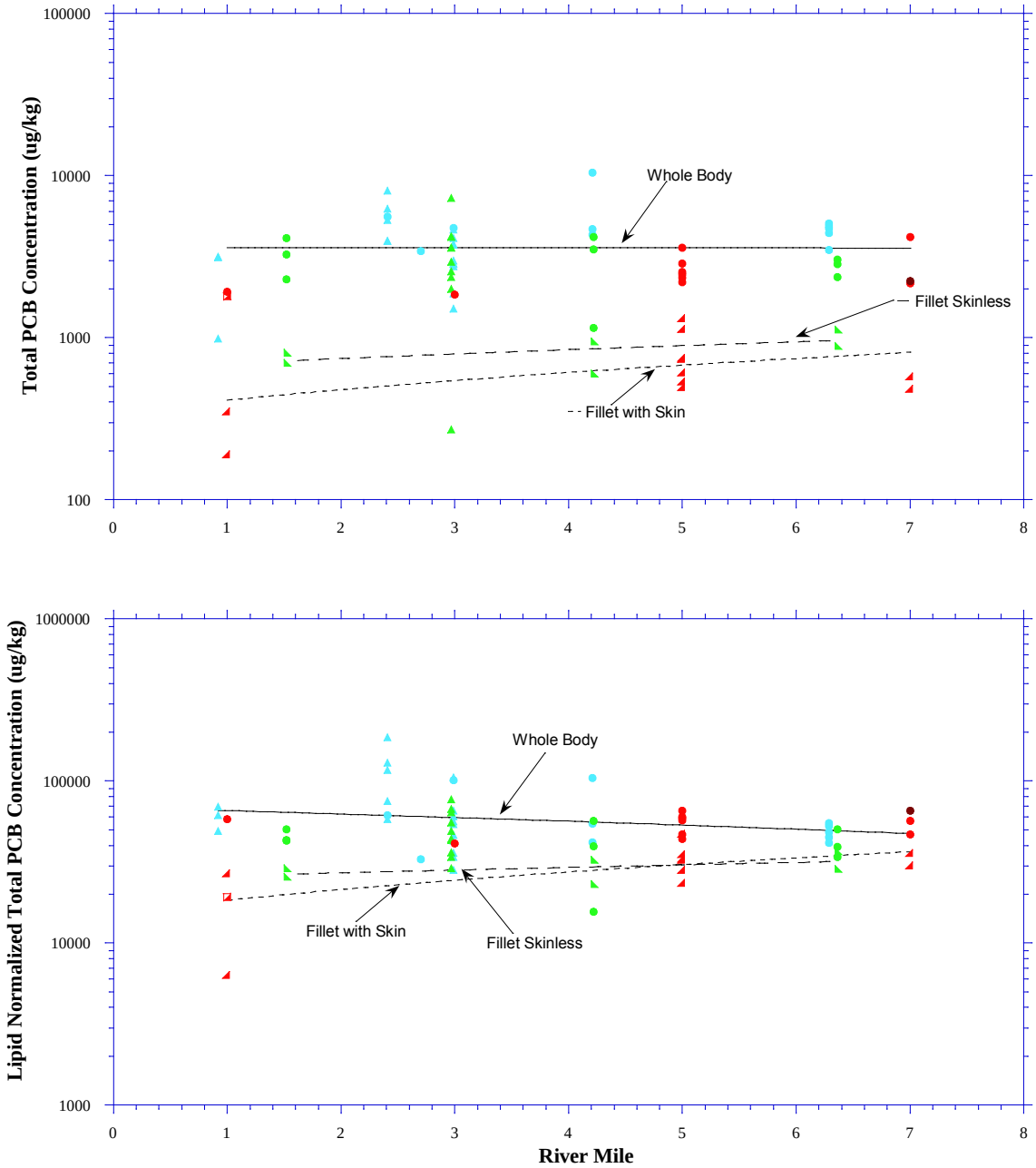
White Perch 2,3,7,8-TCDD Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-3a

2014

R2-0027582



Legend

Tissue Sampling Year

- 1999
- 2000
- 2009
- 2010

Tissue Type

- Whole Body - Head&Viscera
- Whole Body
- Fillet Skinless
- Carcass
- Fillet with Skin

Note

Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.

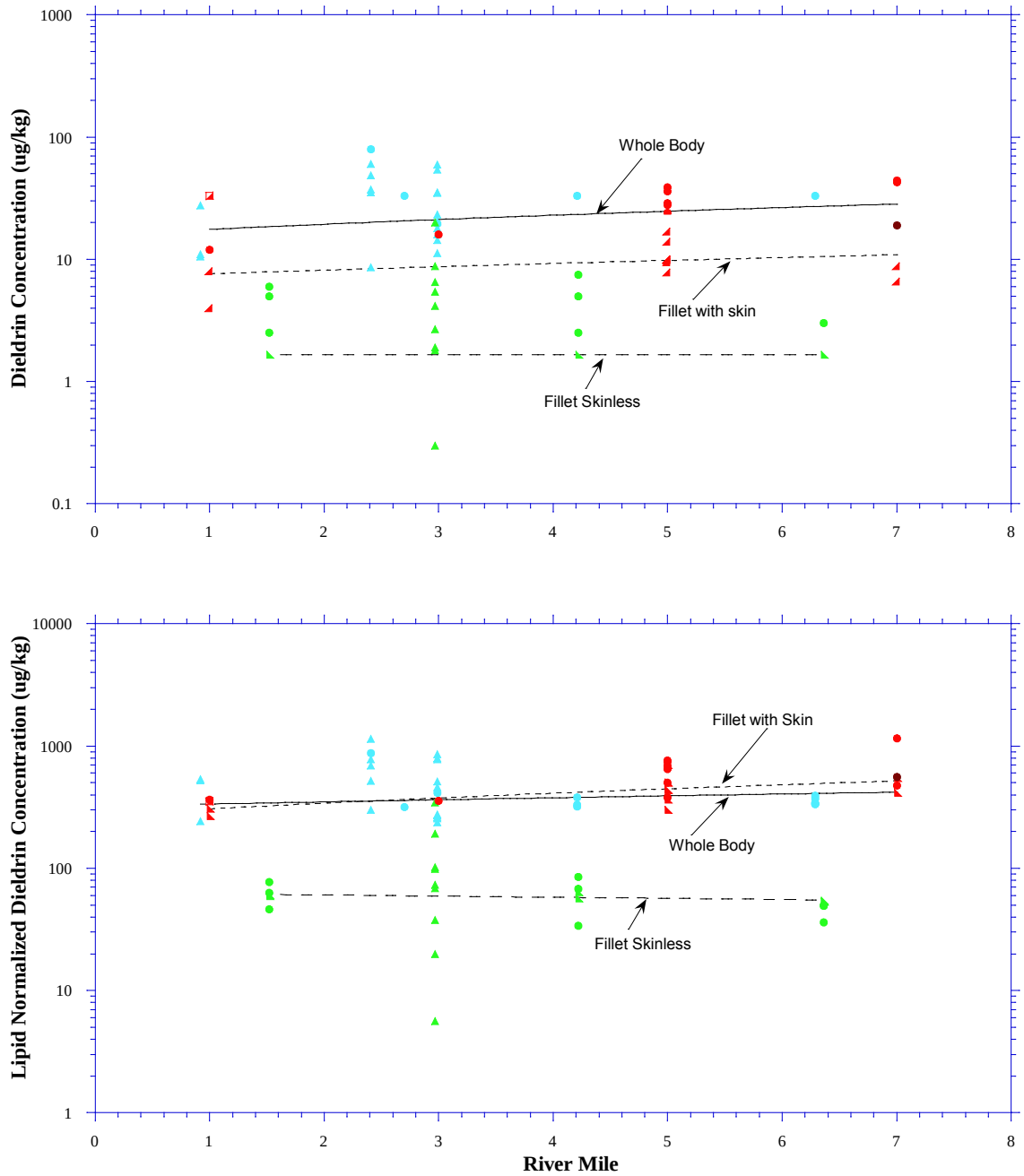
White Perch Total PCB Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-3b

2014

R2-0027583



Legend

Tissue Sampling Year

- 1999
- 2000
- 2009
- 2010

Tissue Type

- Whole Body - Head&Viscera
- Whole Body
- Fillet Skinless
- Carcass
- Fillet with Skin

Note

Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.

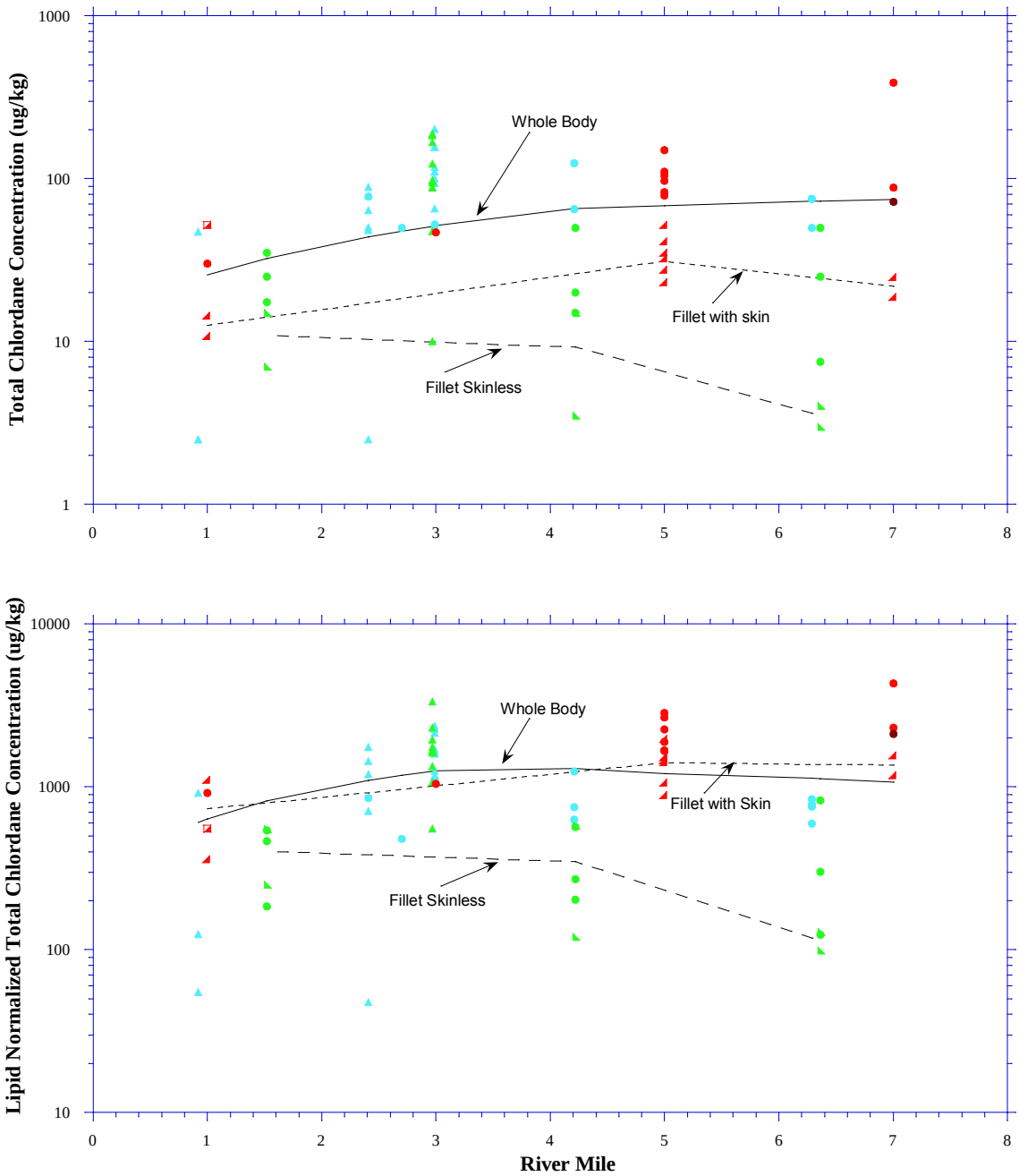
White Perch Dieldrin Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-3c

2014

R2-0027584



Legend

Tissue Sampling Year

- 1999
- 2000
- 2009
- 2010

Tissue Type

- Whole Body - Head&Viscera
- Whole Body
- Fillet Skinless
- Carcass
- Fillet with Skin

Note

Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.

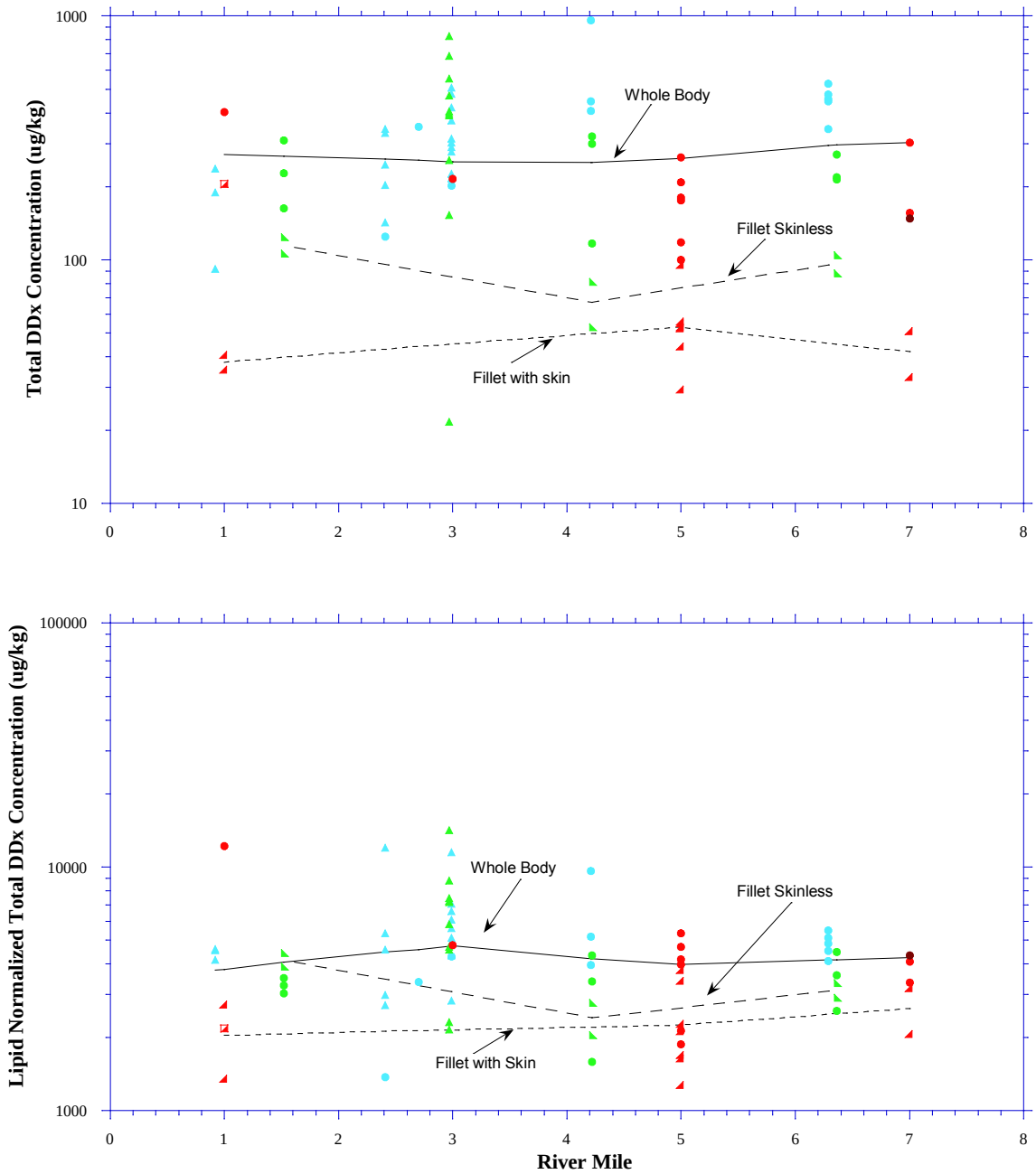
White Perch Total Chlordane Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-3d

2014

R2-0027585



Legend

Tissue Sampling Year

- 1999
- 2000
- 2009
- 2010

Tissue Type

- Whole Body - Head&Viscera
- Whole Body
- Fillet Skinless
- Carcass
- Fillet with Skin

Note

Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.

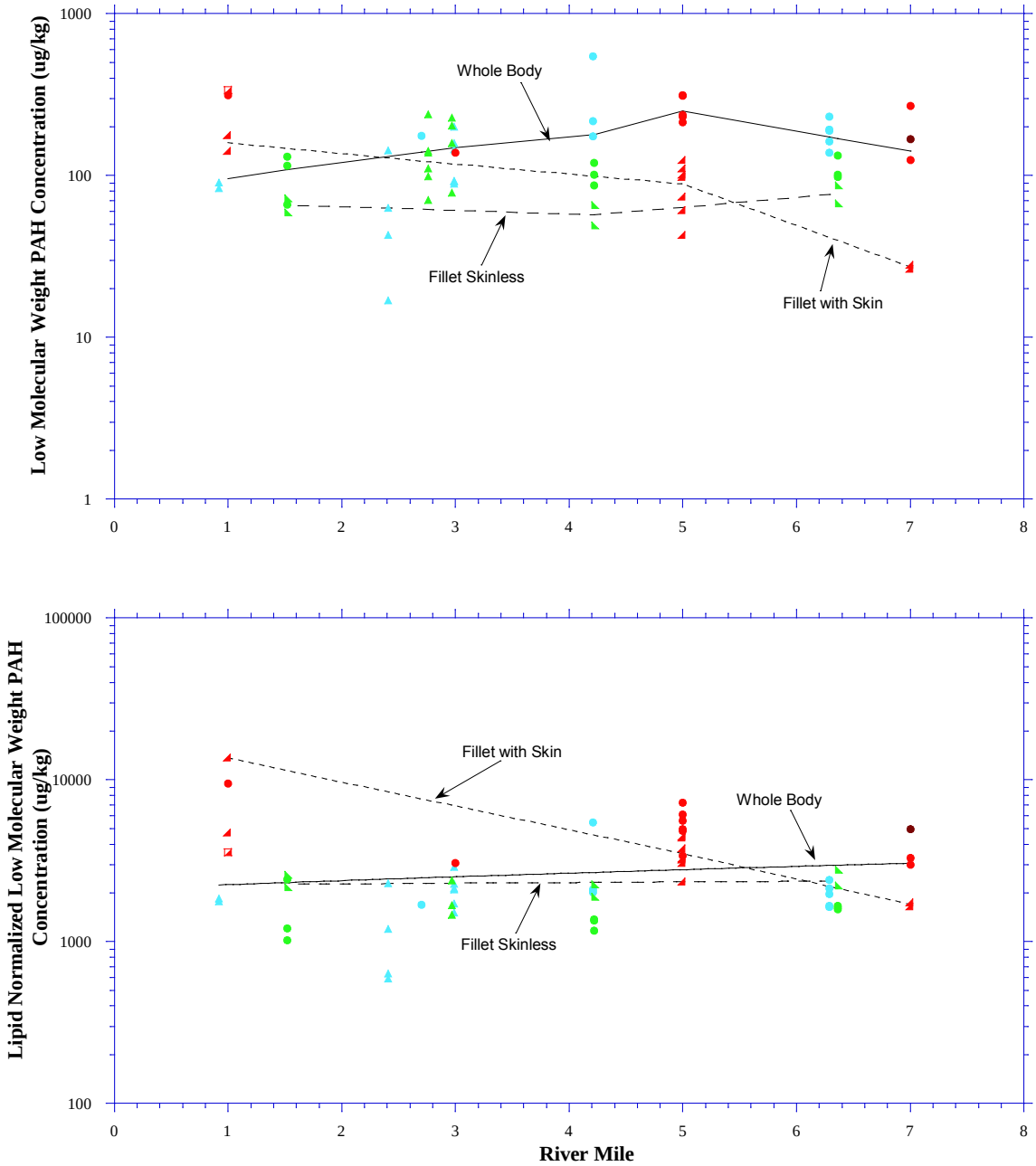
White Perch Total DDx Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-3e

2014

R2-0027586



Legend

Tissue Sampling Year

- 1999
- 2000
- 2009
- 2010

Tissue Type

- Whole Body - Head&Viscera
- Whole Body
- Fillet Skinless
- Carcass
- Fillet with Skin

Note

Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.

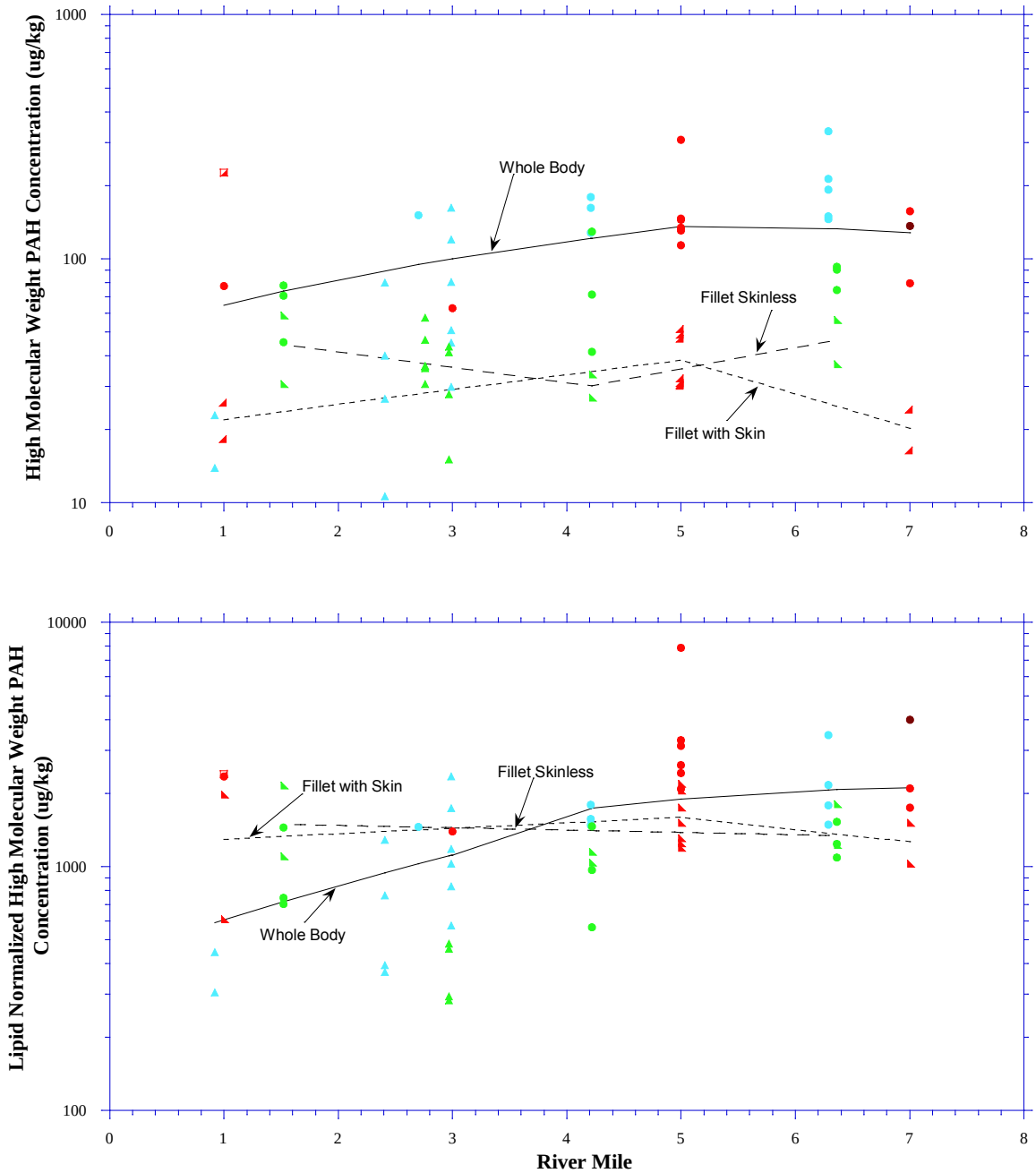
White Perch LMW PAH Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-3f

2014

R2-0027587



Legend

Tissue Sampling Year

- 1999
- 2000
- 2009
- 2010

Tissue Type

- Whole Body - Head&Viscera
- Whole Body
- Fillet Skinless
- Carcass
- Fillet with Skin

Note

Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.

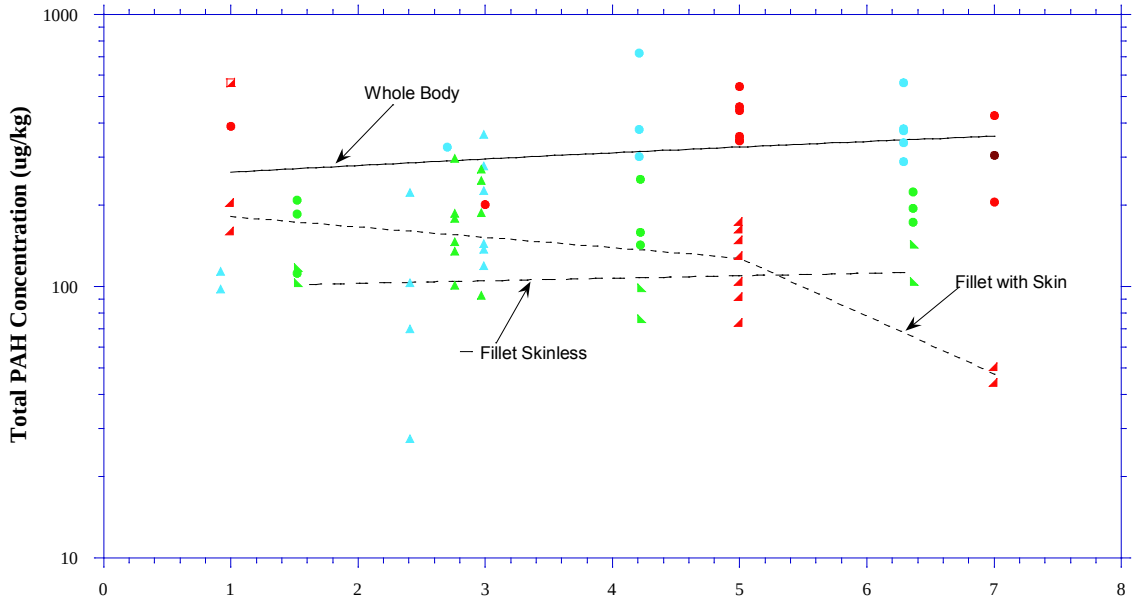
White Perch HMW PAH Concentration *vs.* River Mile

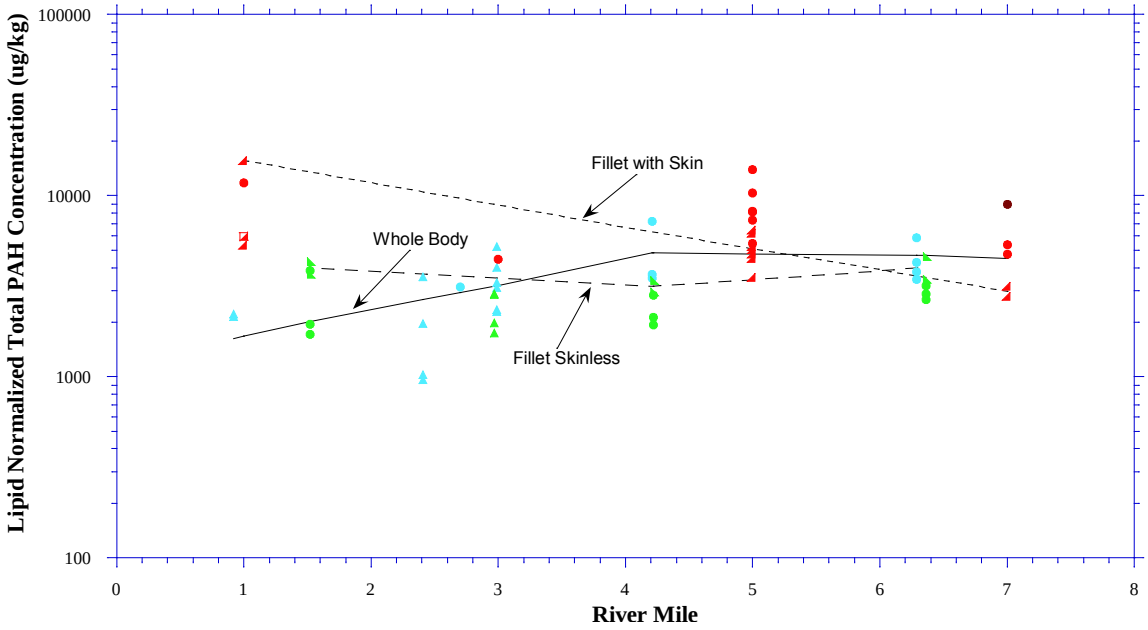
Lower Eight Miles of the Lower Passaic River

Figure 2-3g

2014

R2-0027588





Legend

Tissue Sampling Year

- 1999
- 2000
- 2009
- 2010

Tissue Type

- Whole Body - Head&Viscera
- Whole Body
- Fillet Skinless
- Carcass
- Fillet with Skin

Note

Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.

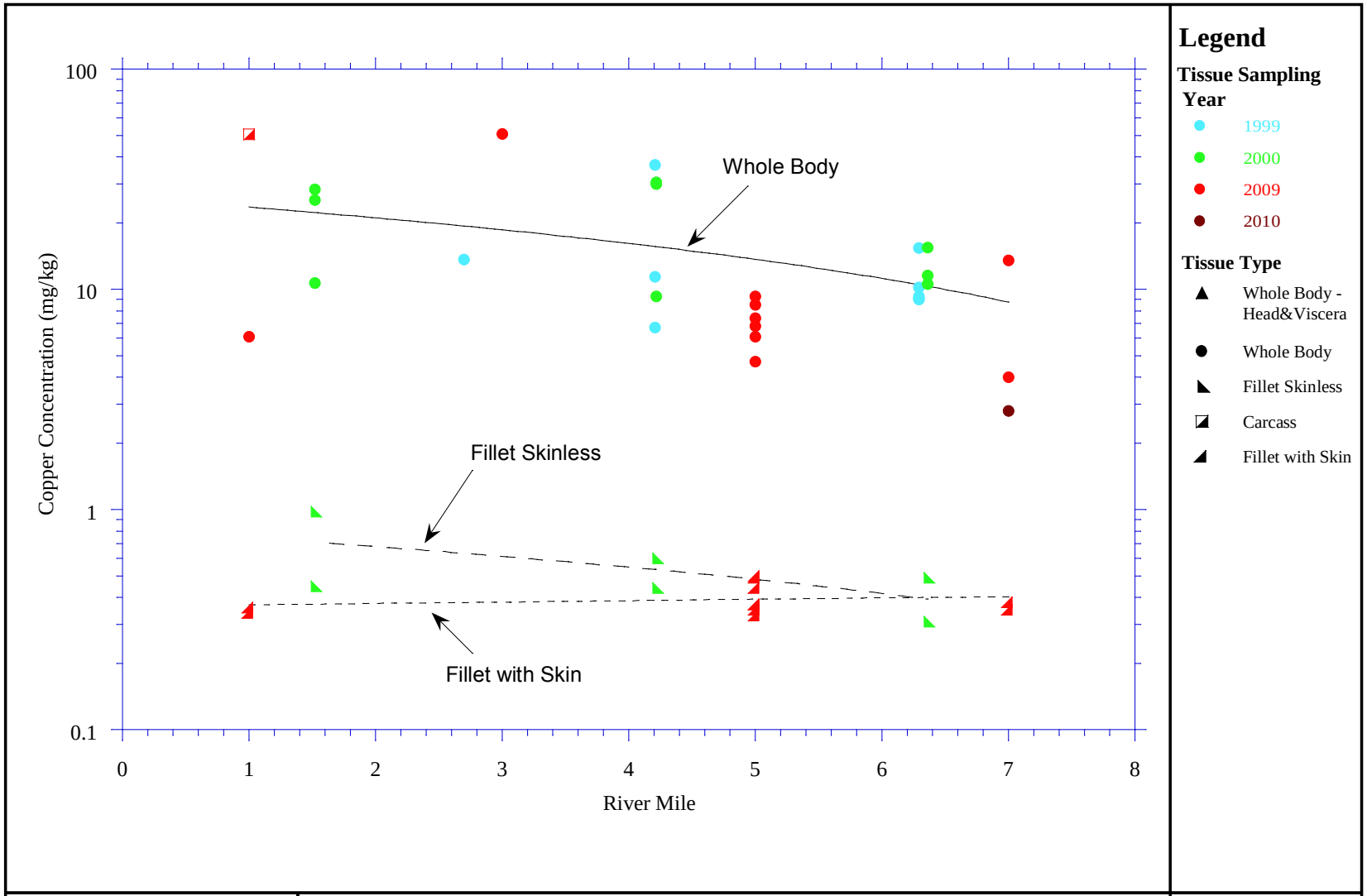
White Perch Total PAH Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-3h

2014

R2-0027589



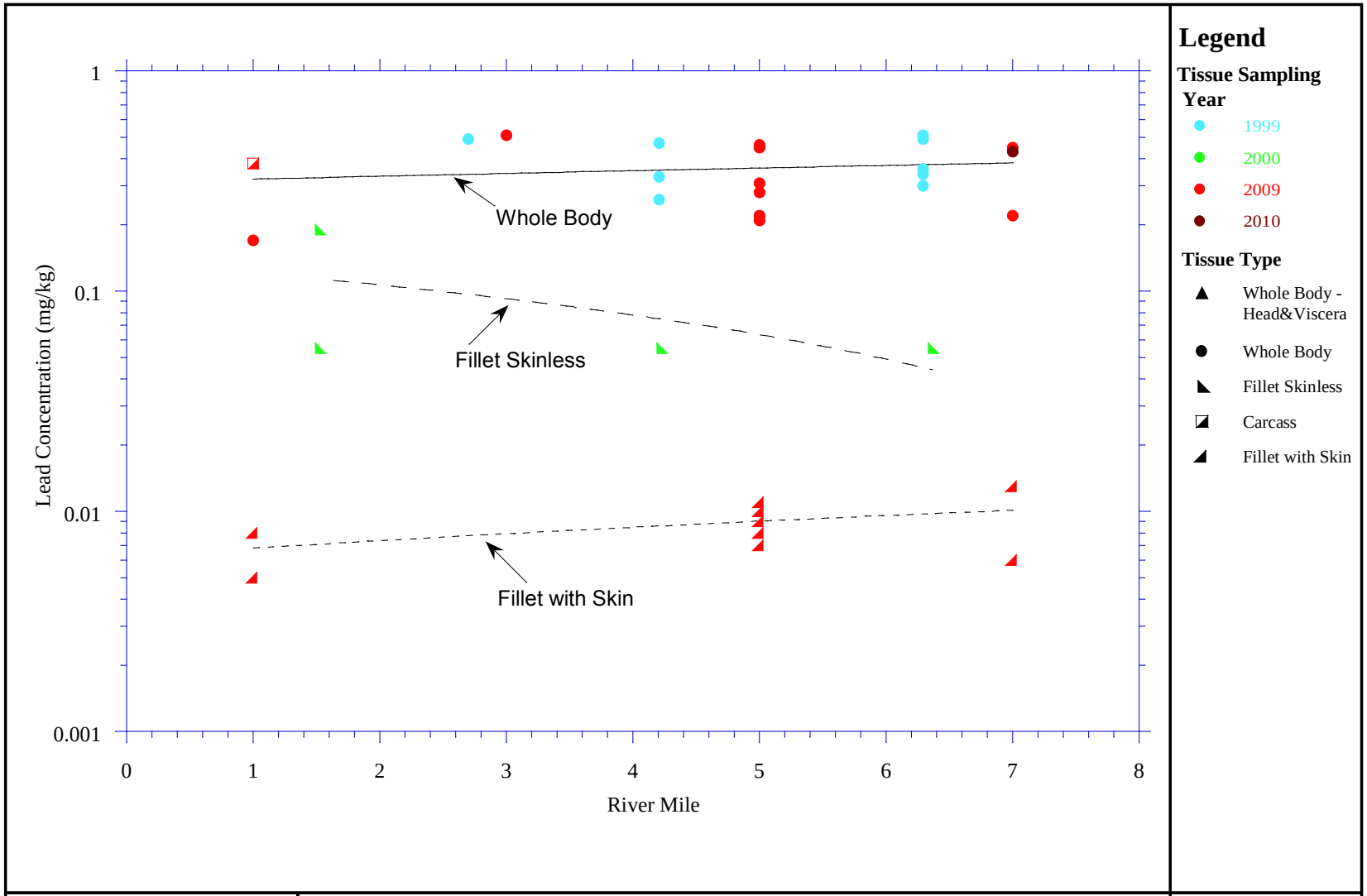
White Perch Copper Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-3i

2014

R2-0027590



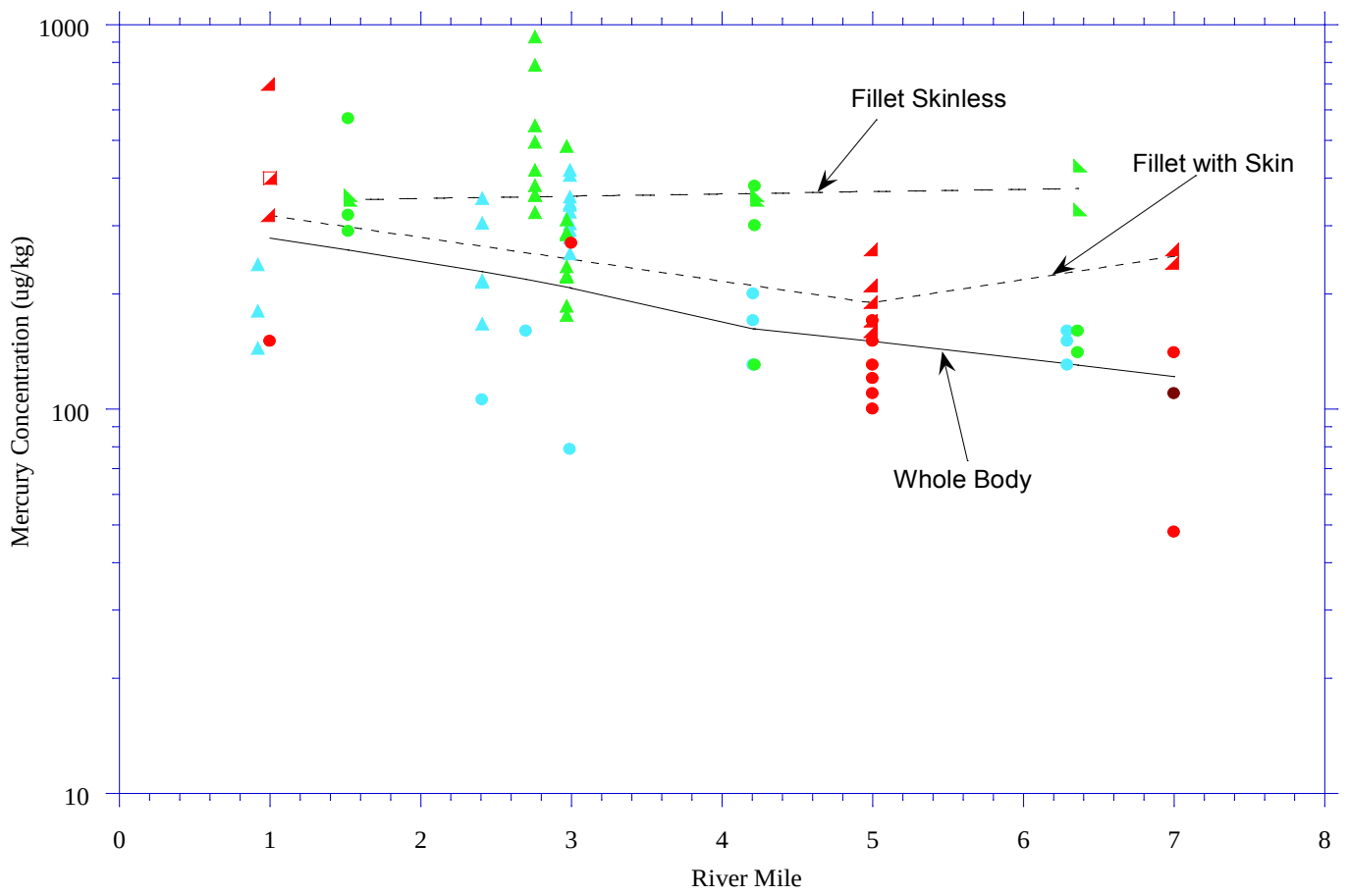
White Perch Lead Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-3j

2014

R2-0027591



Legend

Tissue Sampling Year

- 1999
- 2000
- 2009
- 2010

Tissue Type

- Whole Body - Head&Viscera
- Whole Body
- Fillet Skinless
- Carcass
- Fillet with Skin

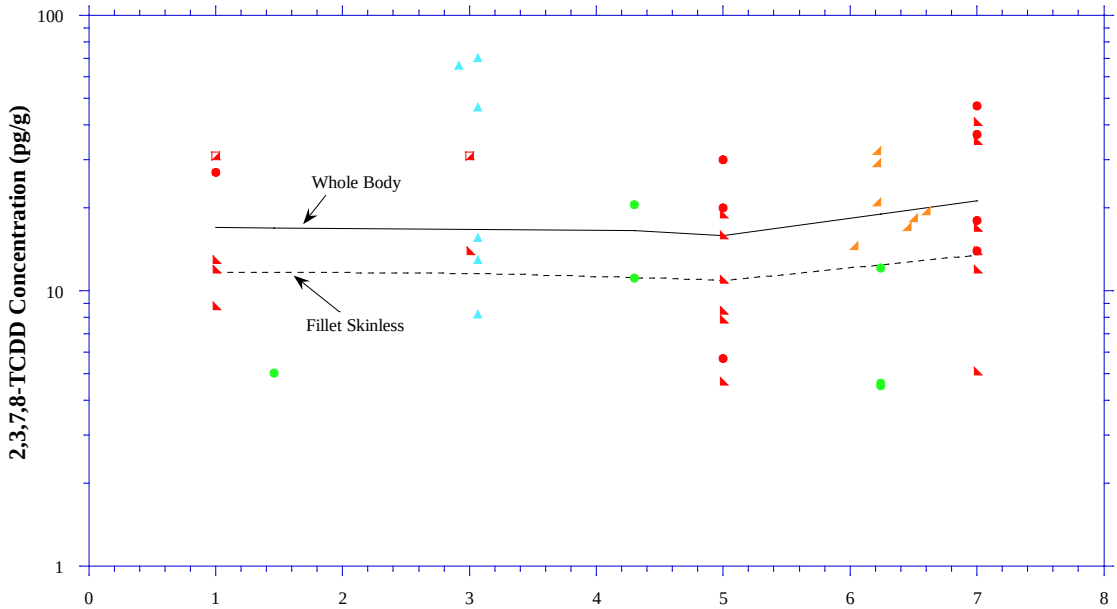
White Perch Mercury Concentration *vs*. River Mile

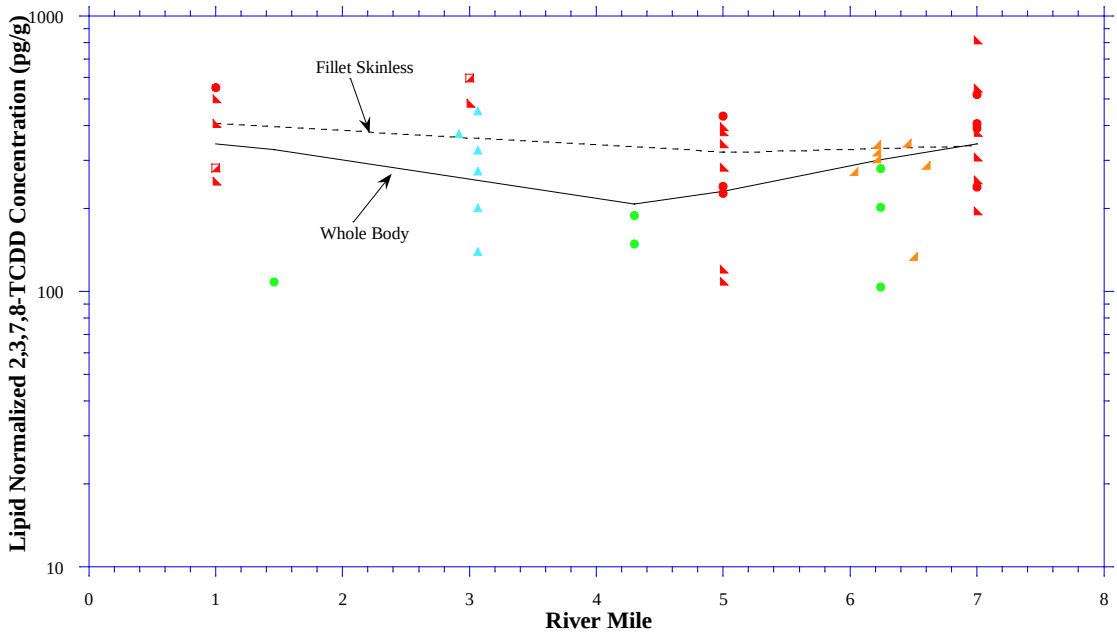
Lower Eight Miles of the Lower Passaic River

Figure 2-3k

2014

R2-0027592





Legend

Tissue Sampling Year

- 1999
- 2000
- 2001
- 2009

Tissue Type

- Whole Body - Head&Viscera
- Whole Body
- Fillet Skinless
- Carcass
- Fillet with Skin

Note

Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.

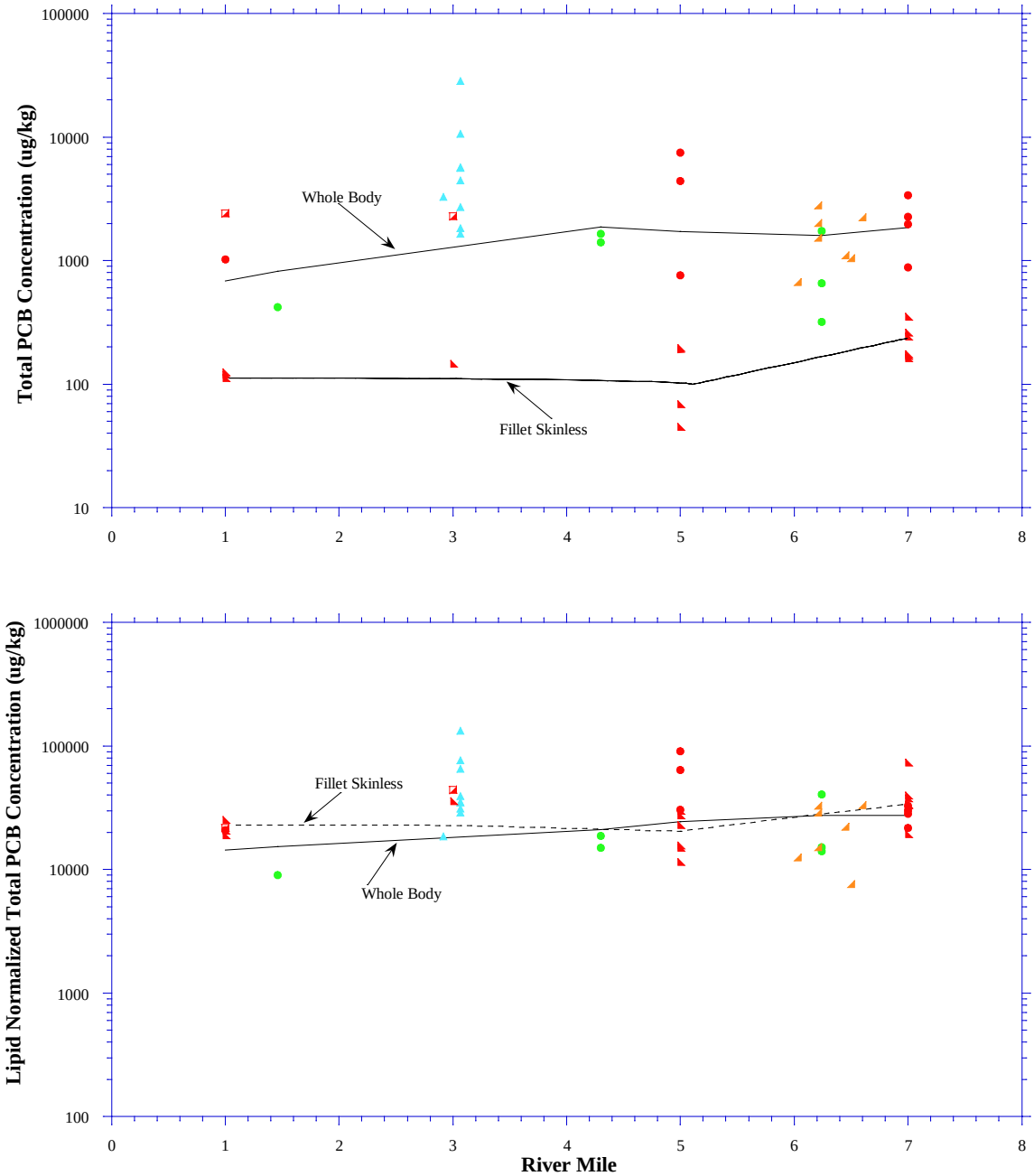
American Eel 2,3,7,8-TCDD Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-4a

2014

R2-0027593



Legend

Tissue Sampling Year

- 1999
- 2000
- 2001
- 2009

Tissue Type

- Whole Body - Head&Viscera
- Whole Body
- Fillet Skinless
- Carcass
- Fillet with Skin

Note

Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.

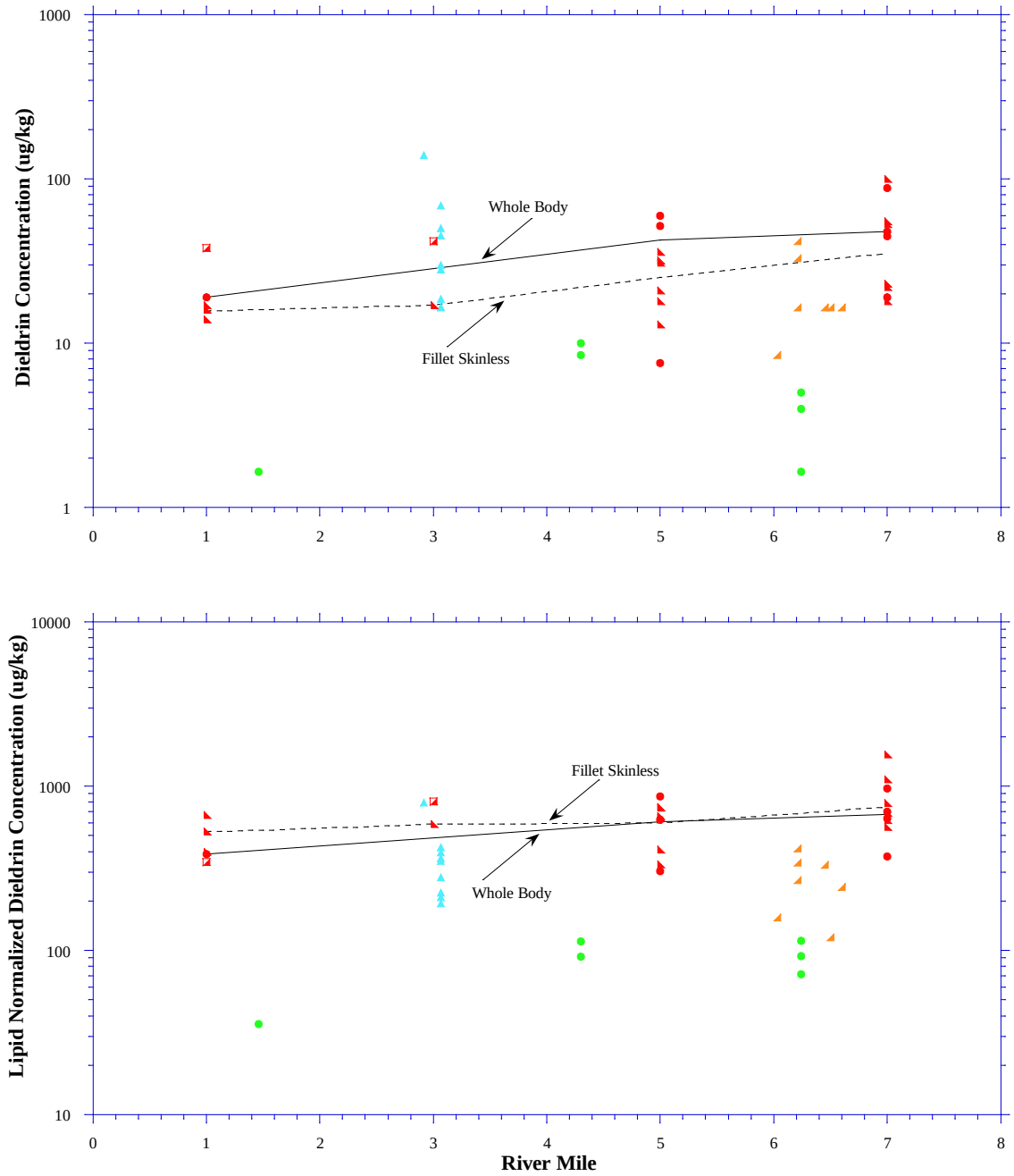
American Eel Total PCB Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-4b

2014

R2-0027594



Legend

Tissue Sampling Year

- 1999
- 2000
- 2001
- 2009

Tissue Type

- Whole Body - Head&Viscera
- Whole Body
- Fillet Skinless
- Carcass
- Fillet with Skin

Note

1. Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.
2. Year 2000 whole body data was excluded from the fit line because all data was nondetects.

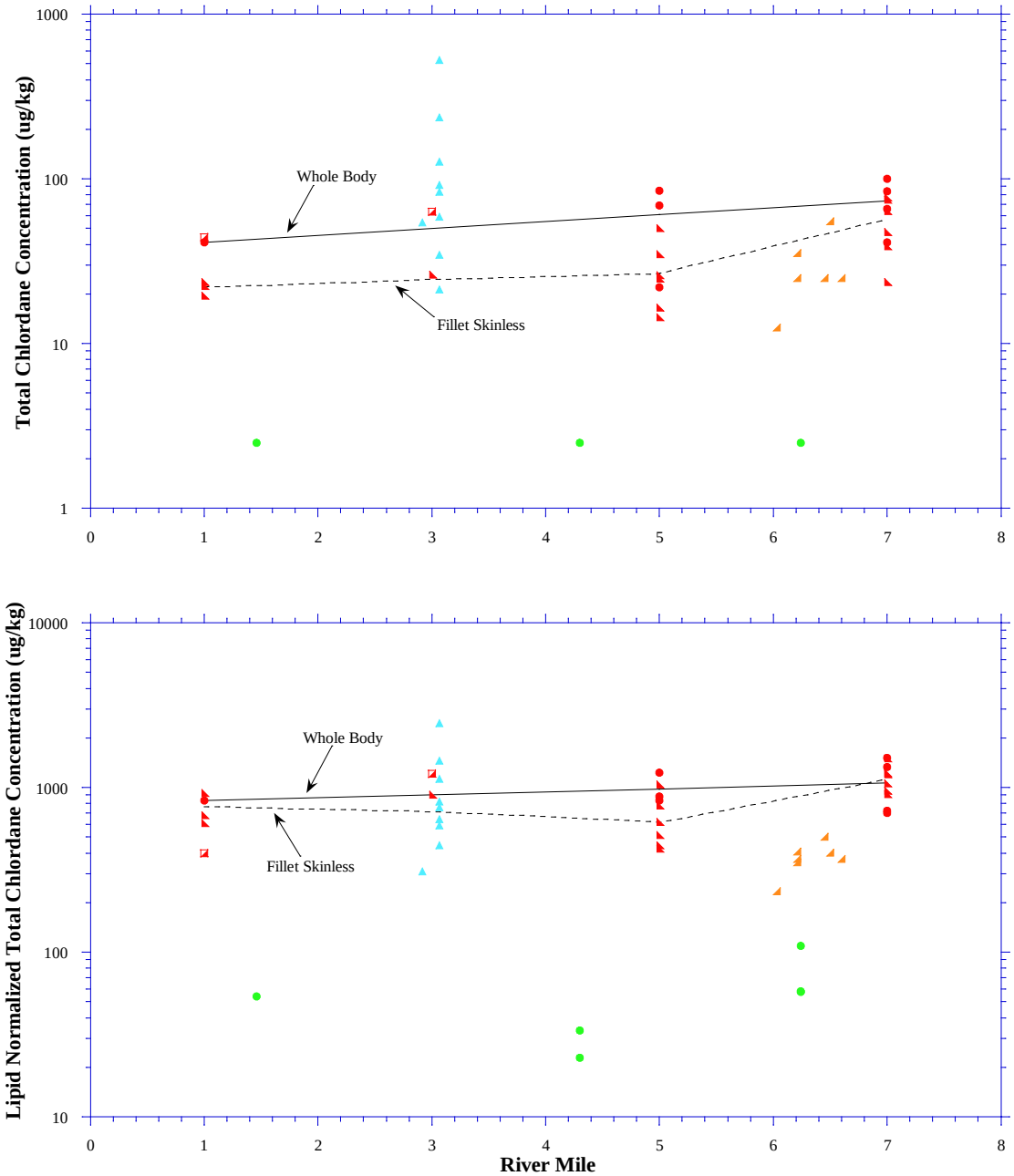
American Eel Dieldrin Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-4c

2014

R2-0027595



Legend

Tissue Sampling Year

- 1999
- 2000
- 2001
- 2009

Tissue Type

- Whole Body - Head&Viscera
- Whole Body
- Fillet Skinless
- Carcass
- Fillet with Skin

Note

1. Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.
2. Year 2000 whole body data was excluded from the fit line because all data was nondetects.

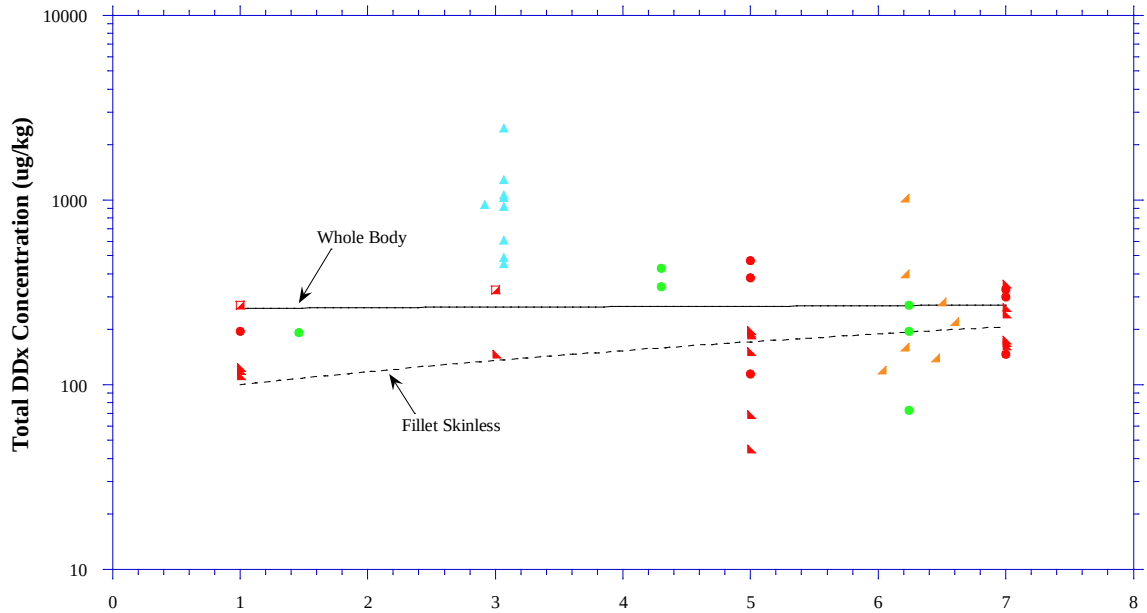
American Eel Total Chlordane Concentration *vs.* River Mile

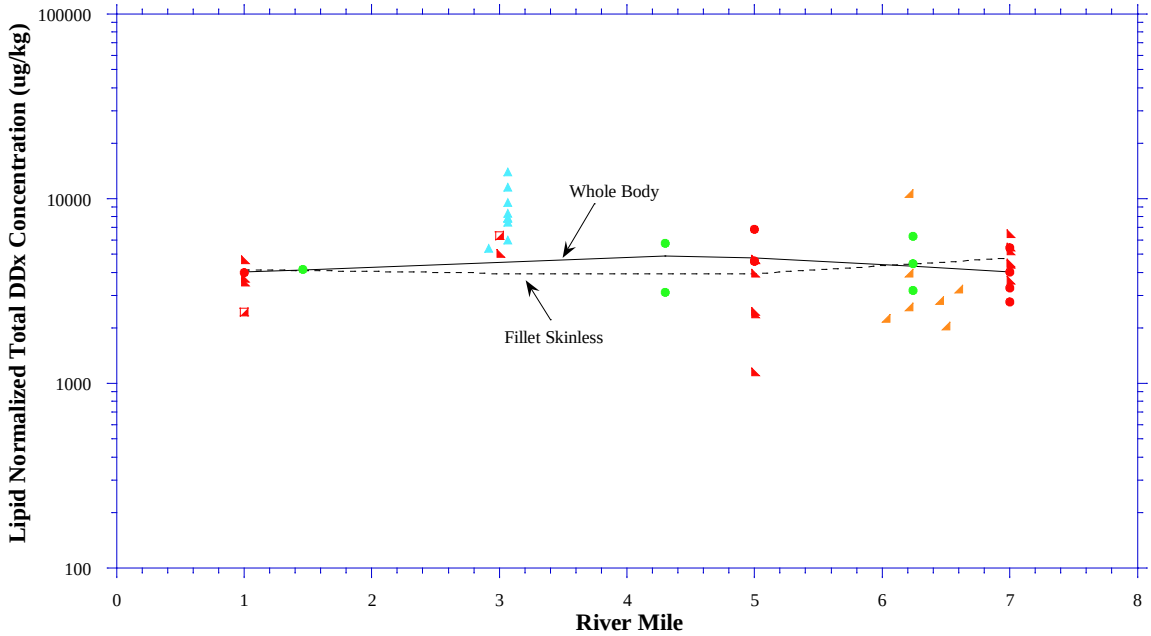
Lower Eight Miles of the Lower Passaic River

Figure 2-4d

2014

R2-0027596





Legend

Tissue Sampling Year

- 1999
- 2000
- 2001
- 2009

Tissue Type

- Whole Body - Head&Viscera
- Whole Body
- Fillet Skinless
- Carcass
- Fillet with Skin

Note

1. Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.
2. Year 2000 whole body data was excluded from the fit line because all data was nondetects.

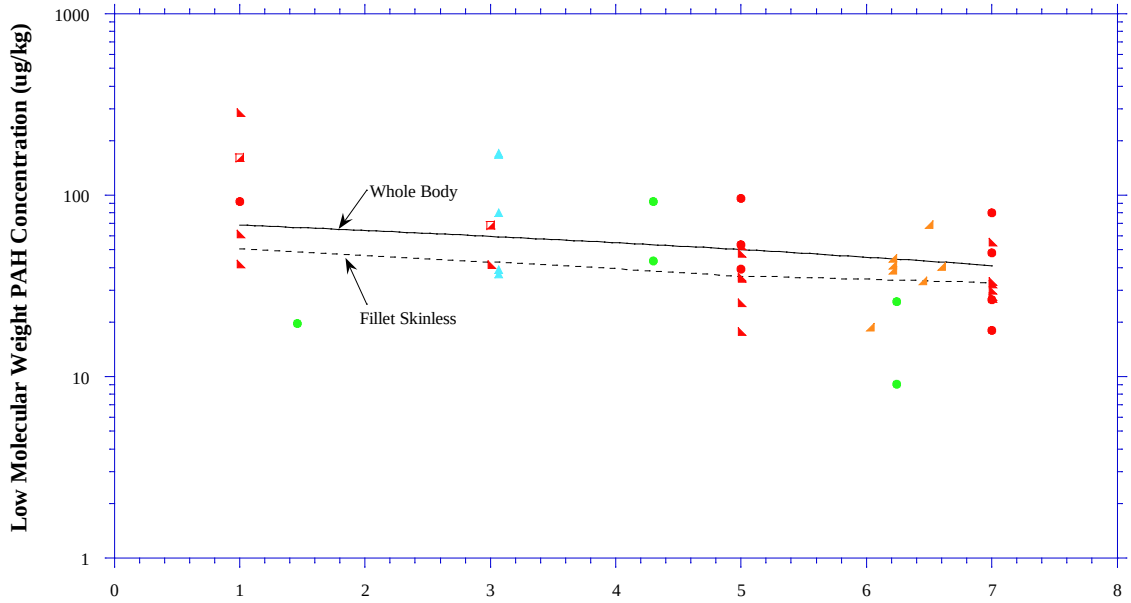
American Eel Total DDx Concentration *vs.* River Mile

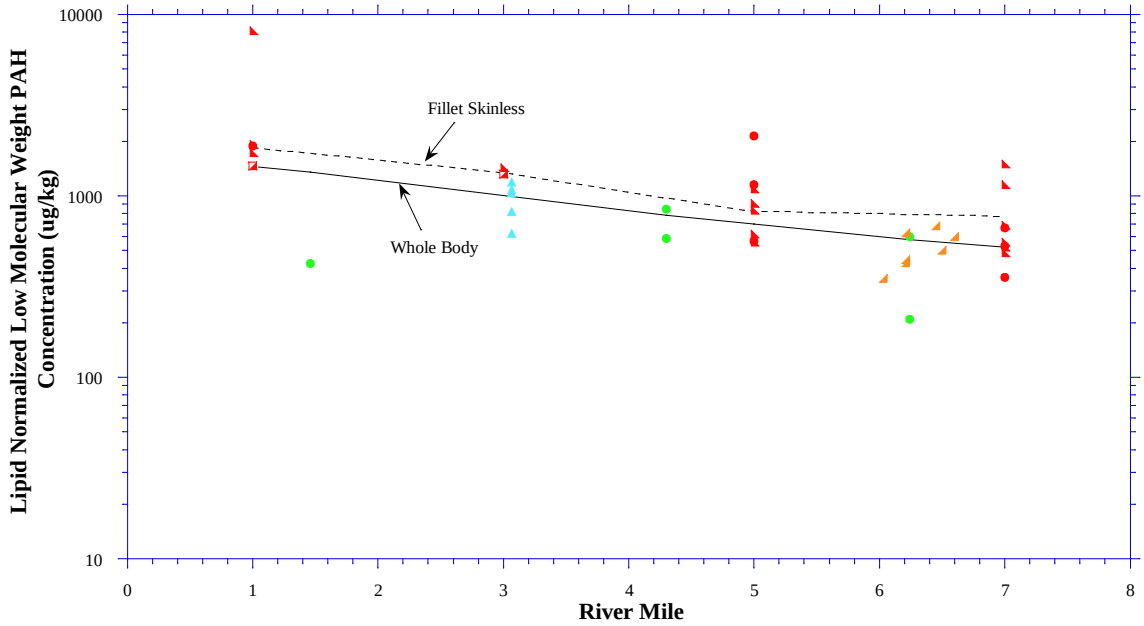
Lower Eight Miles of the Lower Passaic River

Figure 2-4e

2014

R2-0027597





Legend

Tissue Sampling Year

- 1999
- 2000
- 2001
- 2009

Tissue Type

- Whole Body - Head&Viscera
- Whole Body
- Fillet Skinless
- Carcass
- Fillet with Skin

Note

1. Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.
2. Year 2000 whole body data was excluded from the fit line because all data was nondetects.

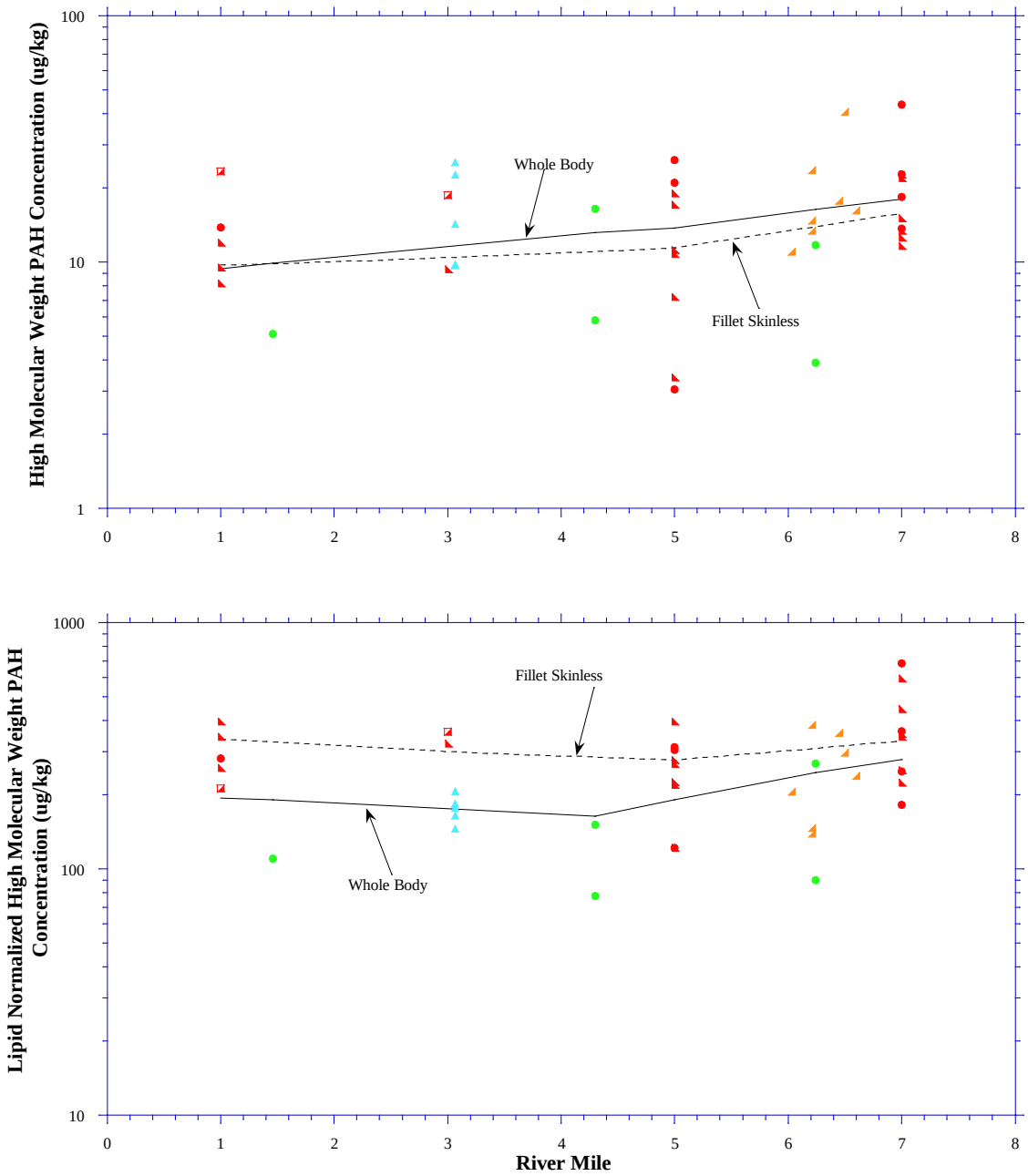
American Eel LMW PAH Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-4f

2014

R2-0027598



Legend

Tissue Sampling Year

- 1999
- 2000
- 2001
- 2009

Tissue Type

- Whole Body - Head&Viscera
- Whole Body
- Fillet Skinless
- Carcass
- Fillet with Skin

Note

1. Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.
2. Year 2000 whole body data was excluded from the fit line because all data was nondetects.

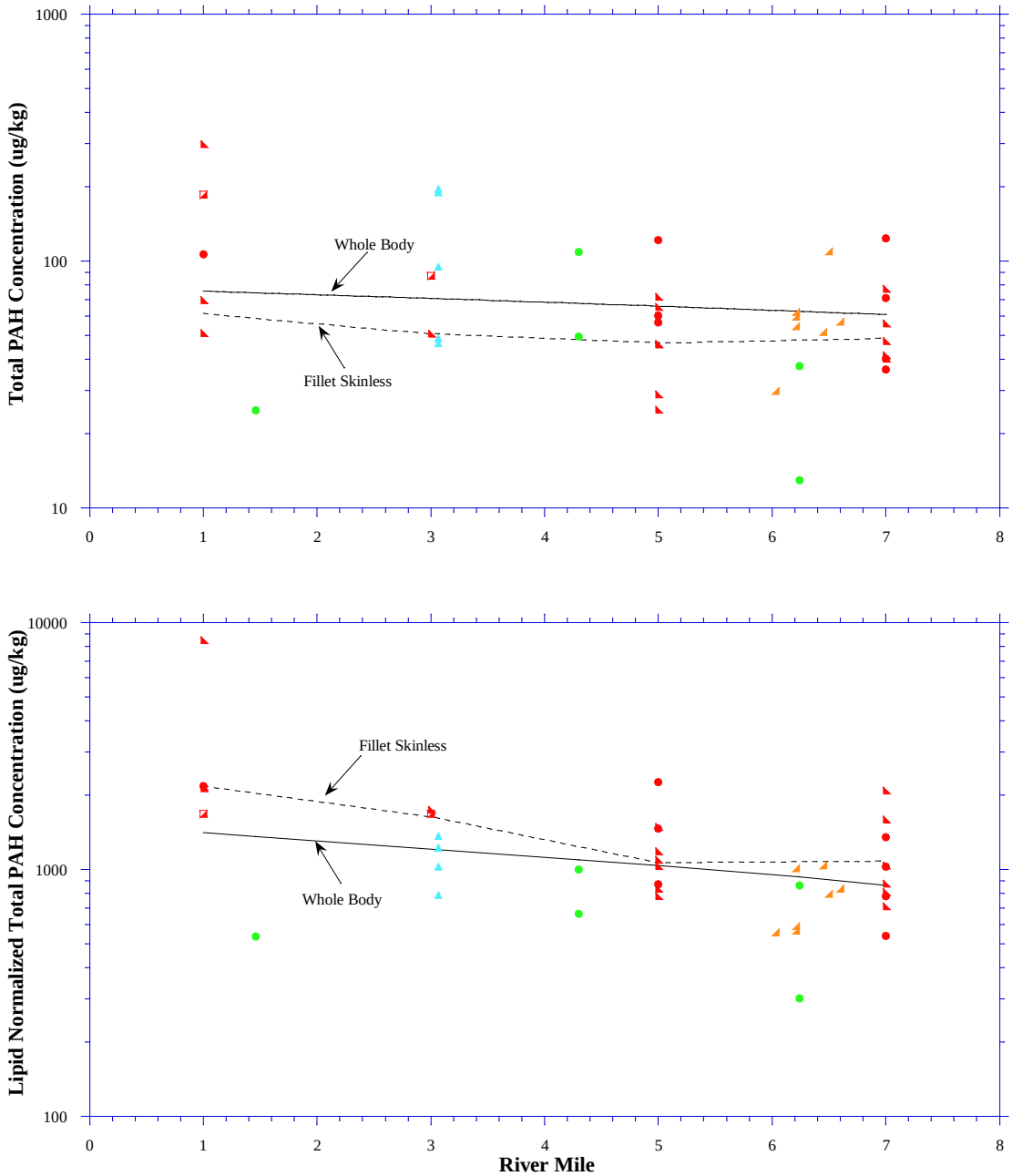
American Eel HMW PAH Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-4g

2014

R2-0027599



Legend

Tissue Sampling Year

- 1999
- 2000
- 2001
- 2009

Tissue Type

- Whole Body - Head&Viscera
- Whole Body
- Fillet Skinless
- Carcass
- Fillet with Skin

Note

1. Fit Lines are weighted curves for illustration purpose only. These curves are based on all available data for given tissue types.
2. Year 2000 whole body data was excluded from the fit line because all data was nondetects.

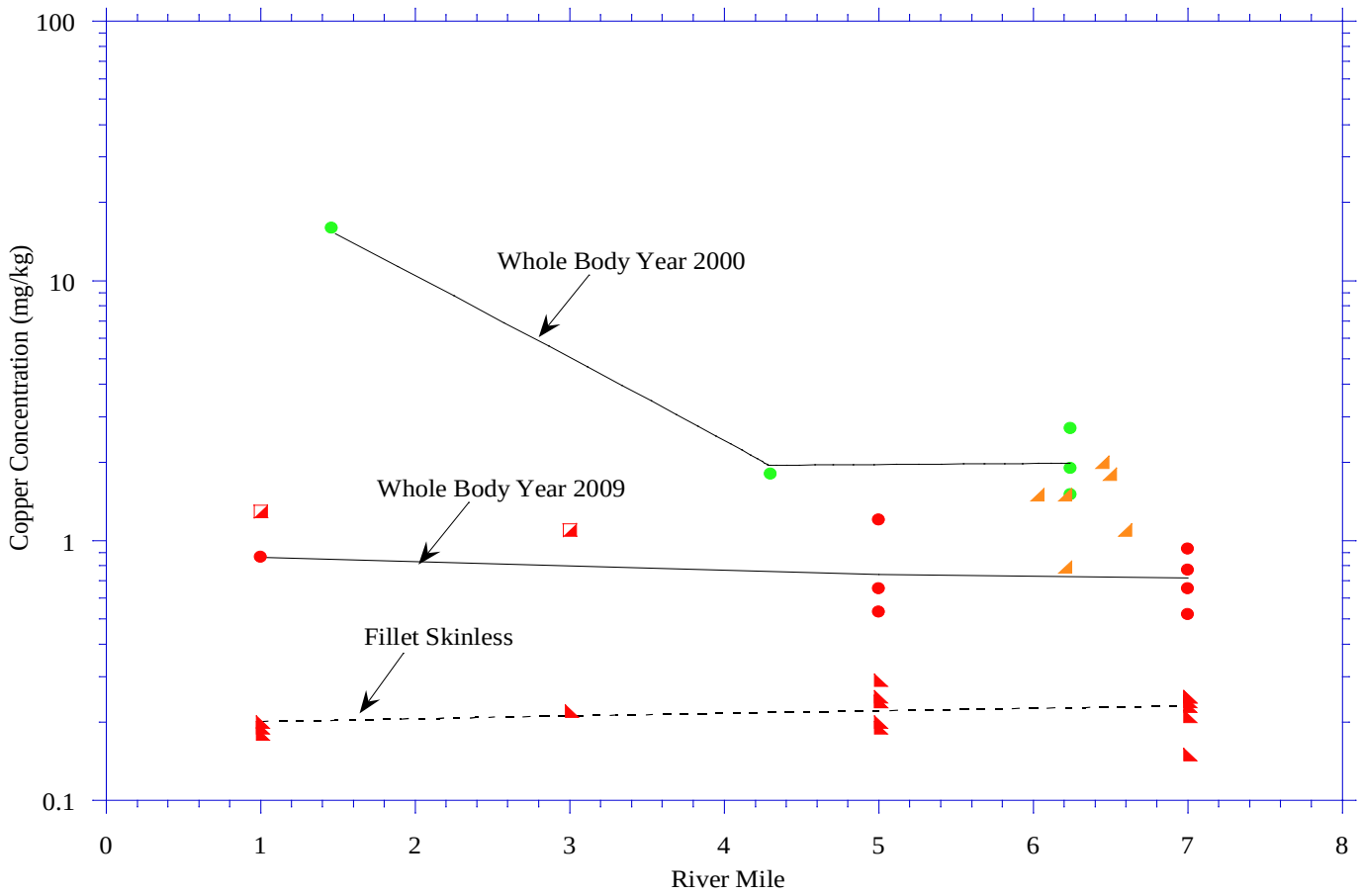
American Eel Total PAH Concentration *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-4h

2014

R2-0027600



Legend

Tissue Sampling Year

- 1999
- 2000
- 2001
- 2009

Tissue Type

- Whole Body - Head&Viscera
- Whole Body
- Fillet Skinless
- Carcass
- Fillet with Skin

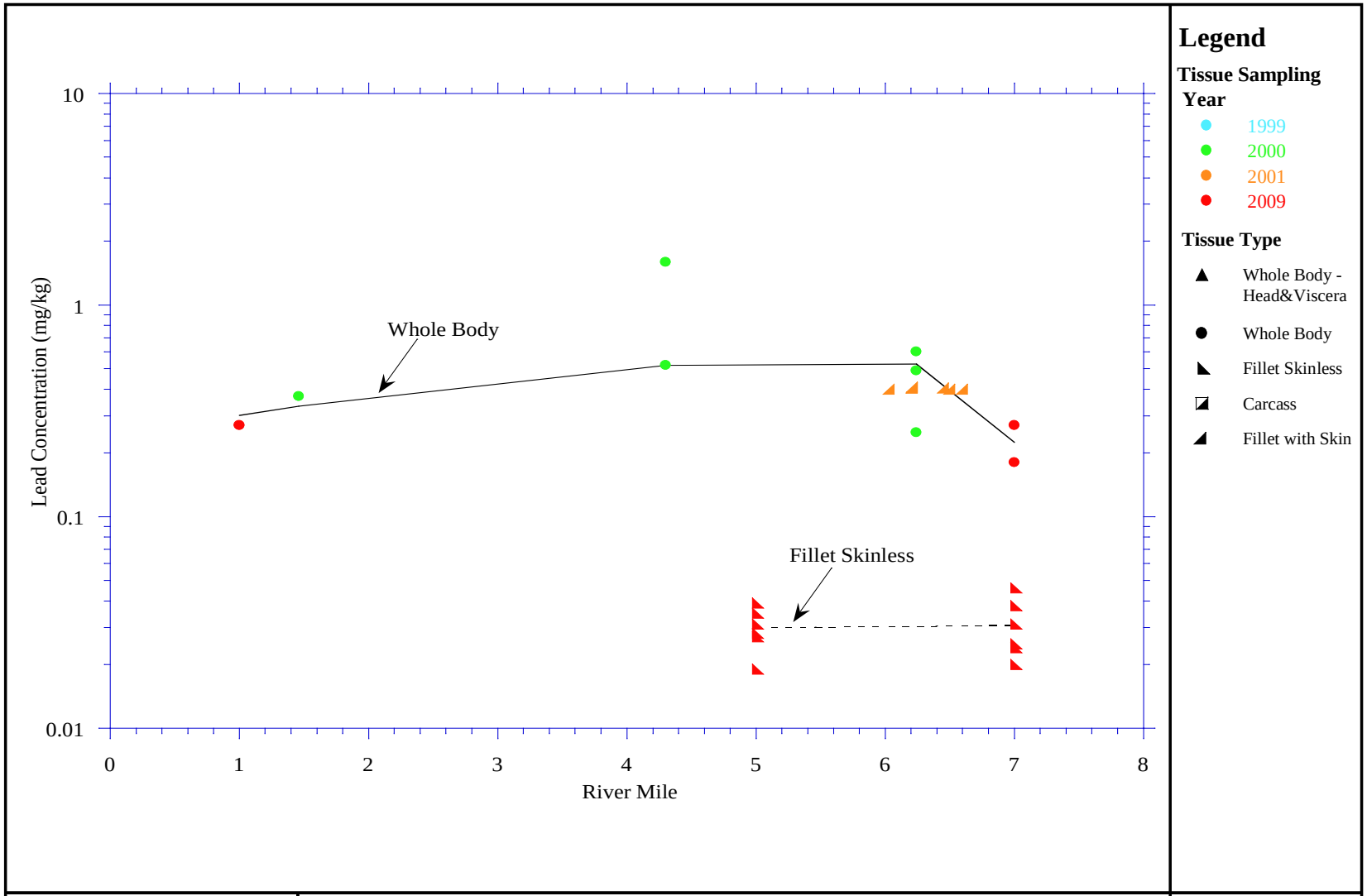
American Eel Copper Concentration *vs*. River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-4i

2014

R2-0027601



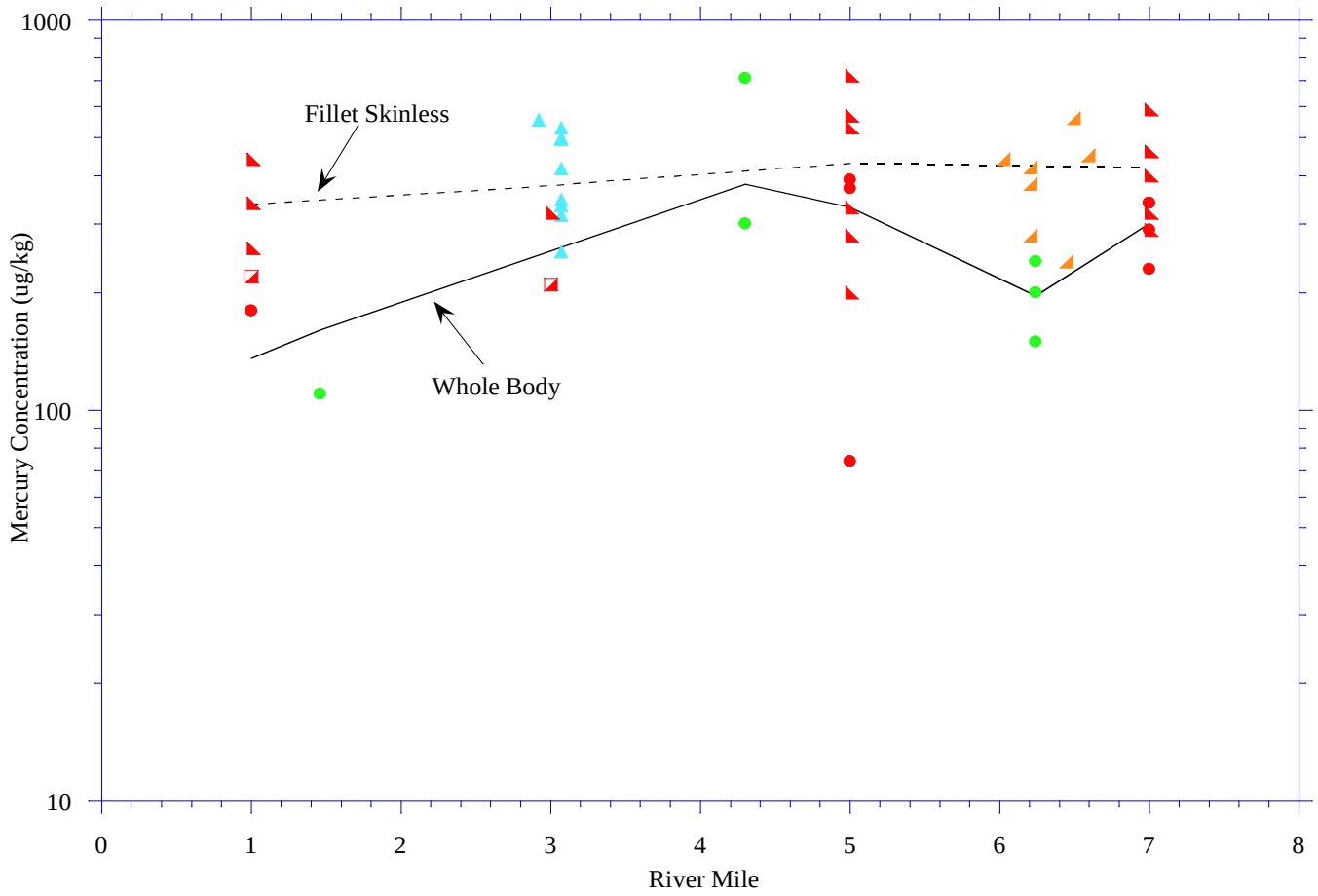
American Eel Lead Concentration *vs*. River Mile

Lower Eight Miles of the Lower Passaic River

Figure 2-4j

2014

R2-0027602



Legend

Tissue Sampling Year

- 1999
- 2000
- 2001
- 2009

Tissue Type

- Whole Body - Head&Viscera
- Whole Body
- Fillet Skinless
- Carcass
- Fillet with Skin

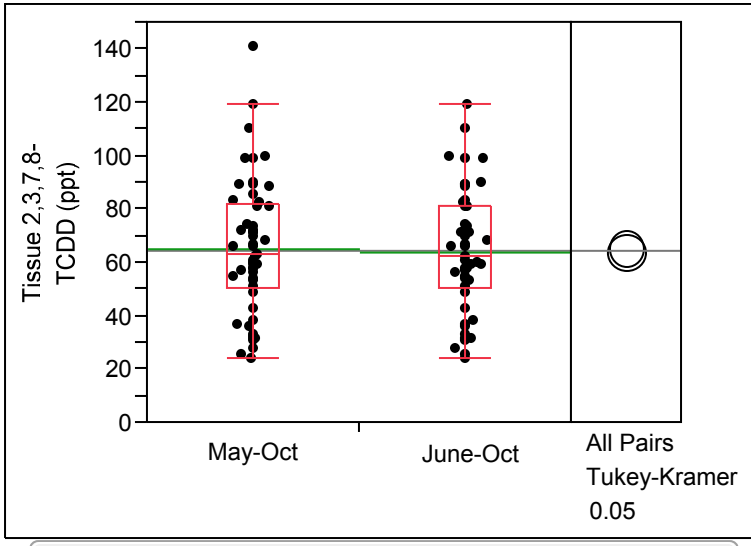
American Eel Mercury Concentration *vs*. River Mile

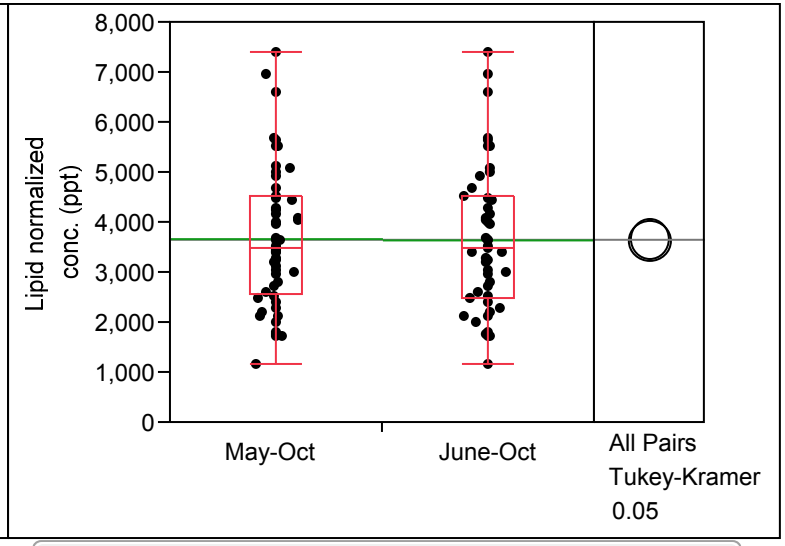
Lower Eight Miles of the Lower Passaic River

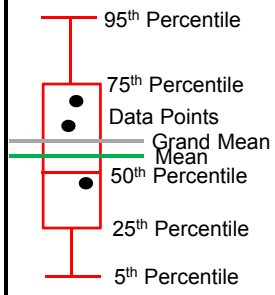
Figure 2-4k

2014

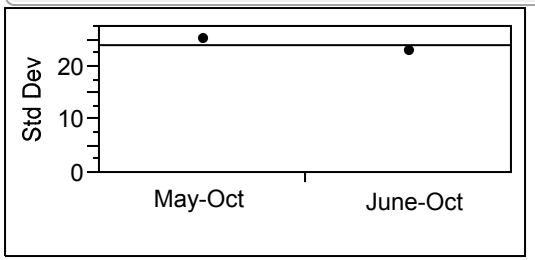
R2-0027603







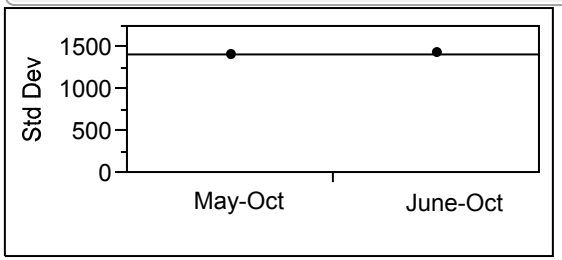
Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
May-Oct	53	25.05158	19.39188	19.36604
June-Oct	49	22.96510	18.26964	18.25102

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.3592	1	100	0.5503
Brown-Forsythe	0.1426	1	100	0.7065
Levene	0.1480	1	100	0.7013
Bartlett	0.3724	1	.	0.5417
F Test 2-sided	1.1900	52	48	0.5442

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
May-Oct	53	1403.672	1113.669	1102.340
June-Oct	49	1441.014	1144.397	1136.490

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0350	1	100	0.8521
Brown-Forsythe	0.0380	1	100	0.8458
Levene	0.0333	1	100	0.8556
Bartlett	0.0341	1	.	0.8535
F Test 2-sided	1.0539	48	52	0.8505

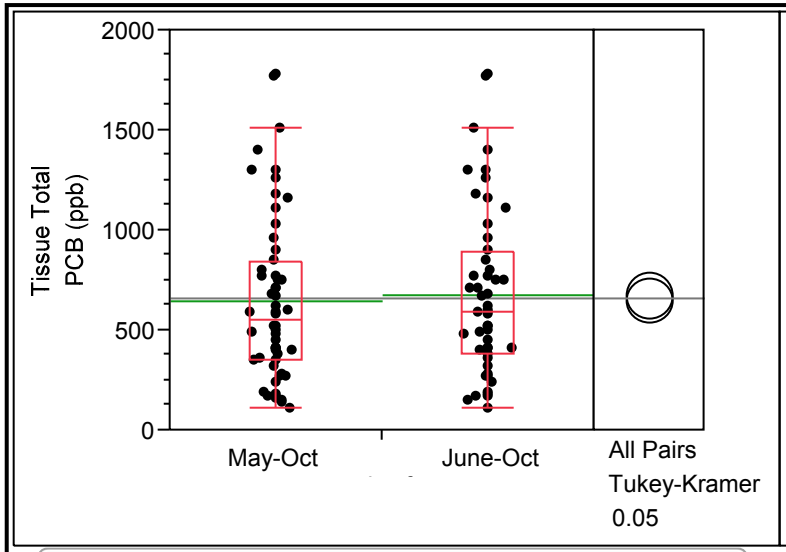
Note

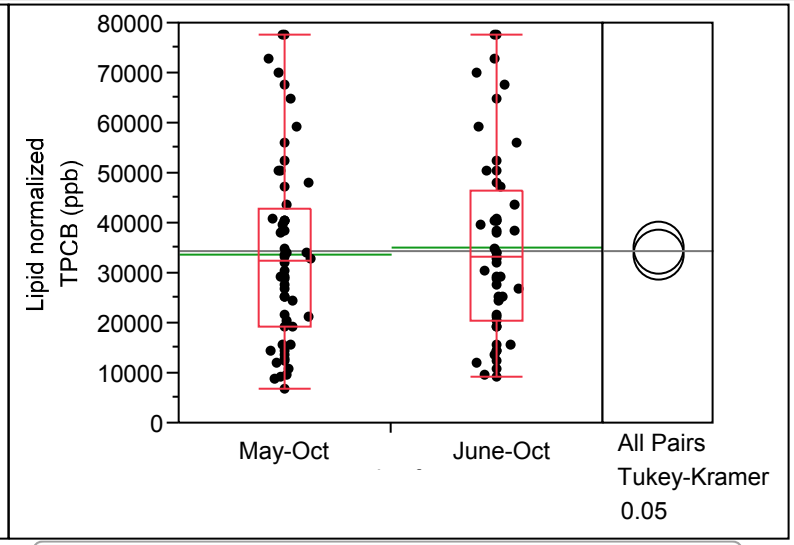
The datasets used in the analysis were ranged from RM0 to RM11.

Blue Crab 2,3,7,8-TCDD Concentration
May-October *vs.* June-October
Lower Eight Miles of the Lower Passaic River

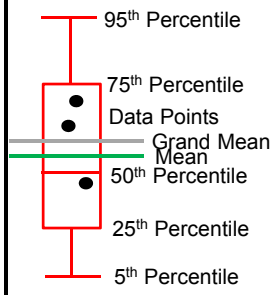
Figure 2-5a

2014

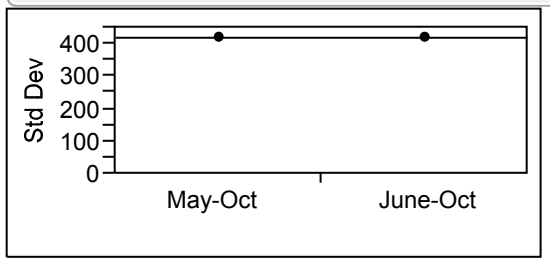




Legend



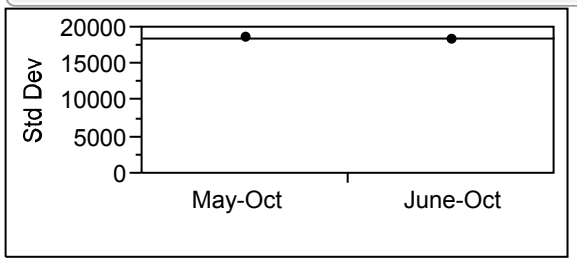
Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
May-Oct	56	419.3617	330.6907	321.9107
June-Oct	52	419.0137	329.4098	320.9808

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0000	1	106	0.9955
Brown-Forsythe	0.0003	1	106	0.9863
Levene	0.0007	1	106	0.9792
Bartlett	0.0000	1	.	0.9952
F Test 2-sided	1.0017	55	51	0.9980

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
May-Oct	56	18654.45	14710.10	14646.04
June-Oct	52	18385.58	14601.54	14415.04

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0126	1	106	0.9109
Brown-Forsythe	0.0109	1	106	0.9169
Levene	0.0026	1	106	0.9598
Bartlett	0.0110	1	.	0.9163
F Test 2-sided	1.0295	55	51	0.9190

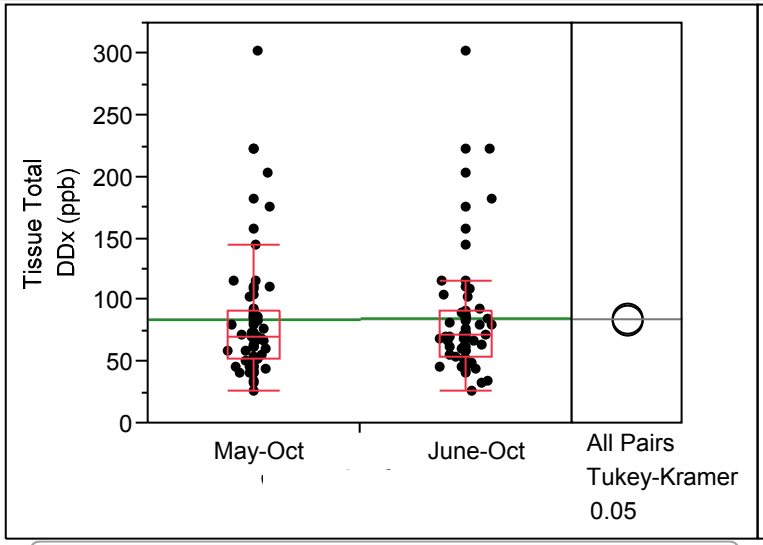
Note

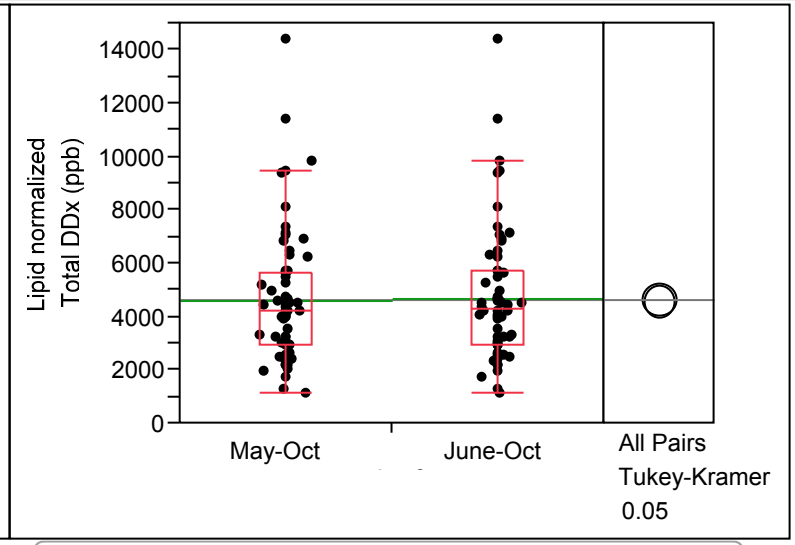
The datasets used in the analysis were ranged from RM0 to RM11.

Blue Crab Total PCB Concentration
May-October *vs.* June-October
Lower Eight Miles of the Lower Passaic River

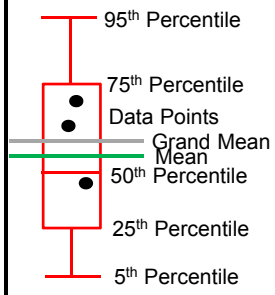
Figure 2-5b

2014

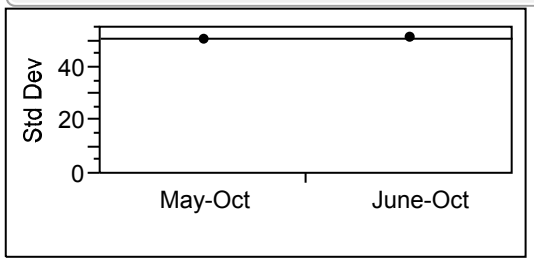




Legend



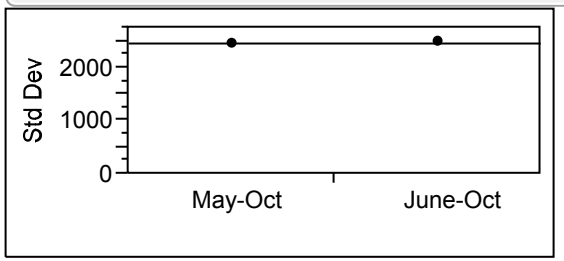
Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
May-Oct	68	50.51603	33.73097	31.36176
June-Oct	64	51.24770	34.03818	31.52500

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0038	1	130	0.9509
Brown-Forsythe	0.0005	1	130	0.9824
Levene	0.0022	1	130	0.9628
Bartlett	0.0133	1	.	0.9081
F Test 2-sided	1.0292	63	67	0.9061

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
May-Oct	68	2437.319	1749.260	1715.044
June-Oct	64	2470.403	1780.413	1737.172

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0046	1	130	0.9462
Brown-Forsythe	0.0051	1	130	0.9430
Levene	0.0112	1	130	0.9159
Bartlett	0.0117	1	.	0.9138
F Test 2-sided	1.0273	63	67	0.9118

Note

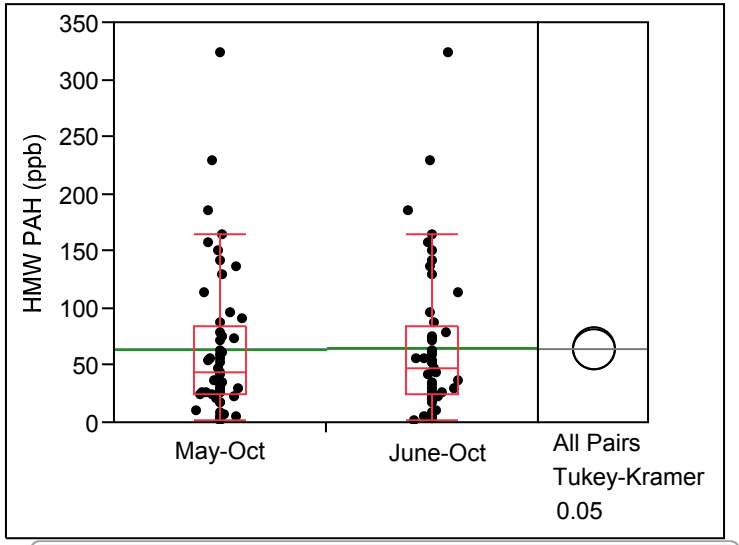
The datasets used in the analysis were ranged from RM0 to RM15.

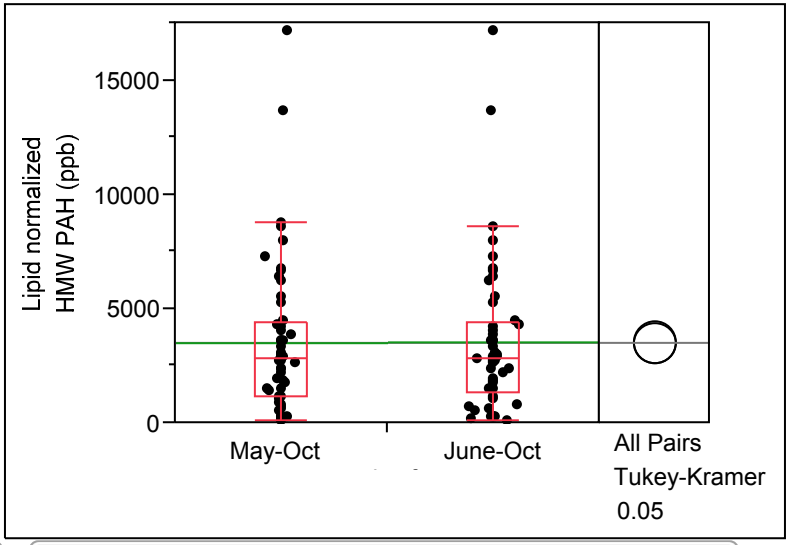
Blue Crab – Total DDx Concentration
May-October *vs.* June-October
Lower Eight Miles of the Lower Passaic River

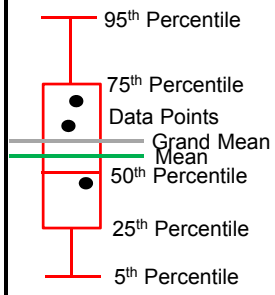
Figure 2-5c

2014

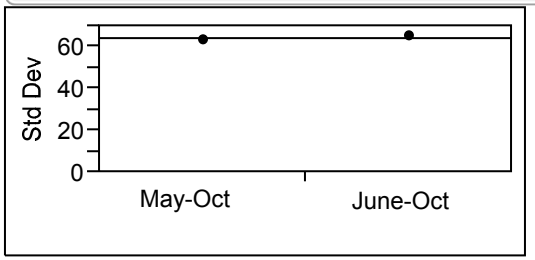
R2-0027606







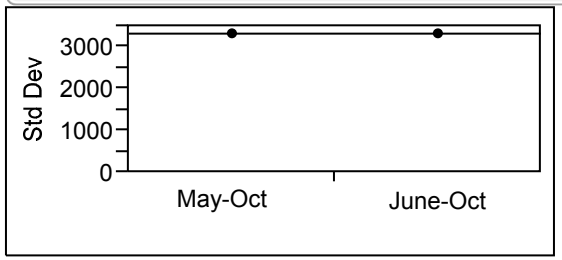
Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
May-Oct	53	63.51444	46.01108	42.86566
June-Oct	49	65.21276	47.44122	44.20776

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0115	1	100	0.9149
Brown-Forsythe	0.0176	1	100	0.8947
Levene	0.0272	1	100	0.8693
Bartlett	0.0344	1	.	0.8528
F Test 2-sided	1.0542	48	52	0.8498

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
May-Oct	53	3323.532	2331.077	2202.902
June-Oct	49	3320.982	2276.843	2158.873

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0000	1	100	0.9977
Brown-Forsythe	0.0073	1	100	0.9319
Levene	0.0133	1	100	0.9083
Bartlett	0.0000	1	.	0.9957
F Test 2-sided	1.0015	52	48	0.9987

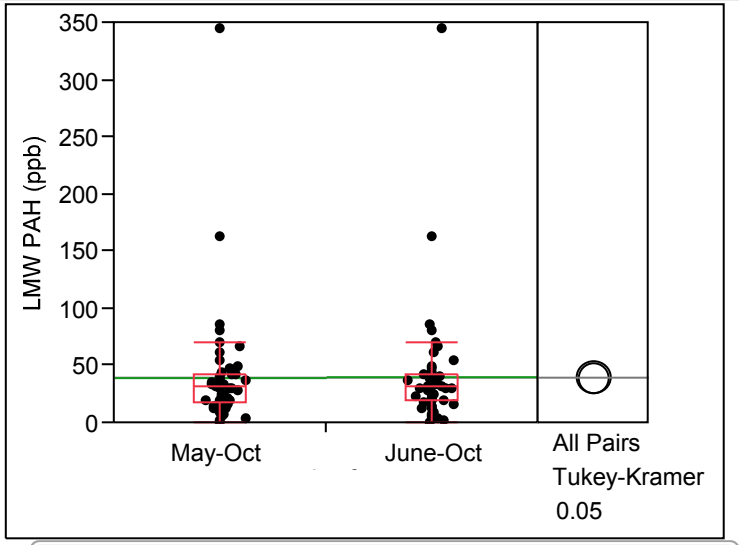
Note

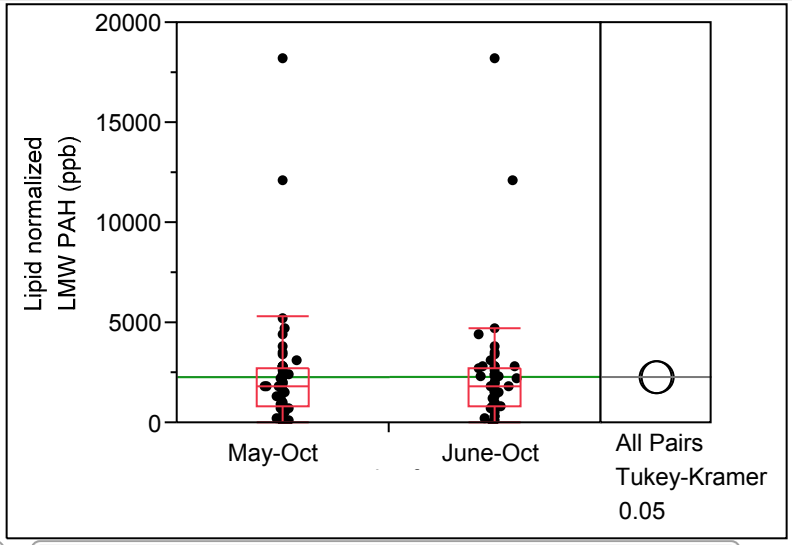
The datasets used in the analysis were ranged from RM0 to RM11.

Blue Crab – High Molecular Weight PAH Concentration
May-October *vs.* June-October
Lower Eight Miles of the Lower Passaic River

Figure 2-5d

2014





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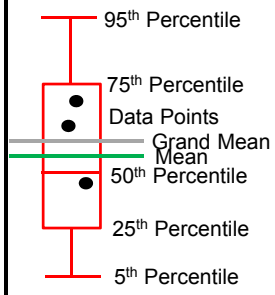
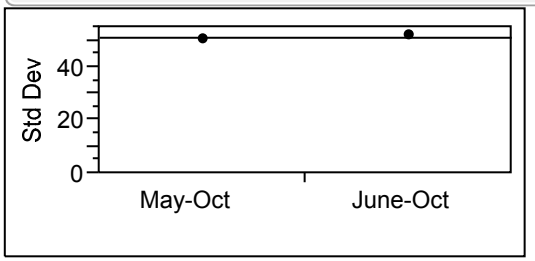


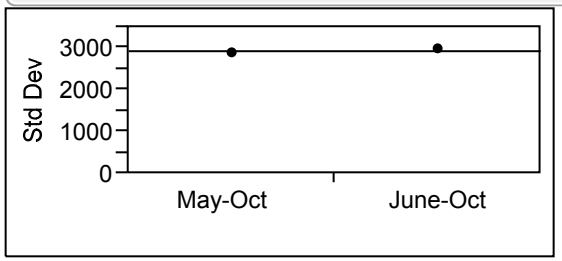
Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
May-Oct	53	50.20239	24.65326	22.59925
June-Oct	49	51.95806	25.59732	23.30735

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0045	1	100	0.9467
Brown-Forsythe	0.0059	1	100	0.9387
Levene	0.0116	1	100	0.9146
Bartlett	0.0584	1	.	0.8090
F Test 2-sided	1.0712	48	52	0.8060

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
May-Oct	53	2895.850	1538.021	1443.453
June-Oct	49	2963.698	1530.585	1443.633

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0027	1	100	0.9583
Brown-Forsythe	0.0000	1	100	0.9997
Levene	0.0002	1	100	0.9880
Bartlett	0.0265	1	.	0.8706
F Test 2-sided	1.0474	48	52	0.8677

Note

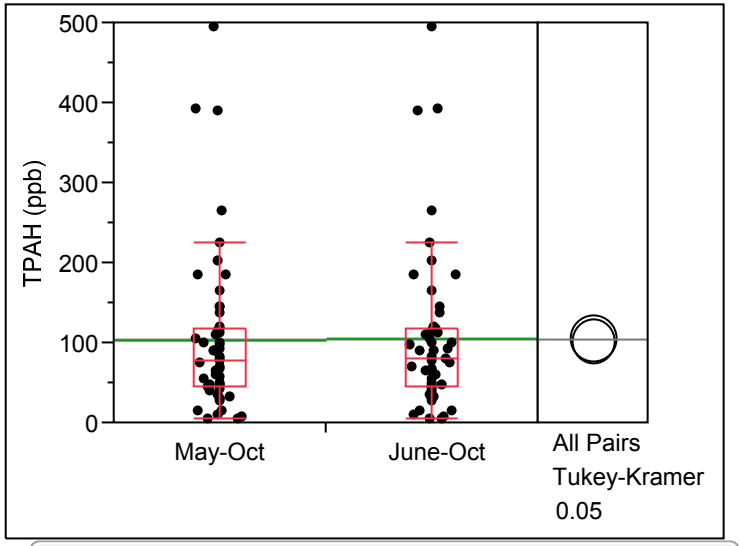
The datasets used in the analysis were ranged from RM0 to RM11.

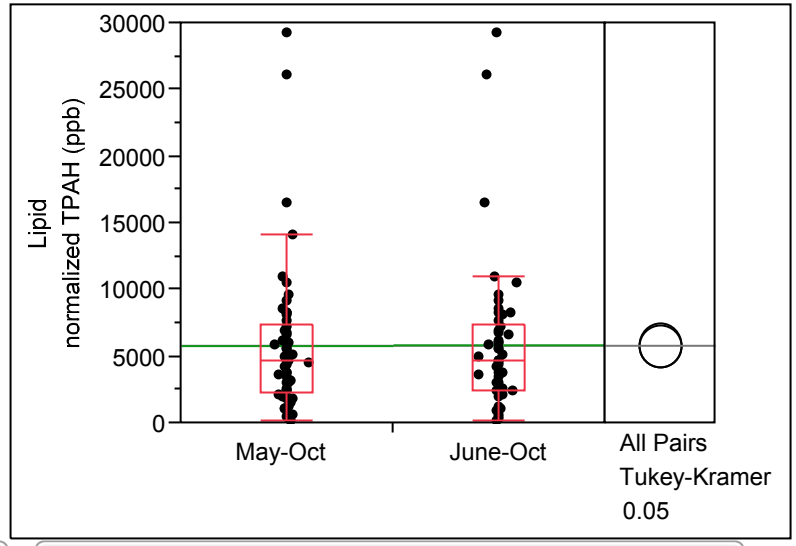
Blue Crab – Low Molecular Weight PAH Concentration
May-October *vs.* June-October

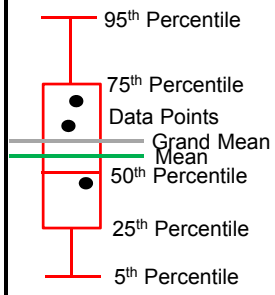
Lower Eight Miles of the Lower Passaic River

Figure 2-5e

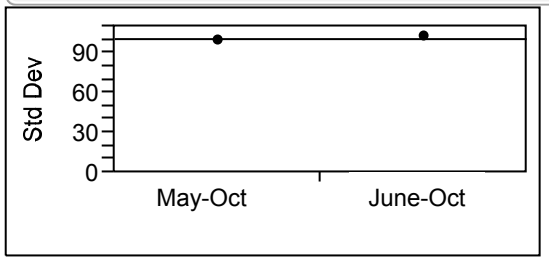
2014







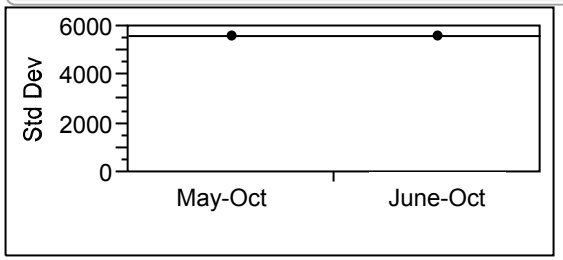
Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
May-Oct	53	99.0930	66.31547	62.27283
June-Oct	49	101.8640	68.19055	63.93388

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0110	1	100	0.9166
Brown-Forsythe	0.0105	1	100	0.9185
Levene	0.0163	1	100	0.8985
Bartlett	0.0376	1	.	0.8462
F Test 2-sided	1.0567	48	52	0.8432

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
May-Oct	53	5593.304	3633.483	3493.057
June-Oct	49	5622.218	3550.262	3433.980

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0003	1	100	0.9866
Brown-Forsythe	0.0043	1	100	0.9478
Levene	0.0097	1	100	0.9219
Bartlett	0.0013	1	.	0.9711
F Test 2-sided	1.0104	48	52	0.9681

Note

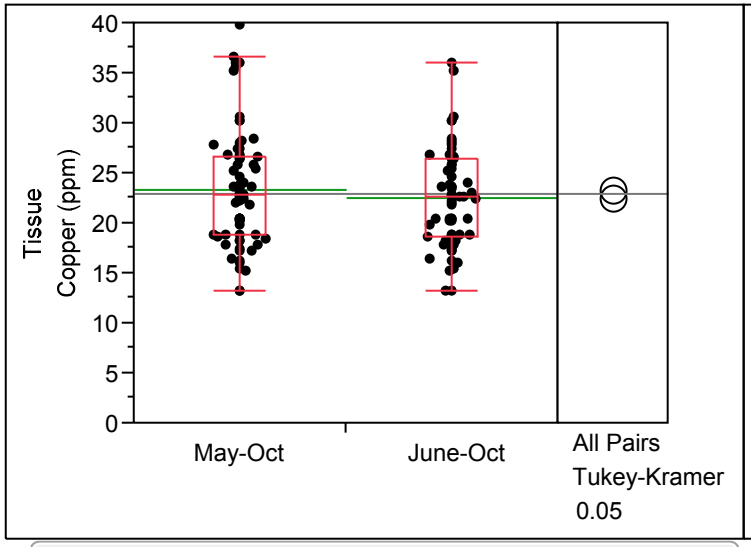
The datasets used in the analysis were ranged from RM0 to RM11.

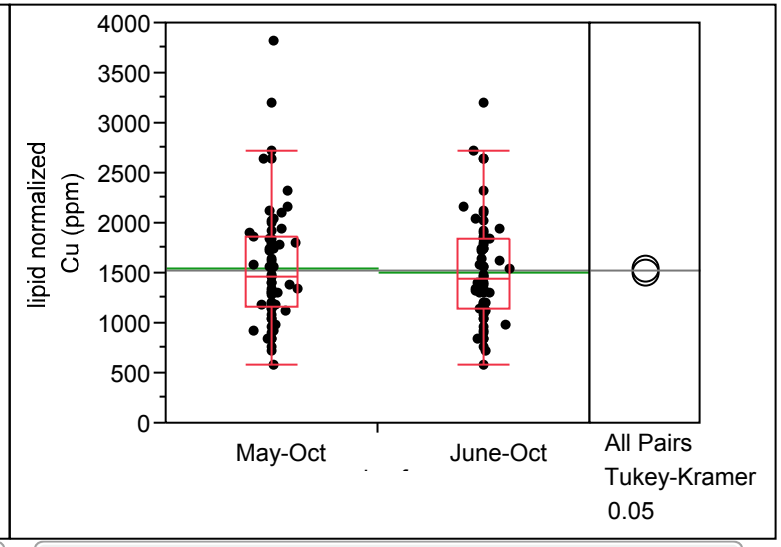
Blue Crab – Total PAH Concentration
May-October *vs.* June-October
Lower Eight Miles of the Lower Passaic River

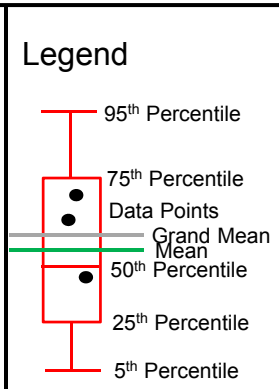
Figure 2-5f

2014

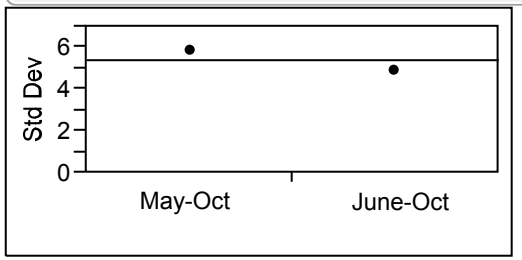
R2-0027609







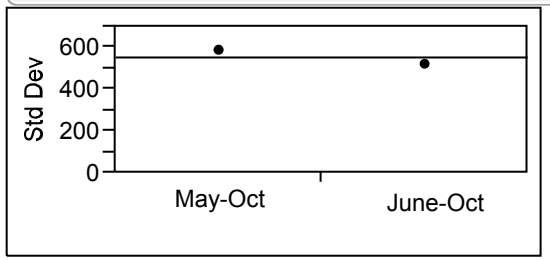
Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
May-Oct	70	5.833037	4.570531	4.544286
June-Oct	66	4.895437	3.953076	3.951515

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	1.7872	1	134	0.1835
Brown-Forsythe	1.1012	1	134	0.2959
Levene	1.2293	1	134	0.2695
Bartlett	2.0229	1	.	0.1549
F Test 2-sided	1.4197	69	65	0.1556

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
May-Oct	70	580.5613	438.4212	433.9857
June-Oct	66	521.7670	412.8072	409.2121

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.3795	1	134	0.5389
Brown-Forsythe	0.1586	1	134	0.6911
Levene	0.1838	1	134	0.6688
Bartlett	0.7545	1	.	0.3851
F Test 2-sided	1.2381	69	65	0.3864

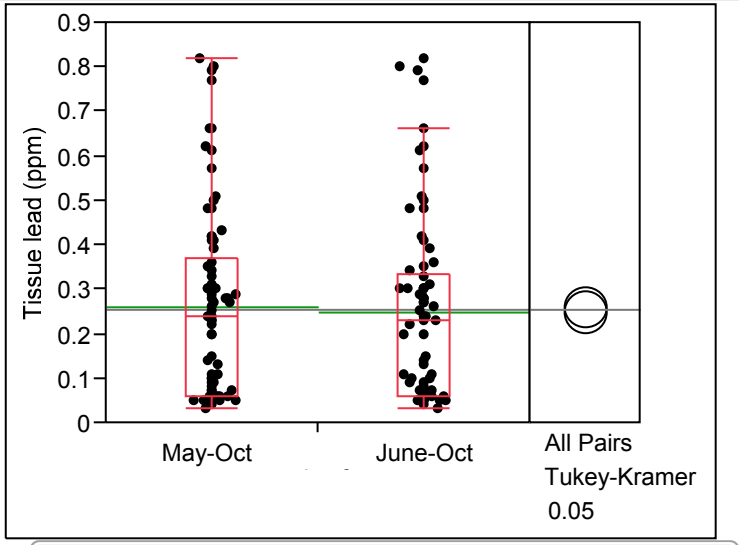
Note

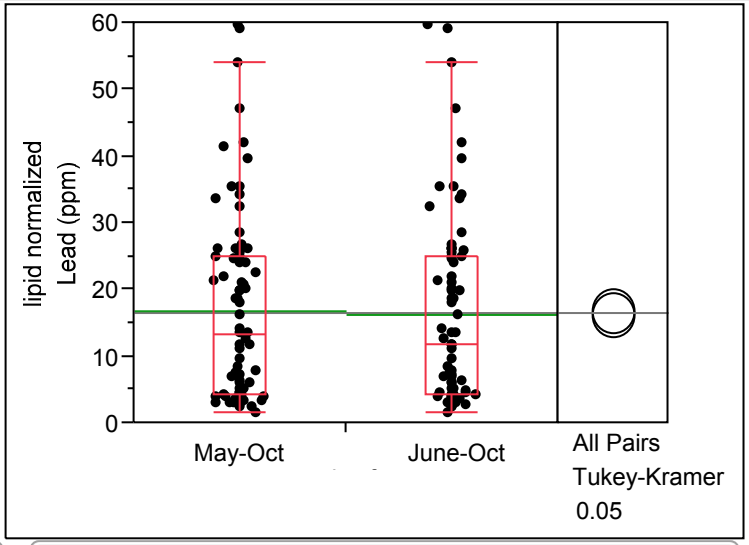
The datasets used in the analysis were ranged from RM0 to RM11.

Blue Crab – Copper Concentration
May-October *vs.* June-October
Lower Eight Miles of the Lower Passaic River

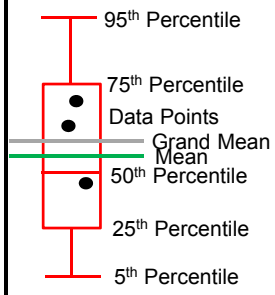
Figure 2-5g

2014

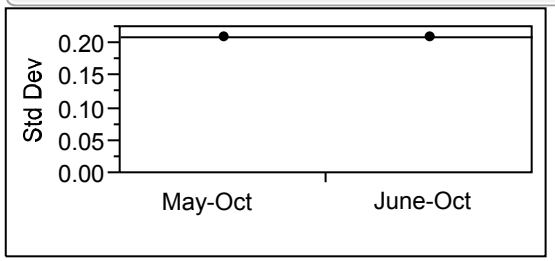




Legend



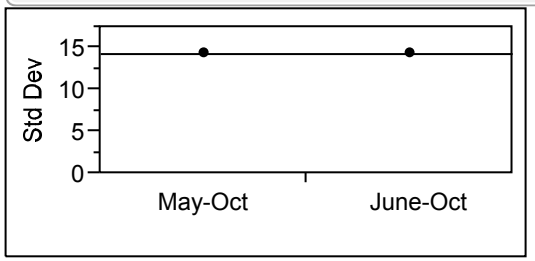
Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
May-Oct	78	0.2107512	0.1668639	0.1660256
June-Oct	74	0.2085249	0.1627611	0.1617568

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0070	1	150	0.9335
Brown-Forsythe	0.0404	1	150	0.8410
Levene	0.0389	1	150	0.8438
Bartlett	0.0084	1	.	0.9270
F Test 2-sided	1.0215	77	73	0.9286

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
May-Oct	78	14.27021	11.65074	11.40167
June-Oct	74	14.31431	11.63211	11.21392

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0005	1	150	0.9822
Brown-Forsythe	0.0146	1	150	0.9041
Levene	0.0002	1	150	0.9888
Bartlett	0.0007	1	.	0.9788
F Test 2-sided	1.0062	73	77	0.9771

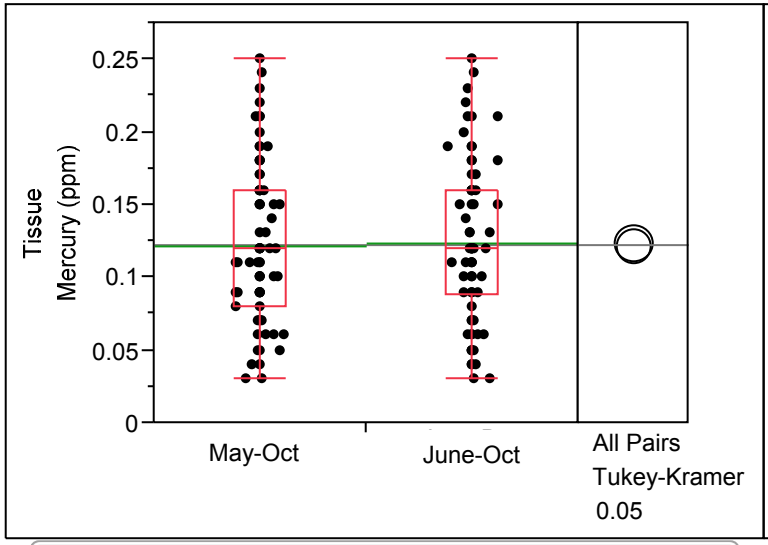
Note

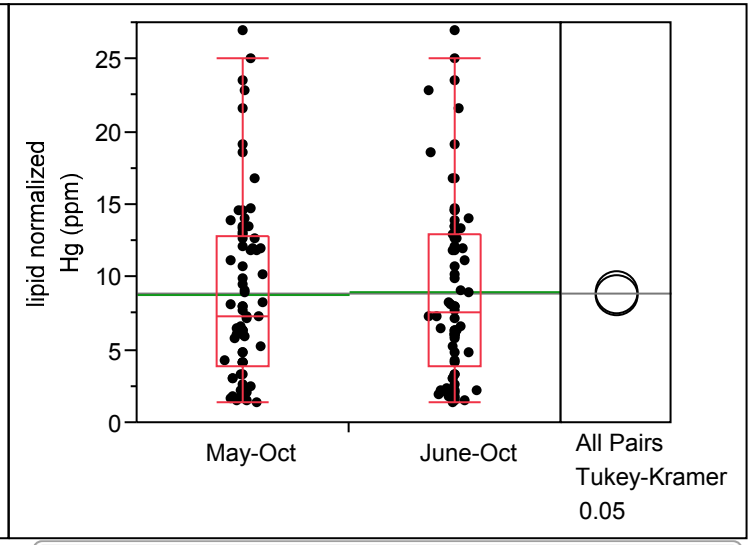
The datasets used in the analysis were ranged from RM0 to RM11.

Blue Crab – Lead Concentration
May-October *vs.* June-October
Lower Eight Miles of the Lower Passaic River

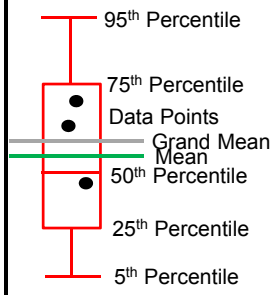
Figure 2-5h

2014

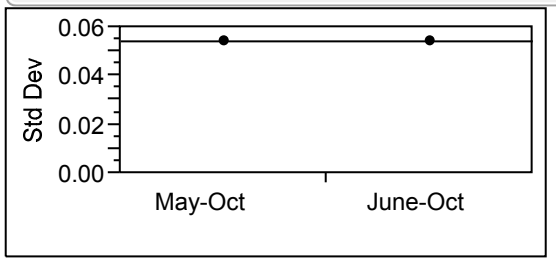




Legend



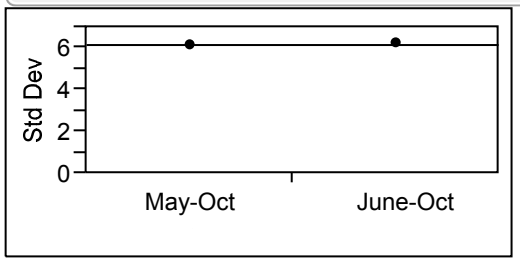
Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
May-Oct	78	0.0538656	0.0433925	0.0430769
June-Oct	74	0.0545576	0.0440833	0.0435135

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0174	1	150	0.8951
Brown-Forsythe	0.0069	1	150	0.9338
Levene	0.0181	1	150	0.8931
Bartlett	0.0121	1	.	0.9123
F Test 2-sided	1.0259	73	77	0.9107

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
May-Oct	78	6.118695	4.940404	4.799872
June-Oct	74	6.188464	5.017206	4.878514

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0081	1	150	0.9285
Brown-Forsythe	0.0142	1	150	0.9052
Levene	0.0176	1	150	0.8947
Bartlett	0.0096	1	.	0.9221
F Test 2-sided	1.0229	73	77	0.9204

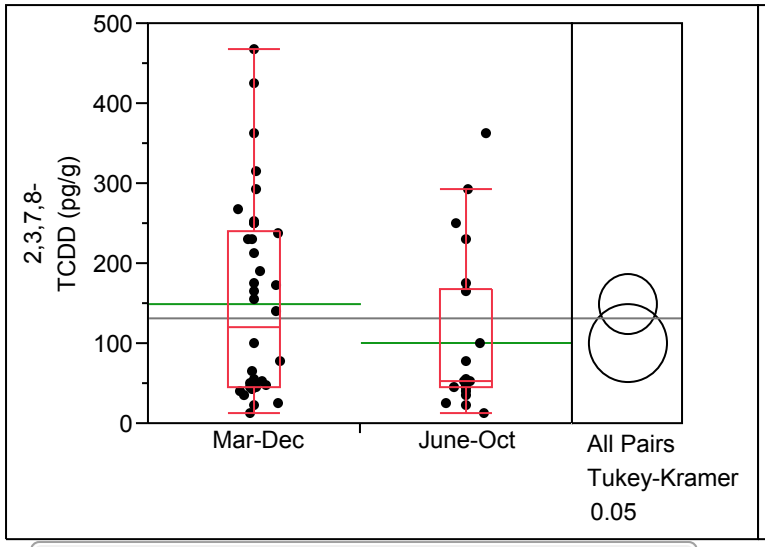
Note

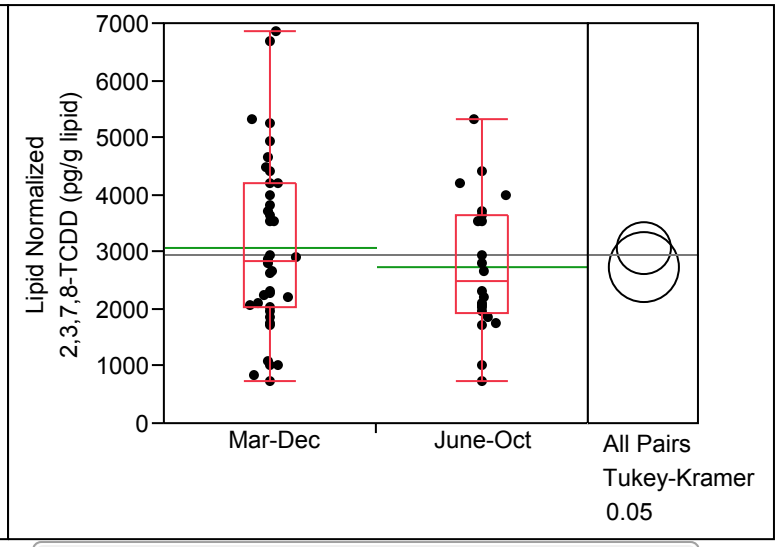
The datasets used in the analysis were ranged from RM0 to RM11.

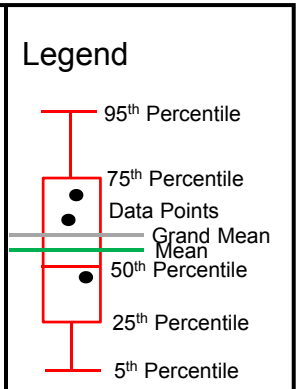
Blue Crab – Mercury Concentration
May-October *vs.* June-October
Lower Eight Miles of the Lower Passaic River

Figure 2-5i

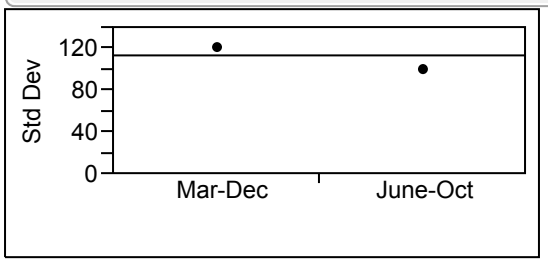
2014







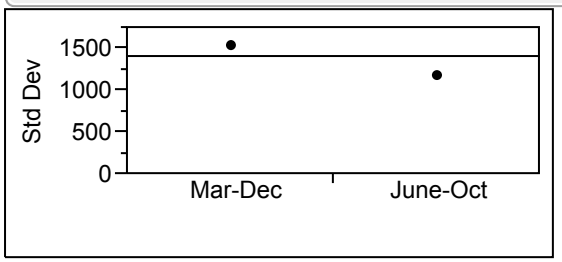
Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Mar-Dec	38	121.4531	102.5992	102.0711
June-Oct	22	98.9441	78.6446	63.4091

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.9286	1	58	0.3392
Brown-Forsythe	3.4039	1	58	0.0701
Levene	2.1539	1	58	0.1476
Bartlett	1.0576	1	.	0.3038
F Test 2-sided	1.5067	37	21	0.3205

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Mar-Dec	38	1538.173	1256.125	1228.684
June-Oct	22	1165.461	963.934	957.409

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	1.7718	1	58	0.1884
Brown-Forsythe	1.4107	1	58	0.2398
Levene	1.9345	1	58	0.1696
Bartlett	1.9038	1	.	0.1676
F Test 2-sided	1.7419	37	21	0.1786

Note

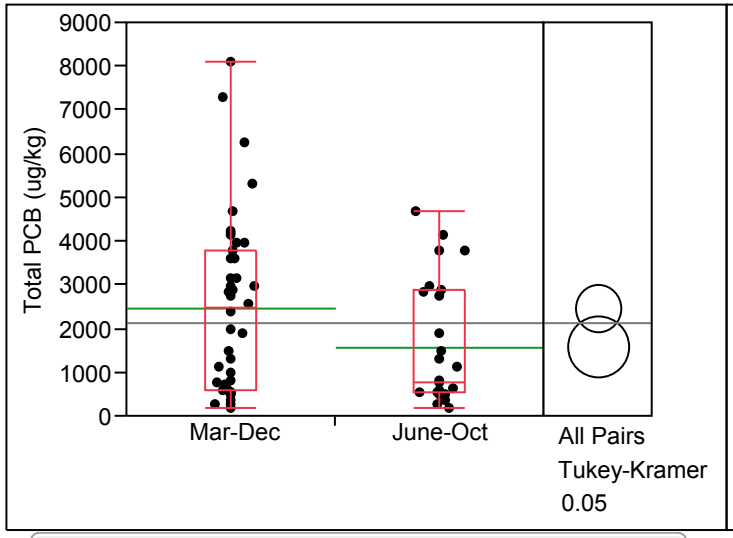
The datasets used in the analysis were ranged from RM0 to RM11.

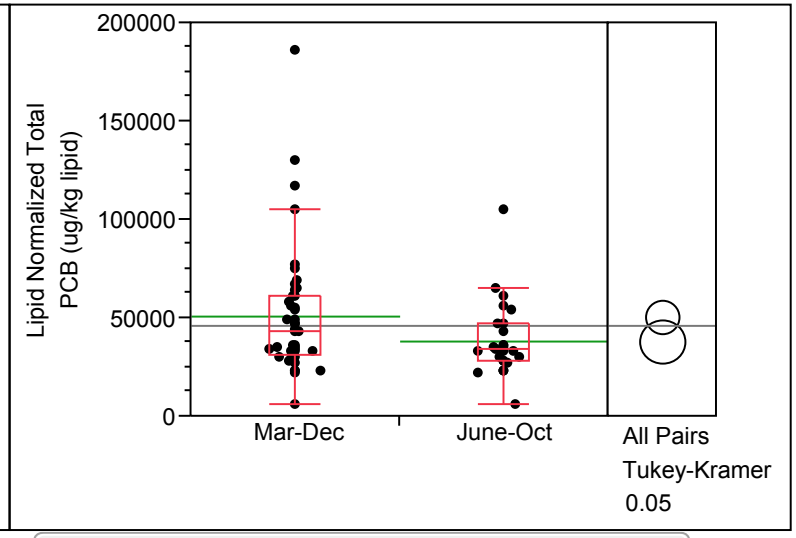
White Perch - 2,3,7,8-TCDD Concentration
March-December *vs.* June-October

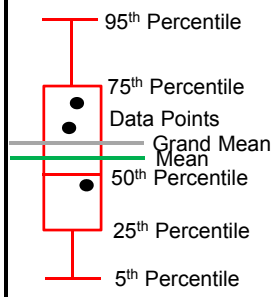
Lower Eight Miles of the Lower Passaic River

Figure 2-6a

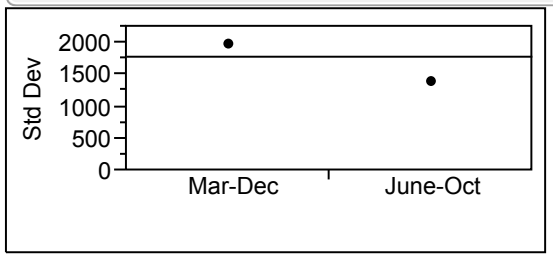
2014







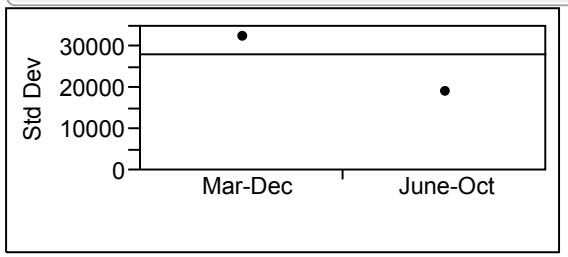
Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Mar-Dec	44	1974.722	1618.364	1618.364
June-Oct	26	1392.171	1189.997	1071.885

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	2.4993	1	68	0.1185
Brown-Forsythe	3.7999	1	68	0.0554
Levene	3.1826	1	68	0.0789
Bartlett	3.5174	1	.	0.0607
F Test 2-sided	2.0120	43	25	0.0650

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Mar-Dec	44	32502.43	22183.35	21000.64
June-Oct	26	19035.17	13280.49	12100.65

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	1.3045	1	68	0.2574
Brown-Forsythe	2.5539	1	68	0.1147
Levene	3.1185	1	68	0.0819
Bartlett	7.8244	1	.	0.0052*
F Test 2-sided	2.9155	43	25	0.0056*

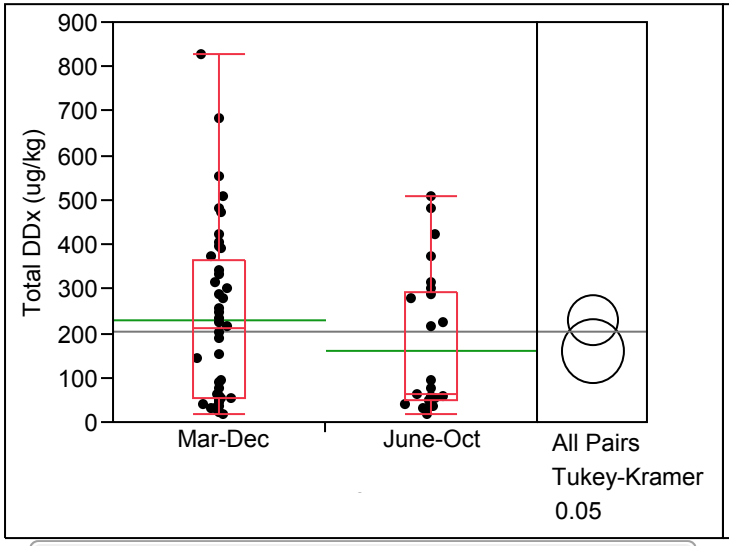
Note

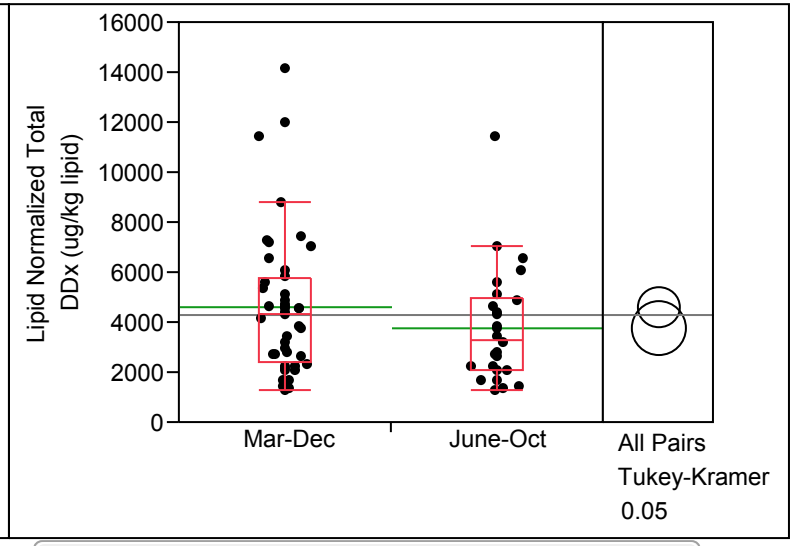
- The datasets used in the analysis were ranged from RM0 to RM11.
- *: indicates p-value is less than 0.05. The two test groups are significantly different.

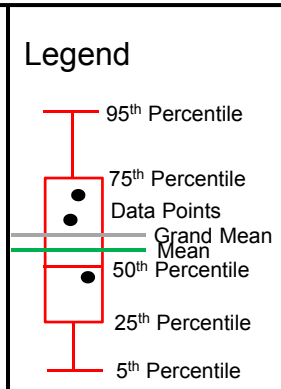
White Perch – Total PCB Concentration
March-December *vs.* June-October
Lower Eight Miles of the Lower Passaic River

Figure 2-6b

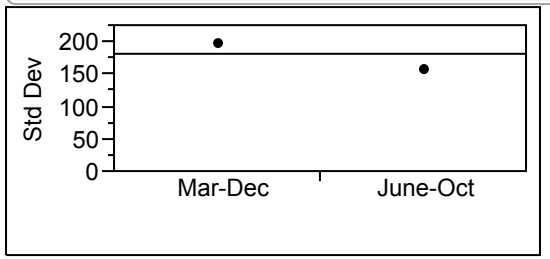
2014







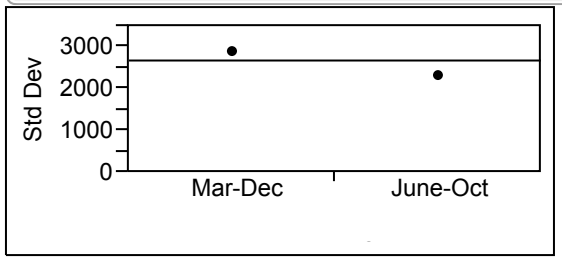
Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Mar-Dec	44	195.7376	158.5537	157.6727
June-Oct	26	156.8338	137.2929	117.7192

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	1.0984	1	68	0.2983
Brown-Forsythe	1.6234	1	68	0.2070
Levene	0.7541	1	68	0.3882
Bartlett	1.4592	1	.	0.2271
F Test 2-sided	1.5576	43	25	0.2392

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Mar-Dec	44	2871.561	2064.137	2042.432
June-Oct	26	2296.599	1714.914	1684.500

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.6003	1	68	0.4411
Brown-Forsythe	0.5952	1	68	0.4431
Levene	0.6091	1	68	0.4378
Bartlett	1.4829	1	.	0.2233
F Test 2-sided	1.5634	43	25	0.2353

Note

The datasets used in the analysis were ranged from RM0 to RM15.

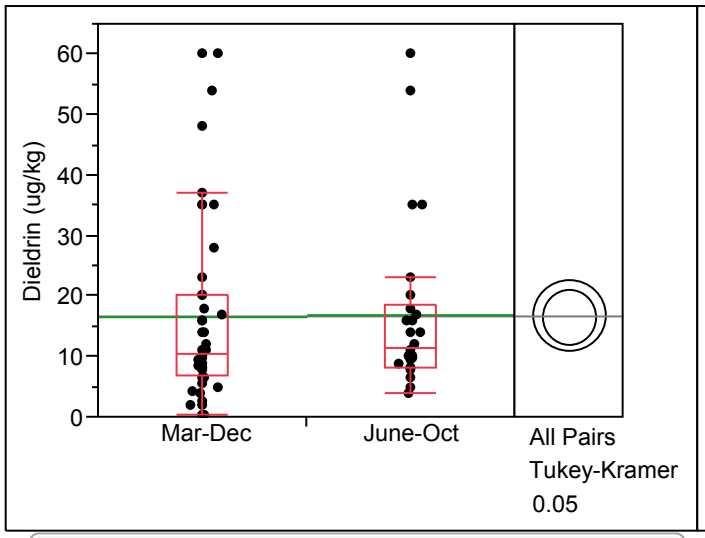
White Perch – Total DDx Concentration
March-December *vs.* June-October

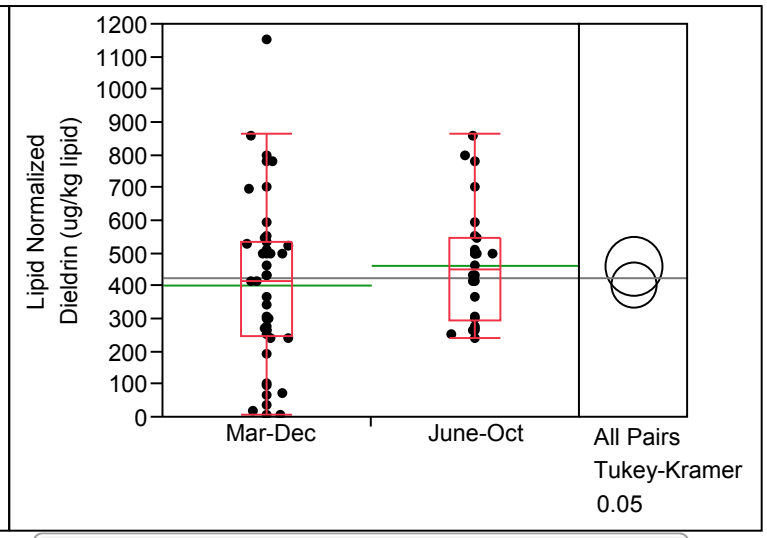
Lower Eight Miles of the Lower Passaic River

Figure 2-6c

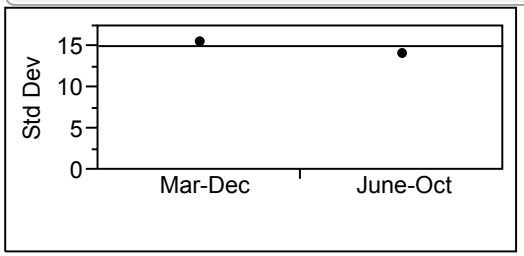
2014

R2-0027615





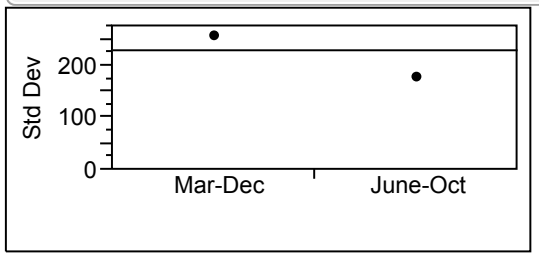
Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Mar-Dec	44	15.63495	11.69897	10.42955
June-Oct	26	14.15840	9.72308	8.74231

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.1501	1	68	0.6997
Brown-Forsythe	0.2833	1	68	0.5963
Levene	0.6160	1	68	0.4352
Bartlett	0.3005	1	.	0.5836
F Test 2-sided	1.2195	43	25	0.6052

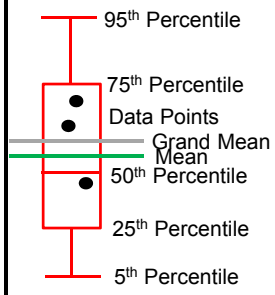
Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Mar-Dec	44	254.8883	201.7411	201.3136
June-Oct	26	176.6185	137.1953	137.1538

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	2.6741	1	68	0.1066
Brown-Forsythe	3.4857	1	68	0.0662
Levene	3.5799	1	68	0.0627
Bartlett	3.8559	1	.	0.0496*
F Test 2-sided	2.0827	43	25	0.0532

Legend



Note

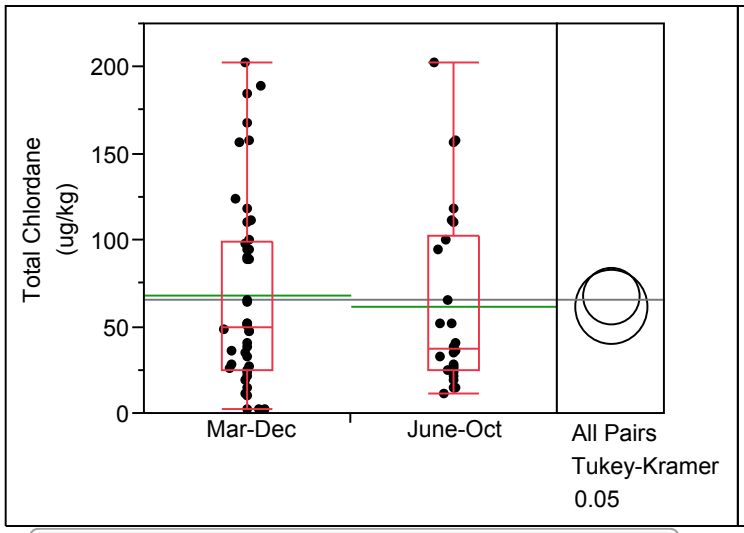
- The datasets used in the analysis were ranged from RM0 to RM15.
- *: indicates p-value is less than 0.05. The two test groups are significantly different.

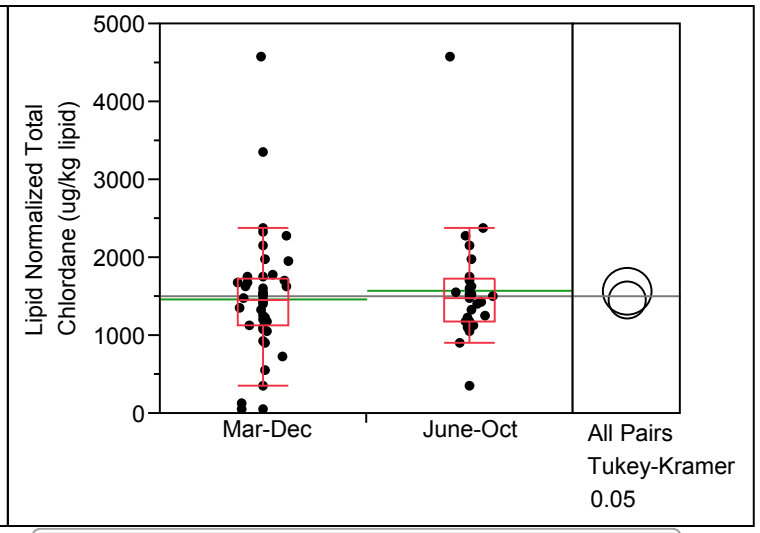
White Perch – Dieldrin Concentration
March-December *vs.* June-October
Lower Eight Miles of the Lower Passaic River

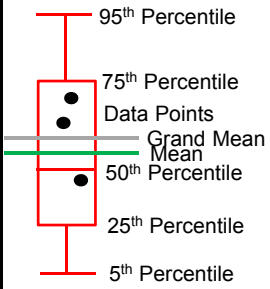
Figure 2-6d

2014

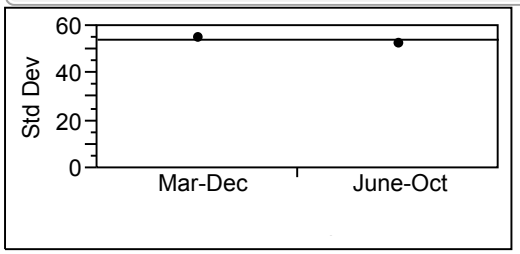
R2-0027616







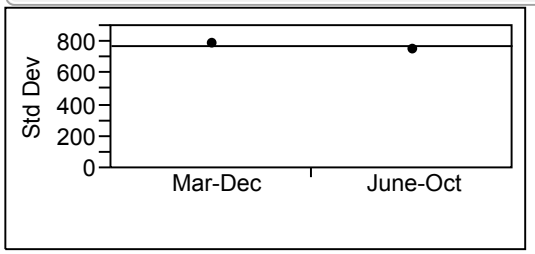
Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Mar-Dec	44	55.36824	45.97686	43.31818
June-Oct	26	52.42364	42.88639	37.88462

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0914	1	68	0.7634
Brown-Forsythe	0.2909	1	68	0.5914
Levene	0.1778	1	68	0.6746
Bartlett	0.0920	1	.	0.7617
F Test 2-sided	1.1155	43	25	0.7857

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Mar-Dec	44	789.4036	516.4298	516.1818
June-Oct	26	746.8265	445.2633	428.6538

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0241	1	68	0.8770
Brown-Forsythe	0.3474	1	68	0.5575
Levene	0.2360	1	68	0.6287
Bartlett	0.0947	1	.	0.7583
F Test 2-sided	1.1173	43	25	0.7823

Note

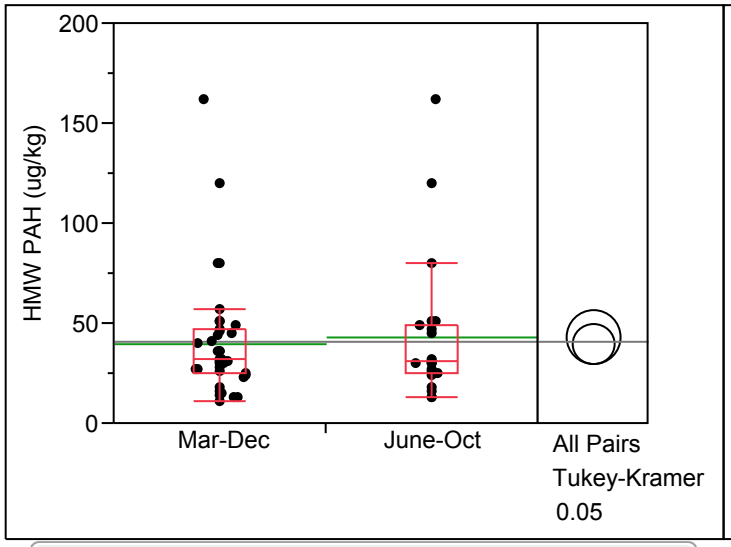
The datasets used in the analysis were ranged from RM0 to RM15.

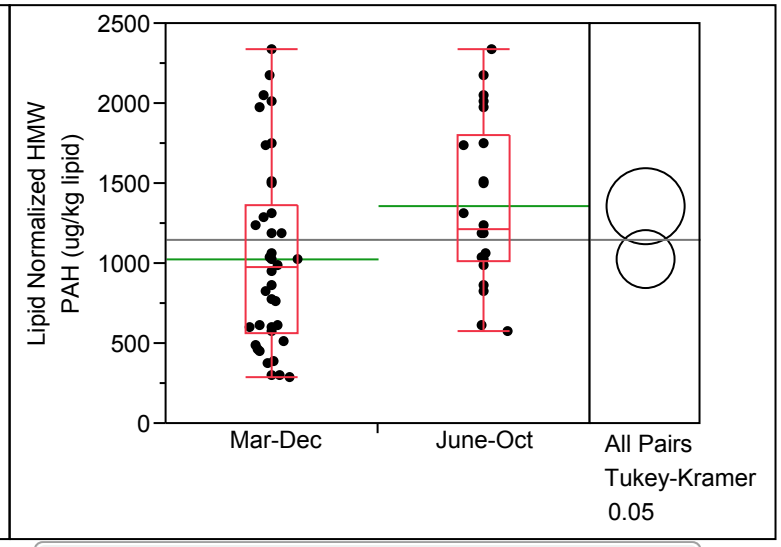
White Perch – Total Chlordane Concentration
March-December *vs.* June-October

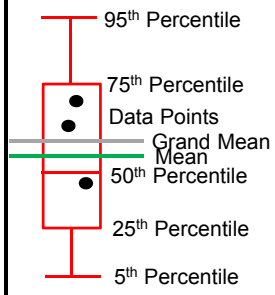
Lower Eight Miles of the Lower Passaic River

Figure 2-6e

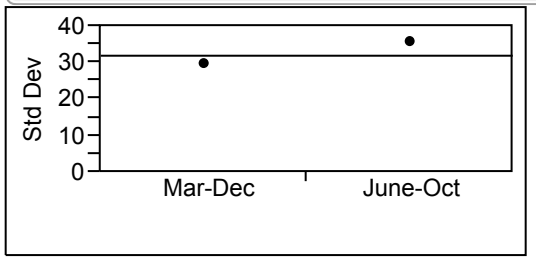
2014







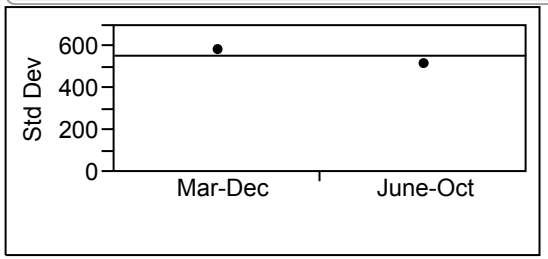
Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Mar-Dec	38	29.42595	18.69917	17.28421
June-Oct	22	35.81406	23.56777	20.43182

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.2796	1	58	0.5990
Brown-Forsythe	0.1797	1	58	0.6732
Levene	0.5724	1	58	0.4524
Bartlett	1.0459	1	.	0.3065
F Test 2-sided	1.4813	21	37	0.2896

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Mar-Dec	38	580.5738	467.8144	465.2632
June-Oct	22	515.0811	434.3099	418.4091

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.5241	1	58	0.4720
Brown-Forsythe	0.2701	1	58	0.6053
Levene	0.1627	1	58	0.6882
Bartlett	0.3677	1	.	0.5443
F Test 2-sided	1.2705	37	21	0.5680

Note

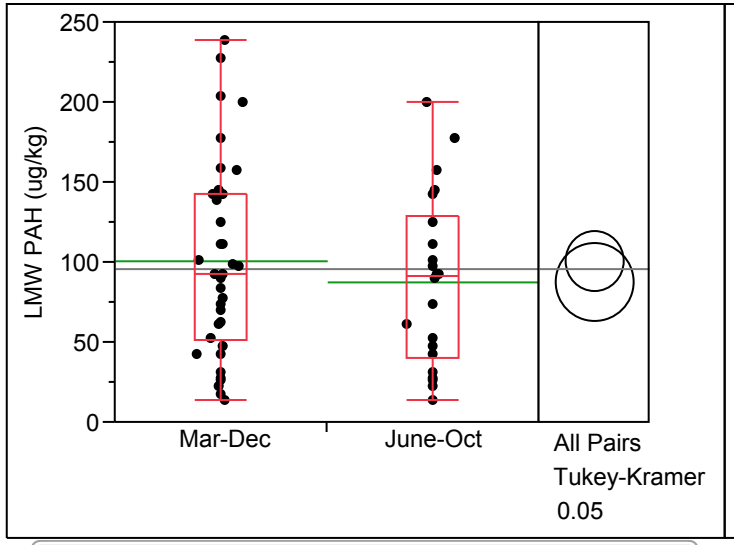
The datasets used in the analysis were ranged from RM0 to RM11.

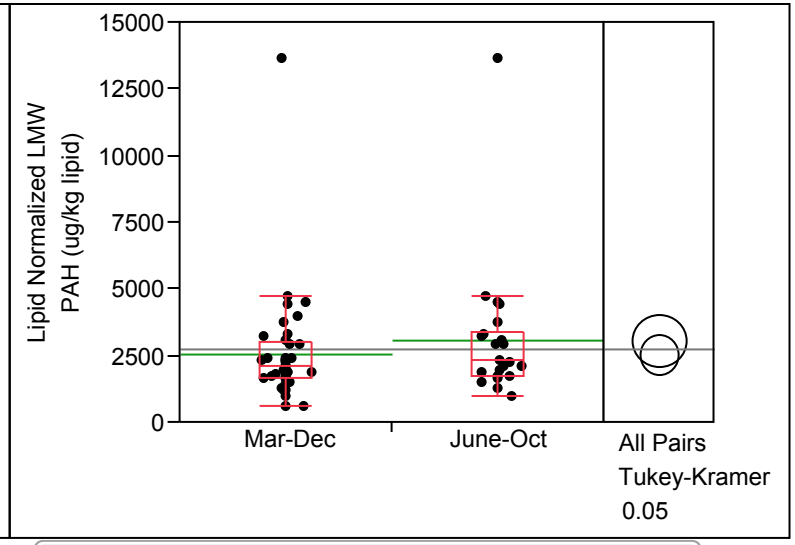
White Perch – High Molecular Weight PAH Concentration
March-December *vs.* June-October

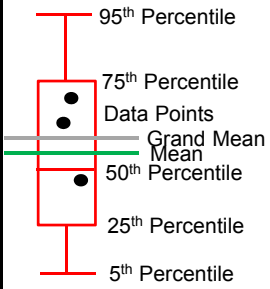
Lower Eight Miles of the Lower Passaic River

Figure 2-6f

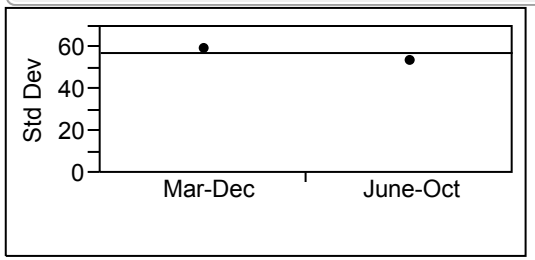
2014







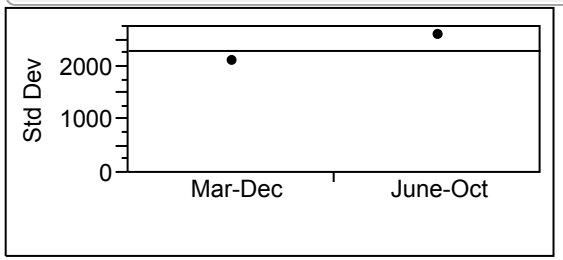
Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Mar-Dec	38	59.62237	47.69321	46.98158
June-Oct	22	53.53189	43.47934	43.33636

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.3835	1	58	0.5382
Brown-Forsythe	0.1544	1	58	0.6958
Levene	0.2253	1	58	0.6368
Bartlett	0.2988	1	.	0.5847
F Test 2-sided	1.2405	37	21	0.6092

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Mar-Dec	38	2112.824	1167.566	1060.658
June-Oct	22	2590.604	1444.376	1345.227

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.1389	1	58	0.7108
Brown-Forsythe	0.2676	1	58	0.6069
Levene	0.2971	1	58	0.5878
Bartlett	1.1272	1	.	0.2884
F Test 2-sided	1.5034	21	37	0.2722

Note

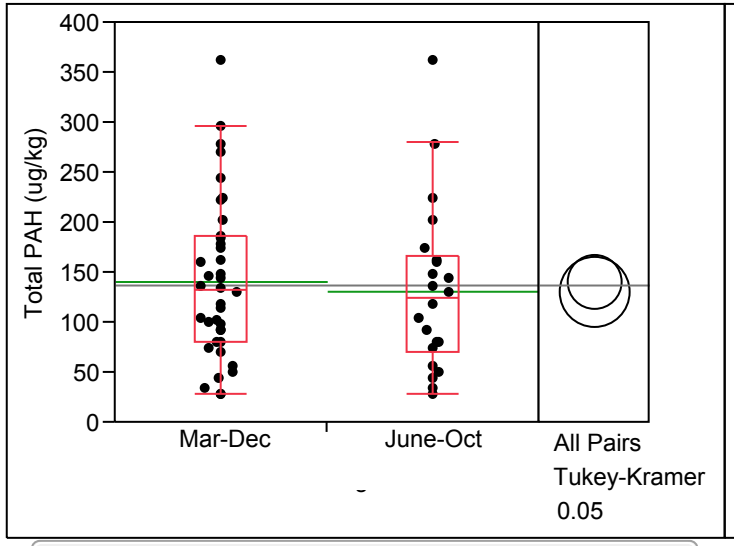
The datasets used in the analysis were ranged from RM0 to RM11.

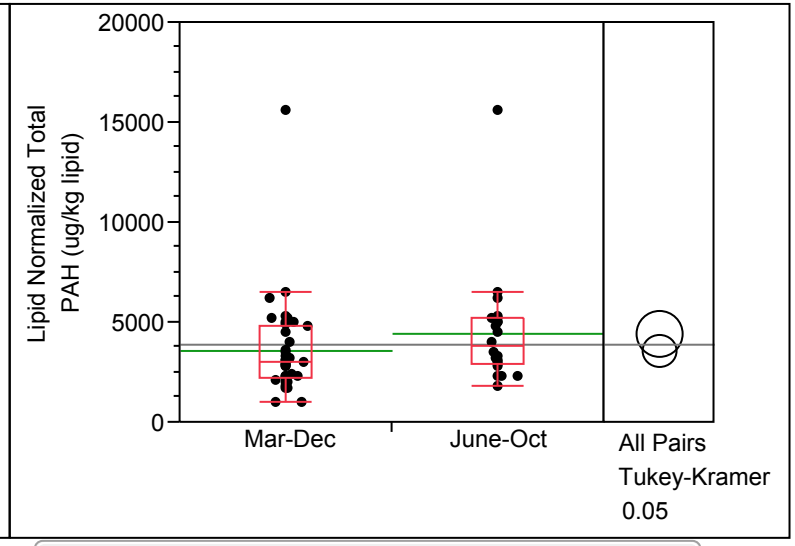
White Perch – Low Molecular Weight PAH Concentration
March-December *vs.* June-October

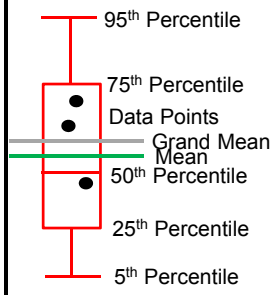
Lower Eight Miles of the Lower Passaic River

Figure 2-6g

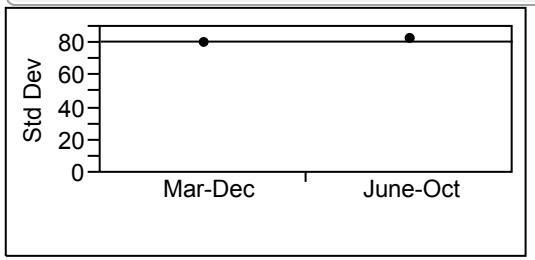
2014







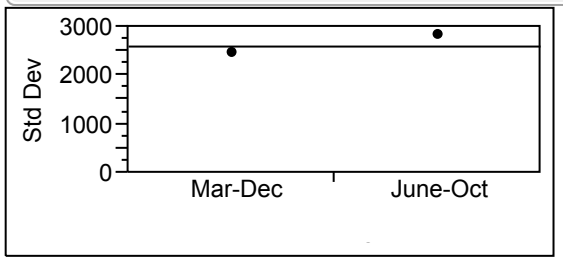
Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Mar-Dec	38	79.81070	62.69515	62.17632
June-Oct	22	82.83627	62.12810	62.02273

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0292	1	58	0.8648
Brown-Forsythe	0.0001	1	58	0.9911
Levene	0.0018	1	58	0.9664
Bartlett	0.0366	1	.	0.8482
F Test 2-sided	1.0773	21	37	0.8202

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Mar-Dec	38	2447.945	1536.942	1410.842
June-Oct	22	2836.646	1715.810	1676.409

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0883	1	58	0.7674
Brown-Forsythe	0.2047	1	58	0.6527
Levene	0.1095	1	58	0.7419
Bartlett	0.5848	1	.	0.4445
F Test 2-sided	1.3428	21	37	0.4232

Note

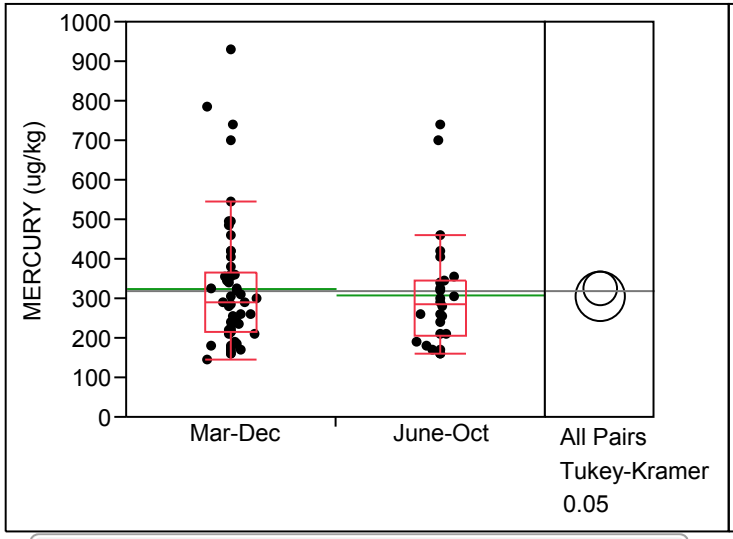
The datasets used in the analysis were ranged from RM0 to RM11.

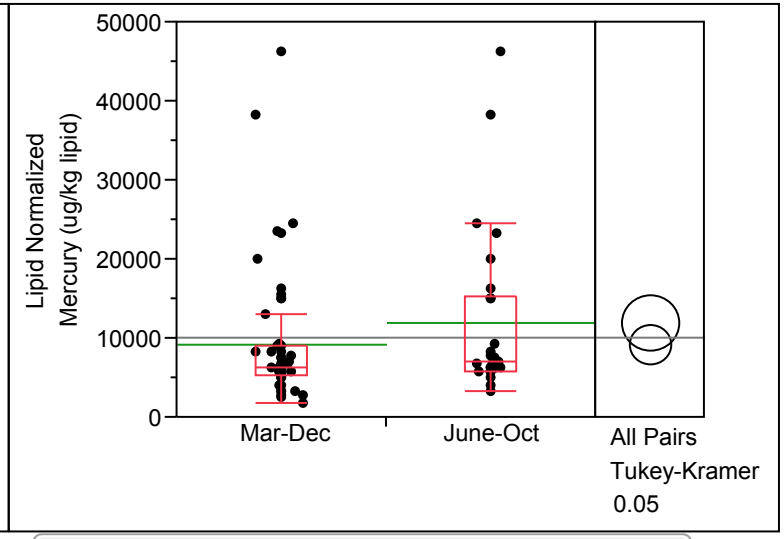
White Perch – Total PAH Concentration
March-December *vs.* June-October
Lower Eight Miles of the Lower Passaic River

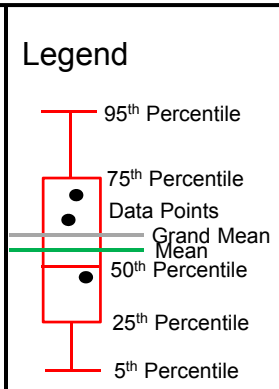
Figure 2-6h

2014

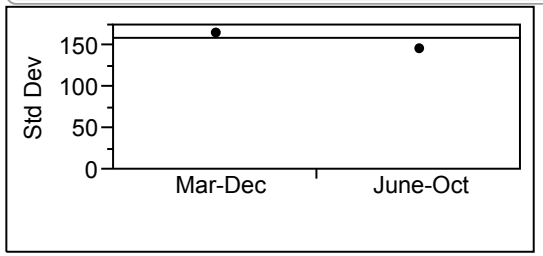
R2-0027620







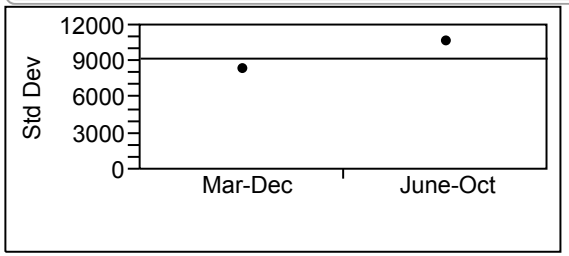
Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Mar-Dec	54	166.2012	118.1091	113.5000
June-Oct	26	146.3591	101.2544	98.6923

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.1963	1	78	0.6589
Brown-Forsythe	0.2643	1	78	0.6086
Levene	0.3969	1	78	0.5305
Bartlett	0.5236	1	.	0.4693
F Test 2-sided	1.2895	53	25	0.4946

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Mar-Dec	54	8462.03	5523.029	4514.648
June-Oct	26	10716.76	7899.722	6340.731

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.5746	1	78	0.4507
Brown-Forsythe	0.7978	1	78	0.3745
Levene	2.2765	1	78	0.1354
Bartlett	1.9602	1	.	0.1615
F Test 2-sided	1.6039	25	53	0.1492

Note

The datasets used in the analysis were ranged from RM0 to RM11.

White Perch – Mercury Concentration
March- December *vs.* June-October
Lower Eight Miles of the Lower Passaic River

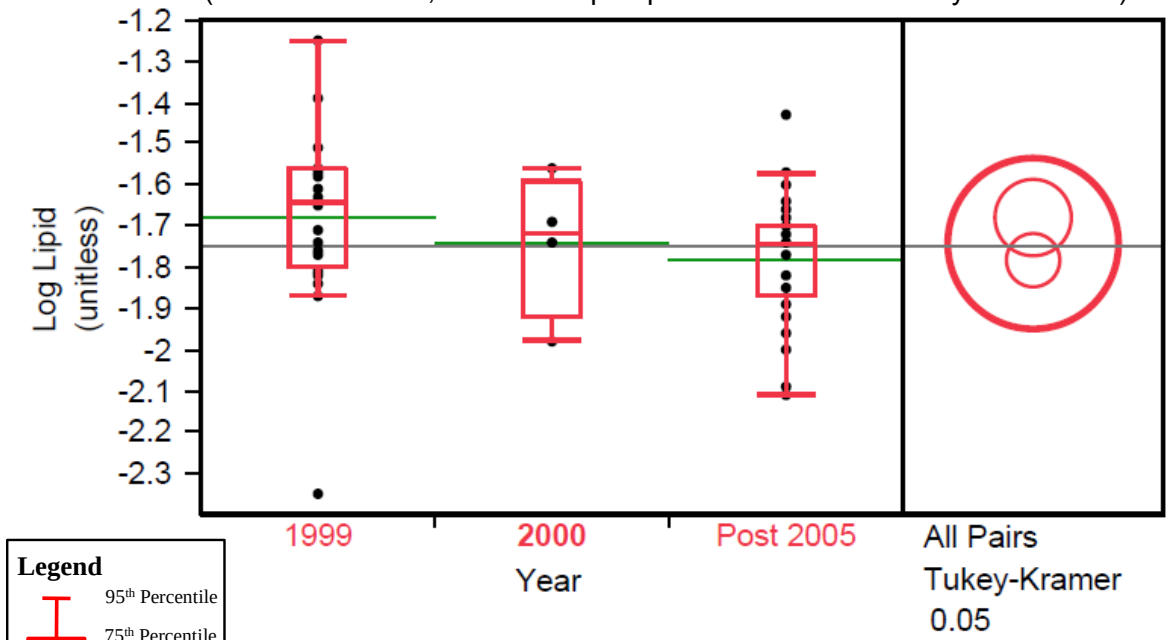
Figure 2-6i

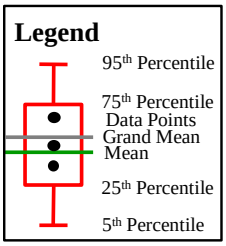
2014

R2-0027621

Blue Crab

(All Edible Tissue, Muscle+Hepatopancreas or Whole Body Soft Tissue)

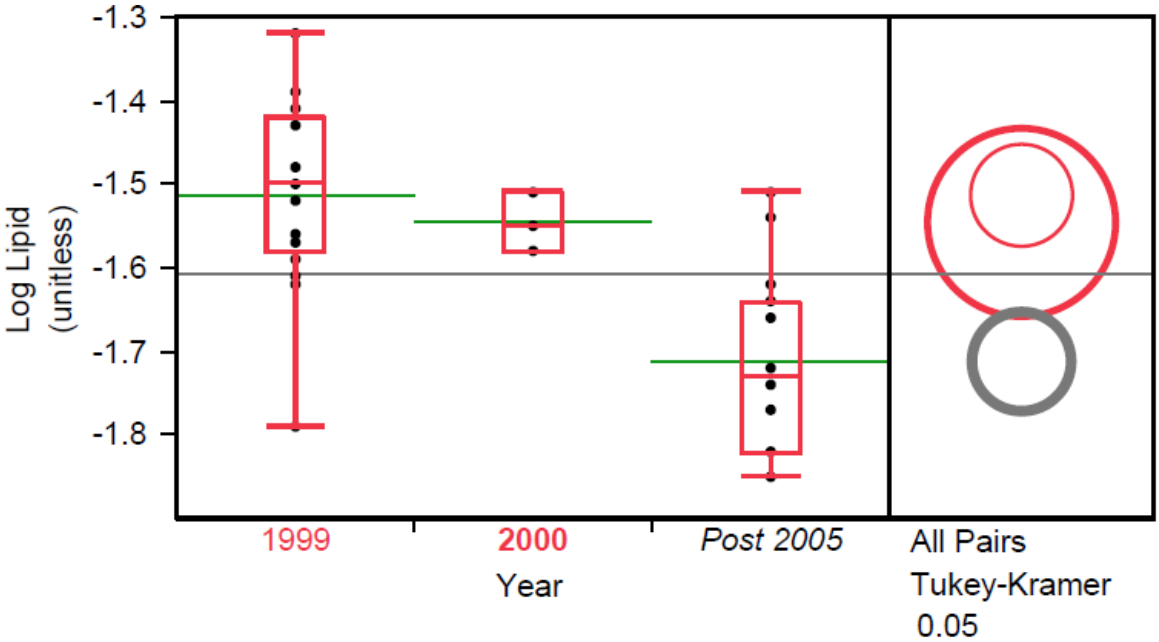




Note: Different colored circles indicate a statistically significant difference in the mean log concentrations (see text for discussions).

Mummichog

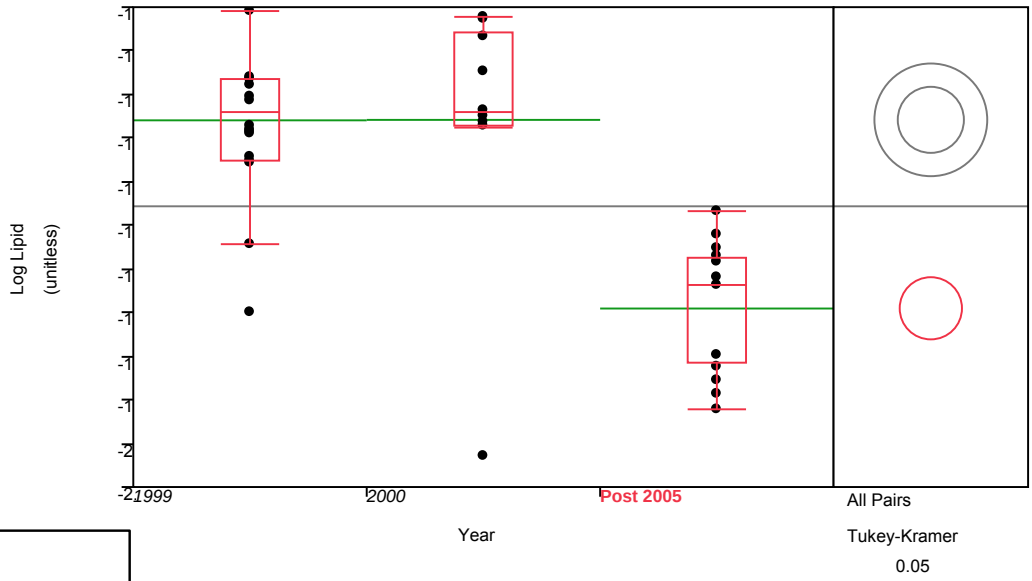
(Whole Body)

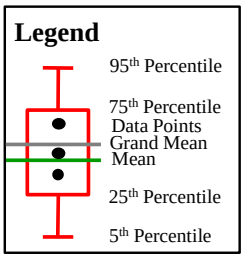


	Blue Crab and Mummichog Lipid *vs.* Year *Lower Eight Miles of the Lower Passaic River*	Figure 2-7a 2014

R2-0027622

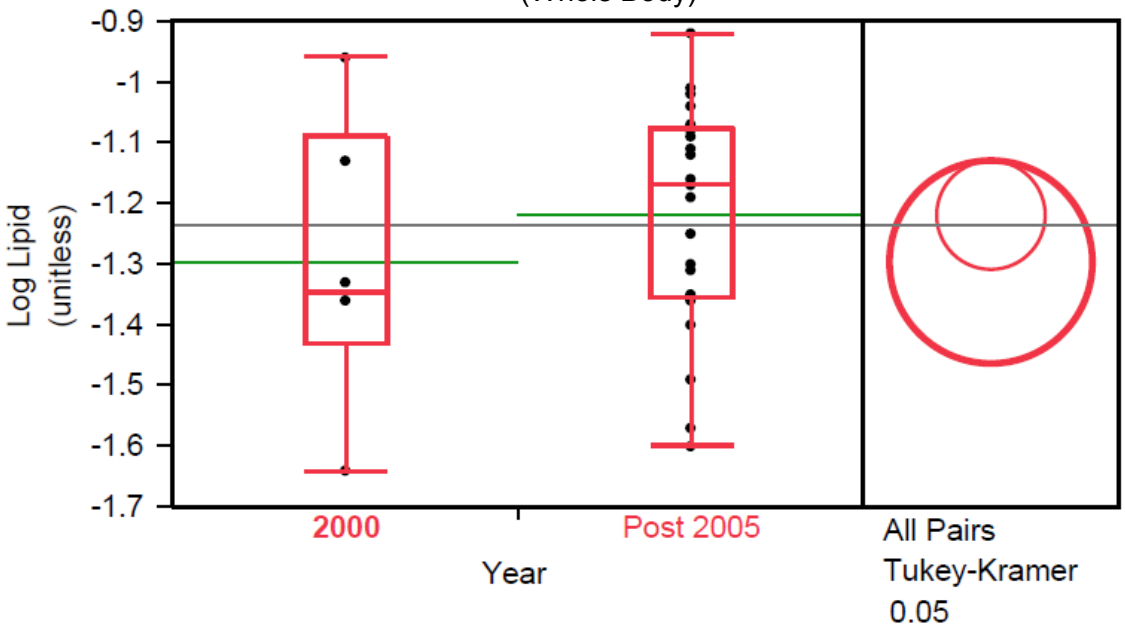
White Perch
(Whole Body-Head&Viscera and Fillet with Skin)





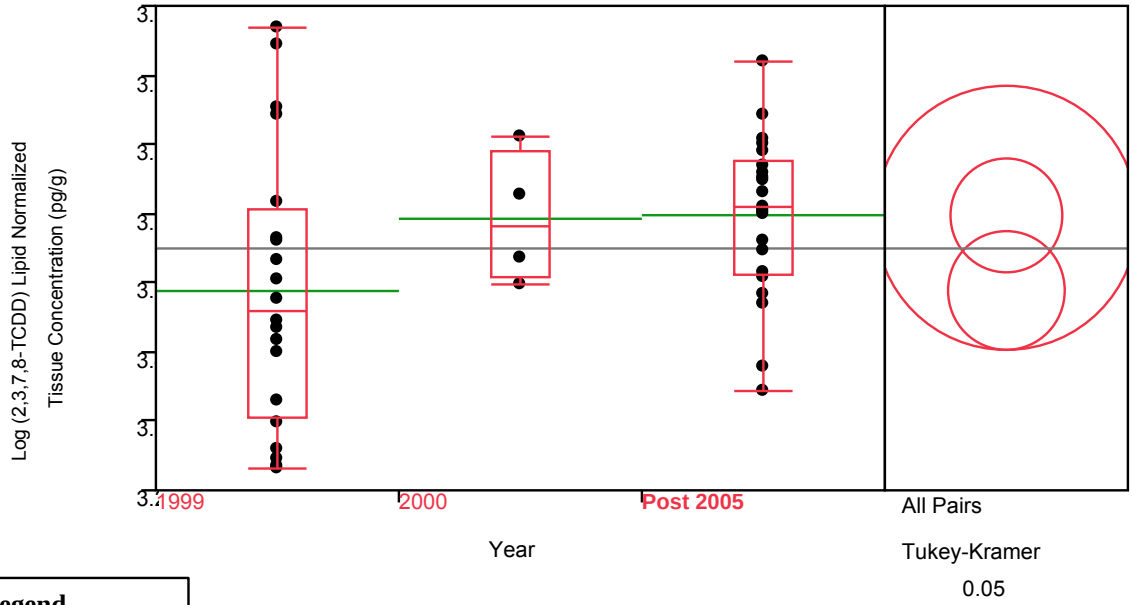
Note: Different colored circles indicate a statistically significant difference in the mean log concentrations (see text for discussions).

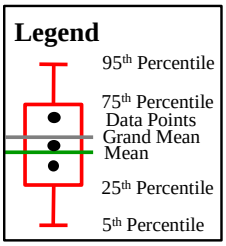
American Eel
(Whole Body)



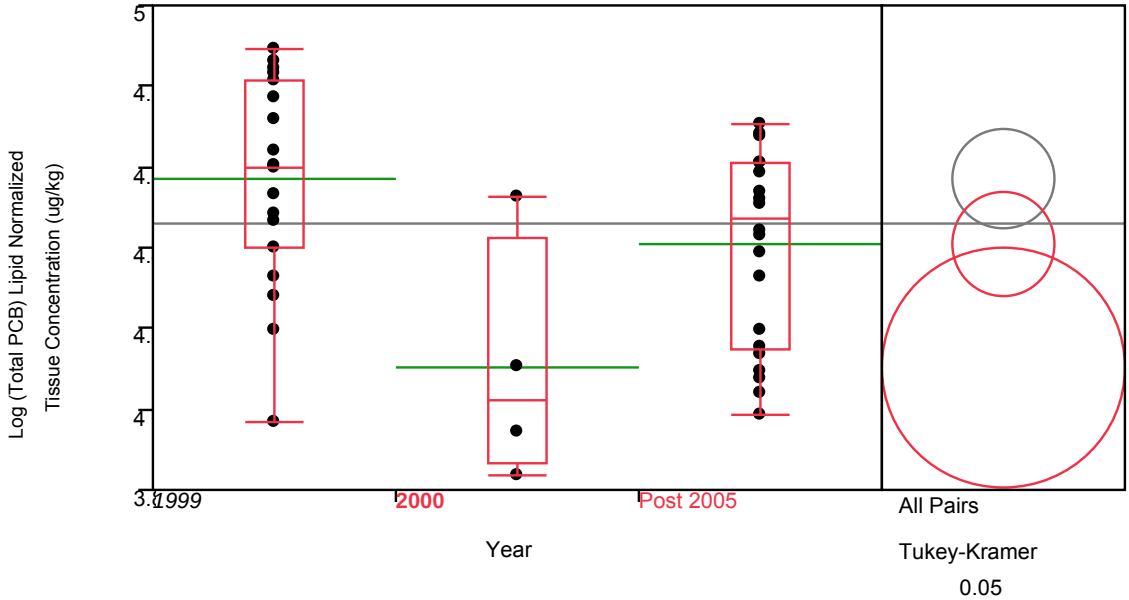
	White Perch and American Eel Lipid *vs.* Year *Lower Eight Miles of the Lower Passaic River*	Figure 2-7b 2014

R2-0027623



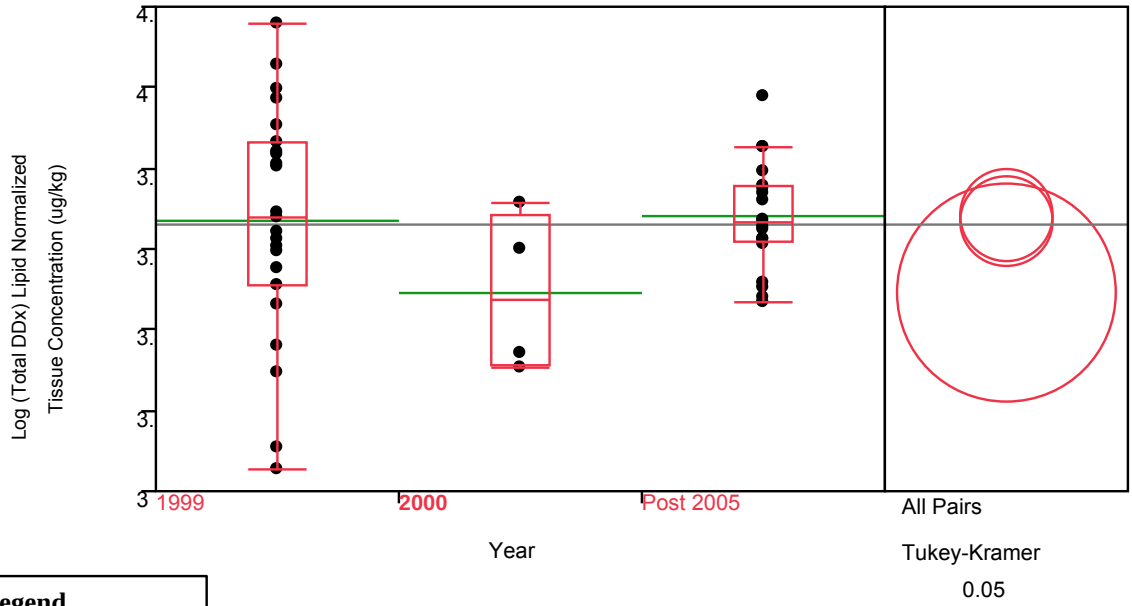


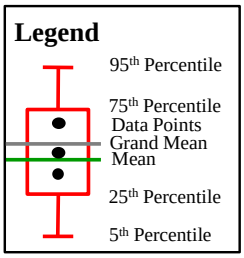
Notes:
1. Different colored circles indicate a statistically significant difference in the mean concentrations.
2. Tissue Type: Muscle+hepatopancreas and equivalent tissue type, all edible muscle



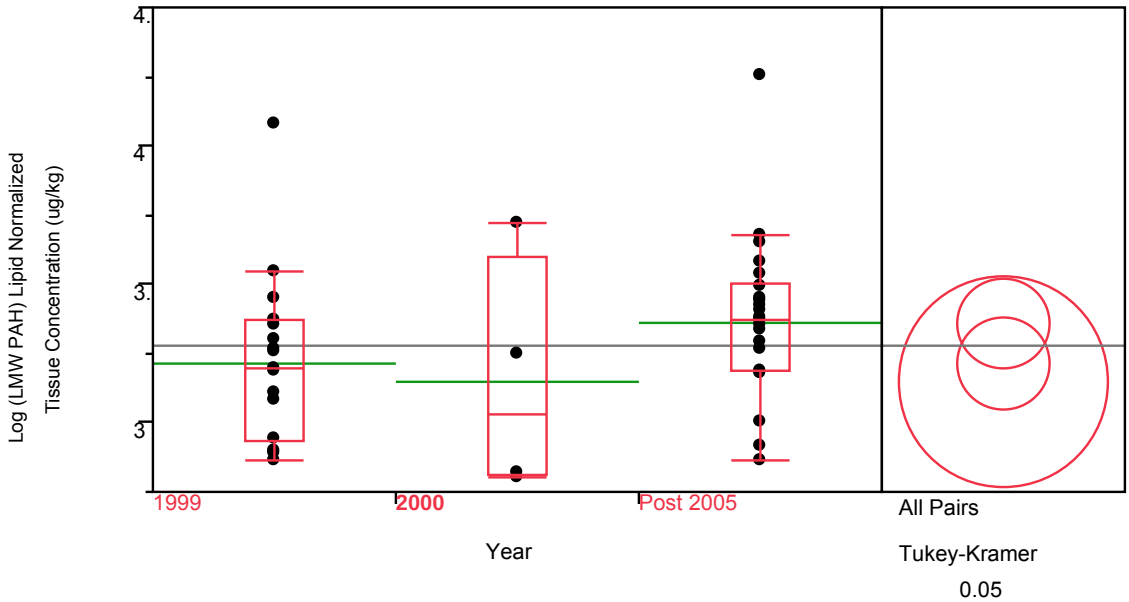
	Blue Crab 2,3,7,8-TCDD and Total PCB *vs.* Year *Lower Eight Miles of the Lower Passaic River*	Figure 2-8a 2014

R2-0027624





Notes:
1. Different colored circles indicate a statistically significant difference in the mean concentrations.
2. Tissue Type: Muscle+hepatopancreas and equivalent tissue type, all edible muscle



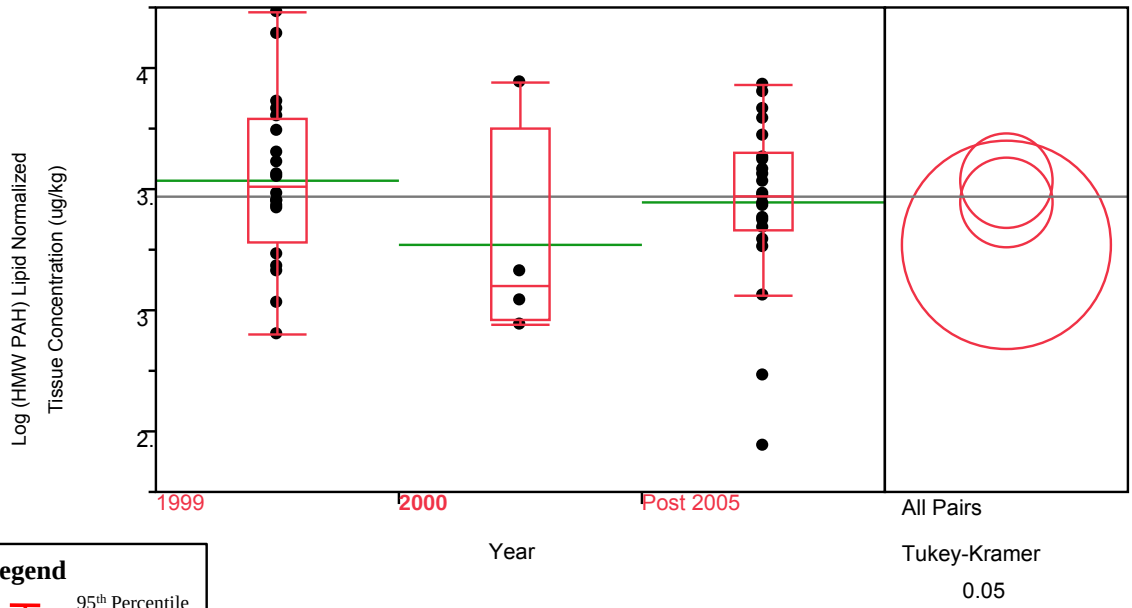
Blue Crab Total DDx and Low Molecular Weight PAH *vs.* Year

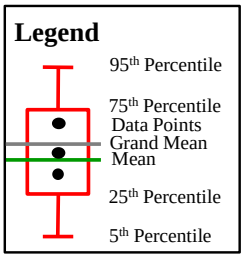
Lower Eight Miles of the Lower Passaic River

Figure 2-8b

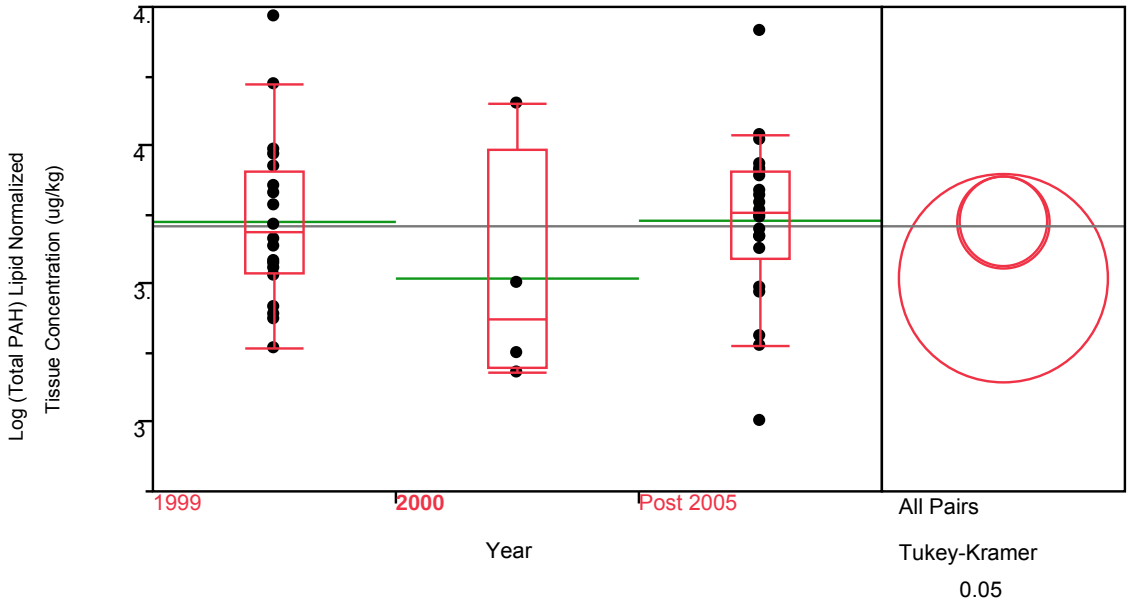
2014

R2-0027625



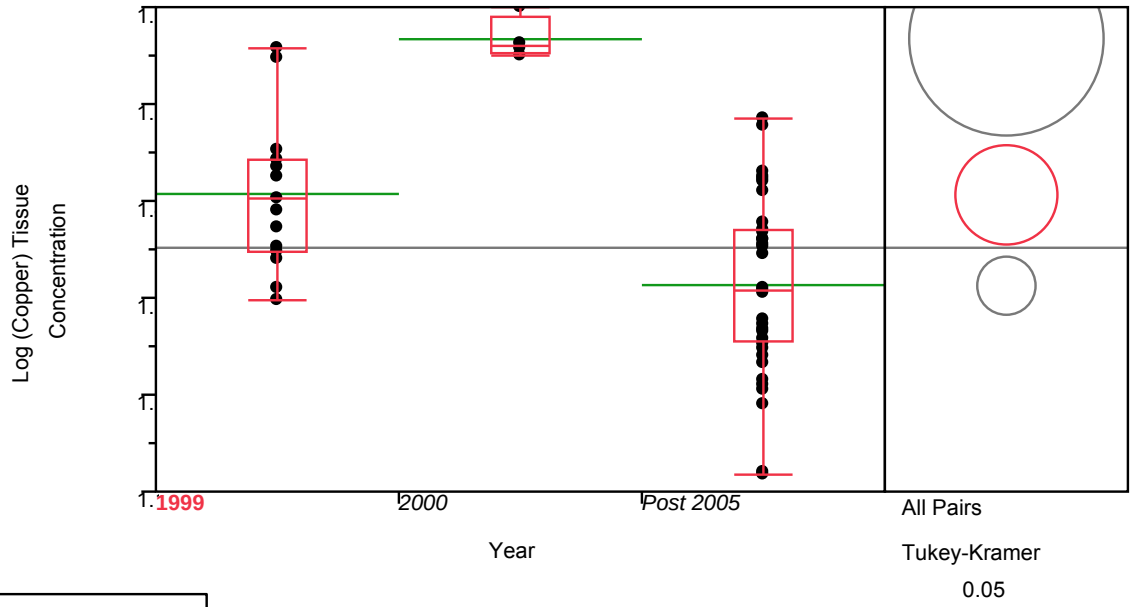


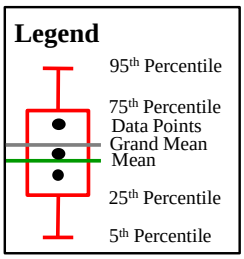
Notes:
1. Different colored circles indicate a statistically significant difference in the mean concentrations.
2. Tissue Type: Muscle+hepatopancreas and equivalent tissue type, all edible muscle



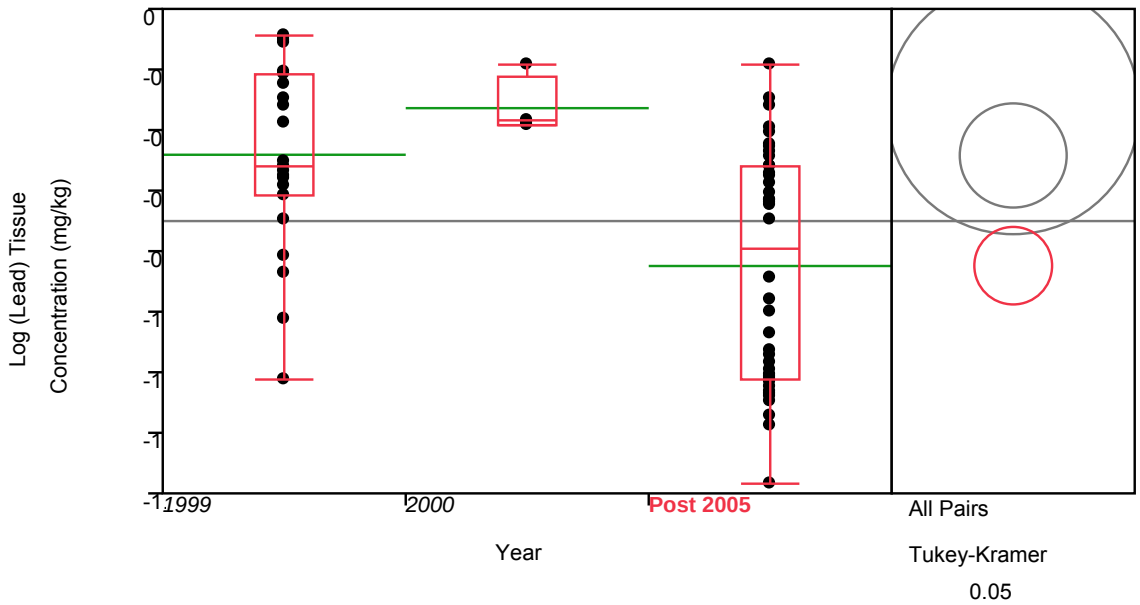
	Blue Crab High Molecular Weight PAH and Total PAH *vs.* Year *Lower Eight Miles of the Lower Passaic River*	Figure 2-8c 2014

R2-0027626



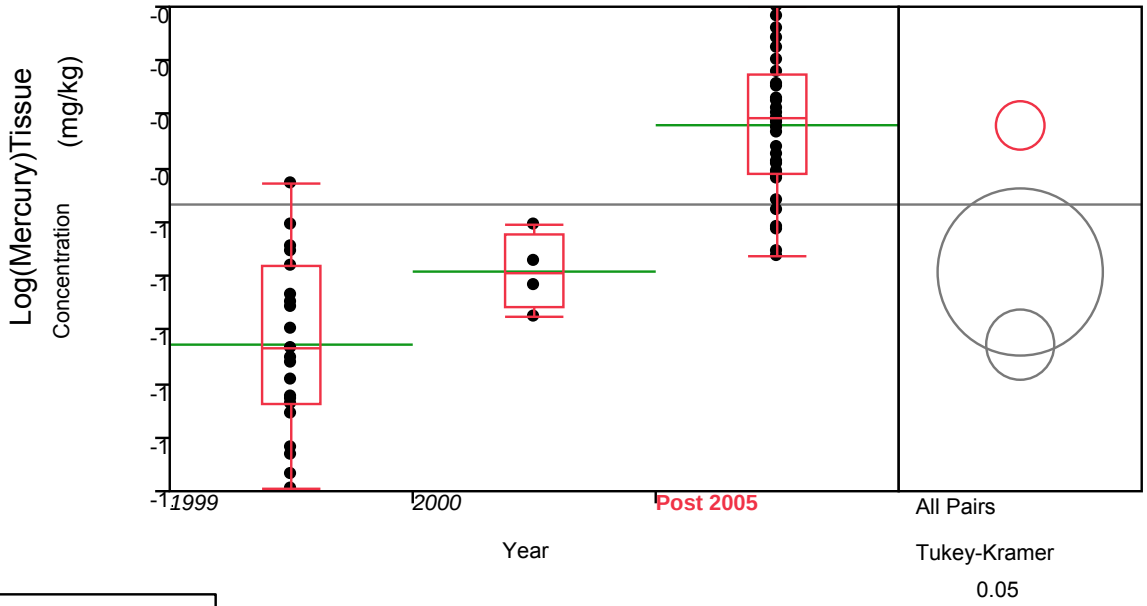


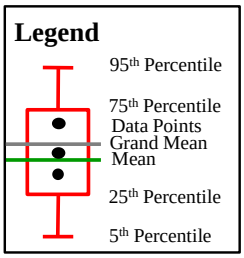
Notes:
1. Different colored circles indicate a statistically significant difference in the mean concentrations.
2. Tissue Type: Muscle+hepatopancreas and equivalent tissue type, all edible muscle



	Blue Crab Copper and Lead *vs.* Year *Lower Eight Miles of the Lower Passaic River*	Figure 2-8d 2014

R2-0027627

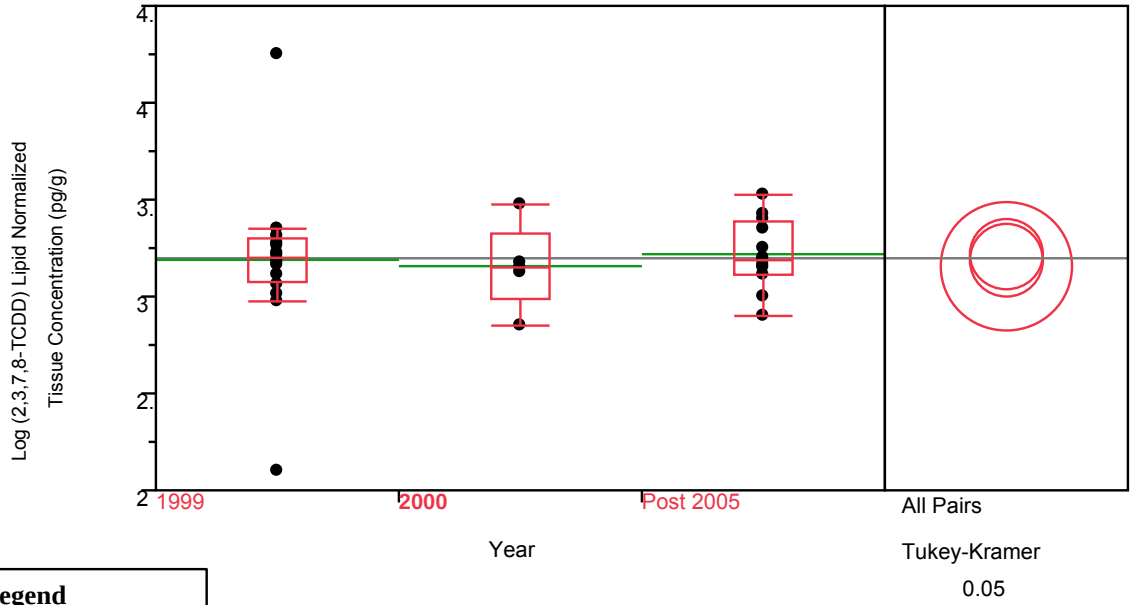


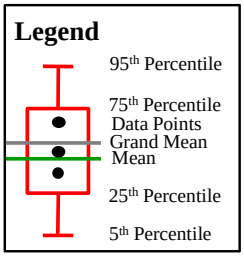


Notes:
1. Different colored circles indicate a statistically significant difference in the mean concentrations.
2. Tissue Type: Muscle+hepatopancreas and equivalent tissue type, all edible muscle

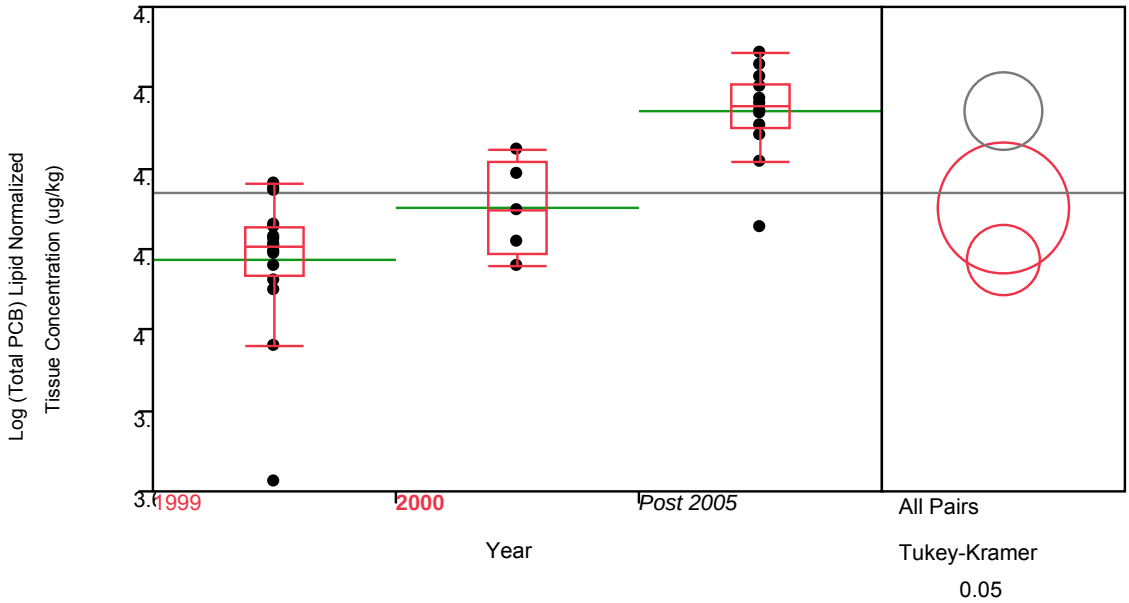
	Blue Crab Mercury *vs.* Year *Lower Eight Miles of the Lower Passaic River*	Figure 2-8e 2014

R2-0027628





Notes:
1. Different colored circles indicate a statistically significant difference in the mean concentrations.
2. Tissue type: whole body



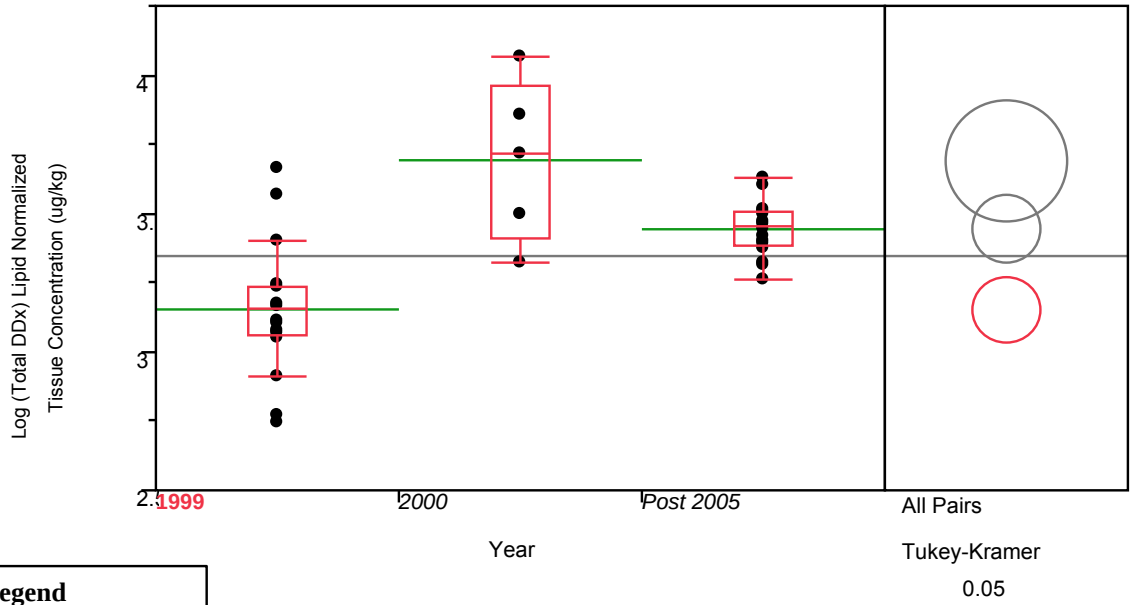
Mummichog 2,3,7,8-TCDD and Total PCB *vs.* Year

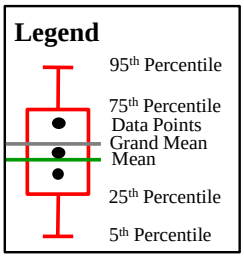
Lower Eight Miles of the Lower Passaic River

Figure 2-9a

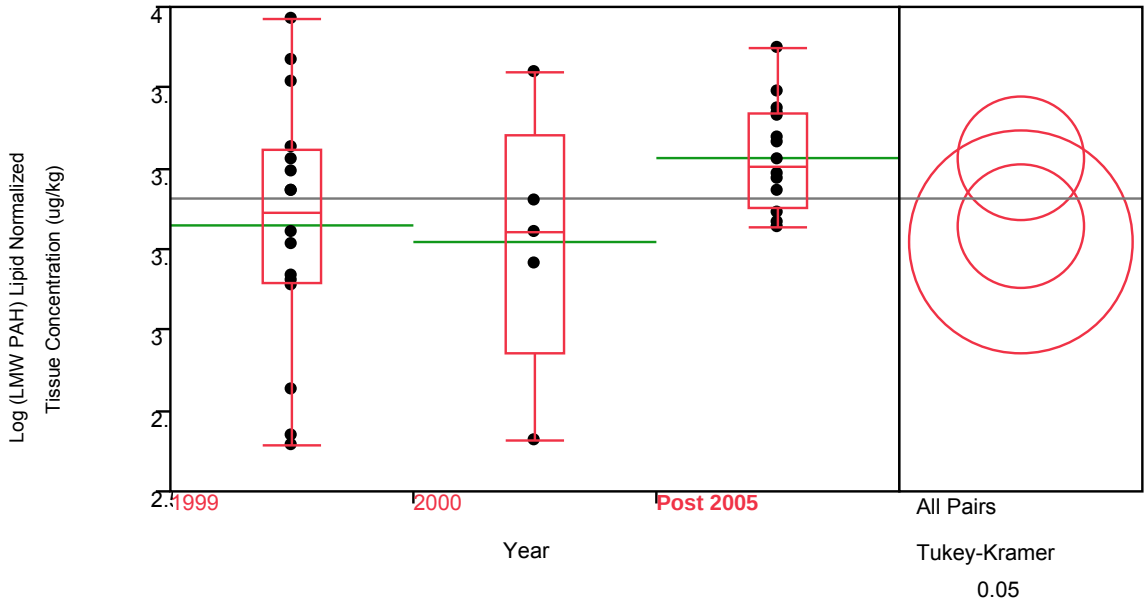
2014

R2-0027629





Notes:
1. Different colored circles indicate a statistically significant difference in the mean concentrations.
2. Tissue type: whole body



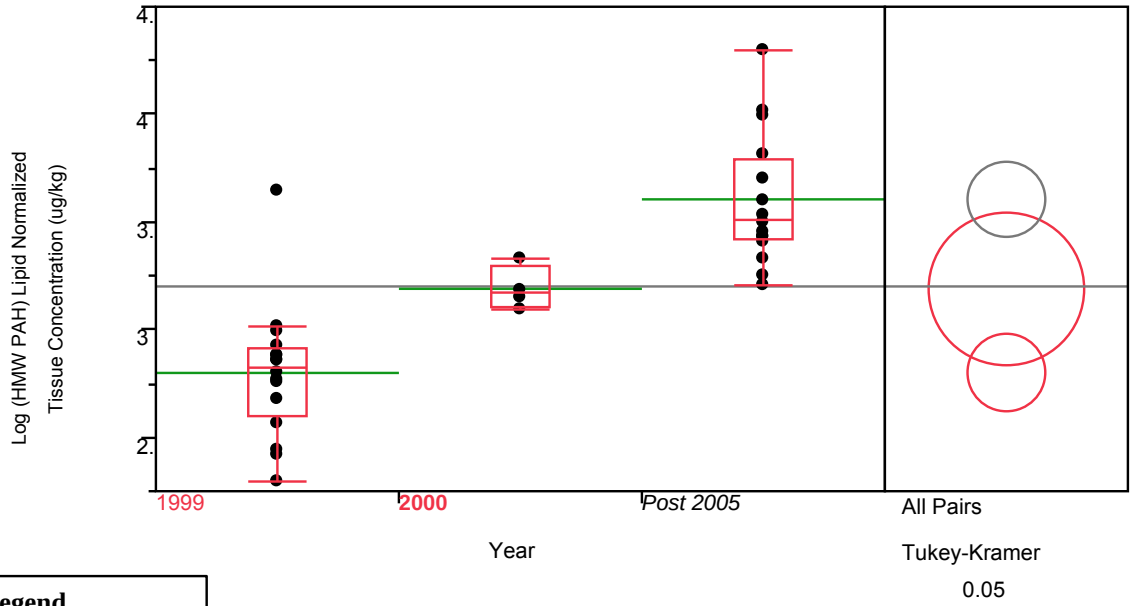
Mummichog Total DDx and Low Molecular Weight PAH *vs*. Year

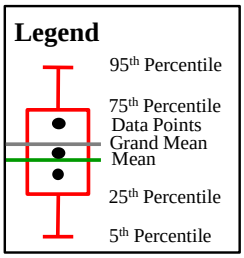
Lower Eight Miles of the Lower Passaic River

Figure 2-9b

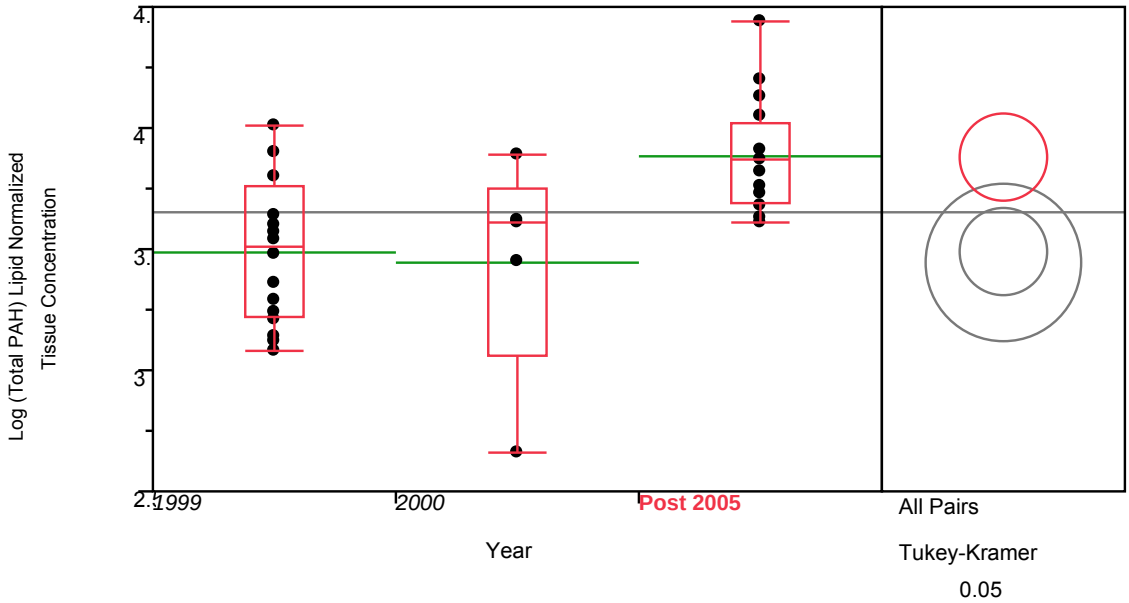
2014

R2-0027630



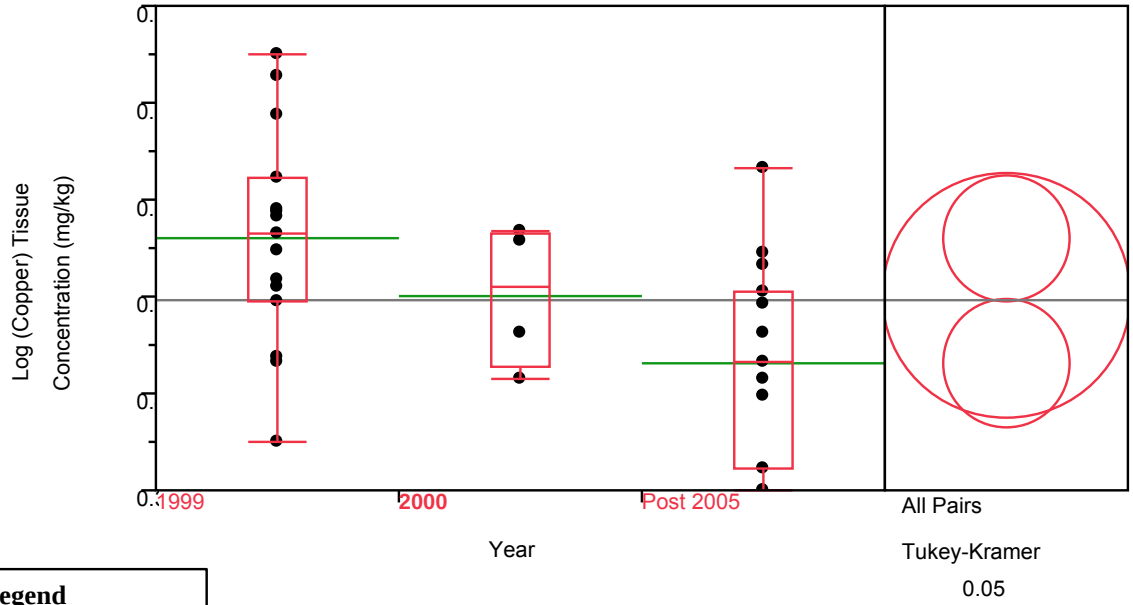


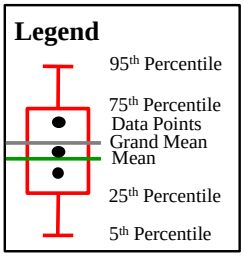
Notes:
1. Different colored circles indicate a statistically significant difference in the mean concentrations.
2. Tissue type: whole body



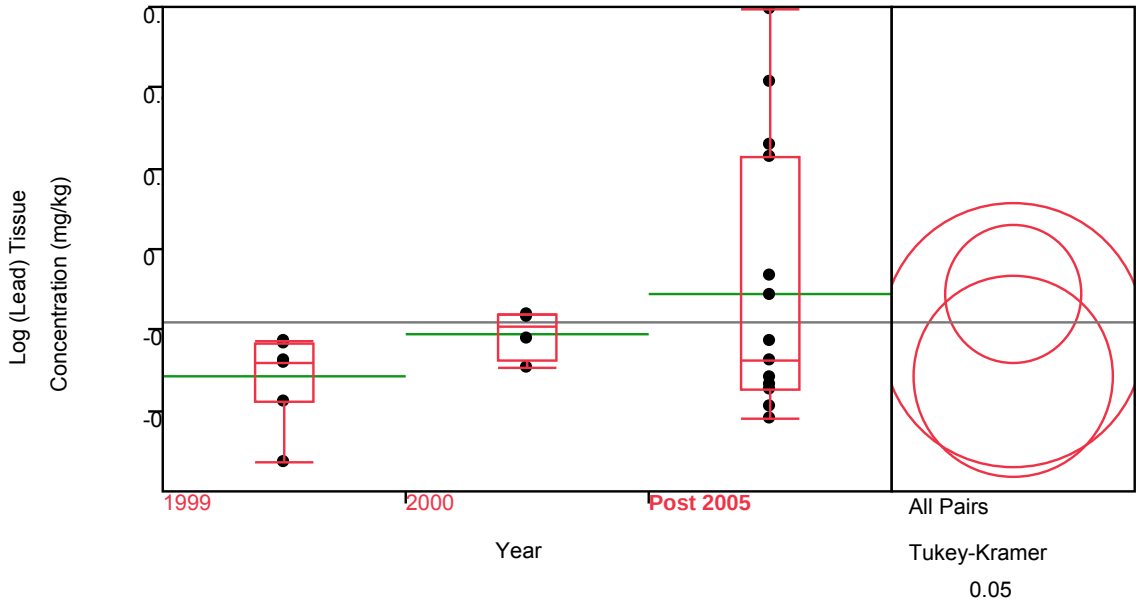
	Mummichog High Molecular Weight PAH and Total PAH *vs*. Year *Lower Eight Miles of the Lower Passaic River*	Figure 2-9c 2014

R2-0027631





Notes:
1. Different colored circles indicate a statistically significant difference in the mean concentrations.
2. Tissue type: whole body



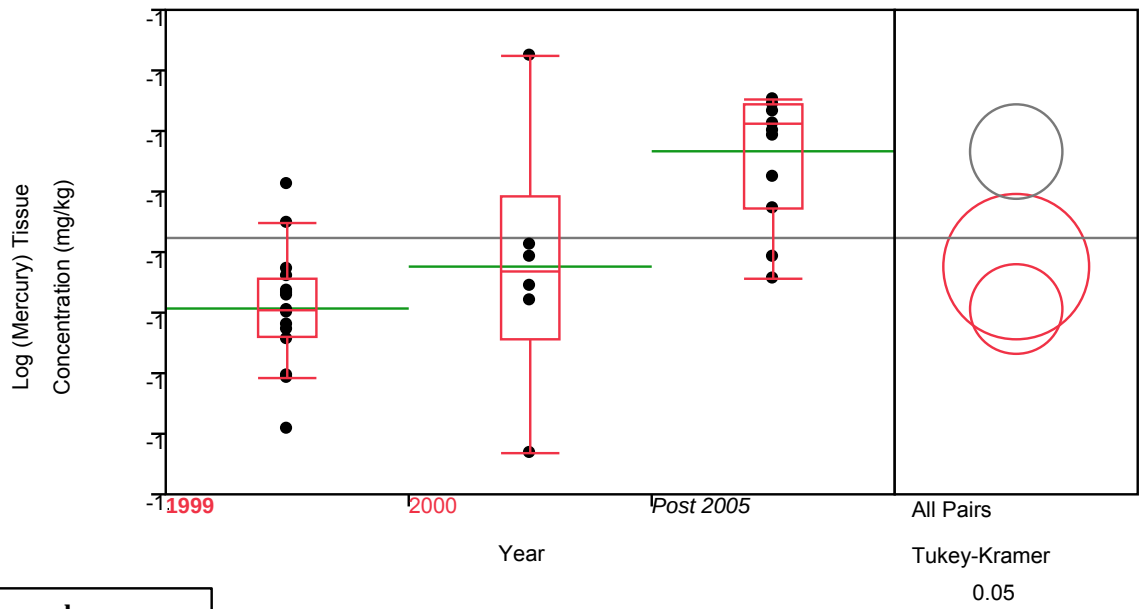
Mummichog Copper and Lead *vs.* Year

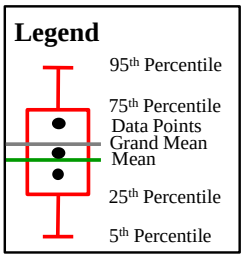
Lower Eight Miles of the Lower Passaic River

Figure 2-9d

2014

R2-0027632

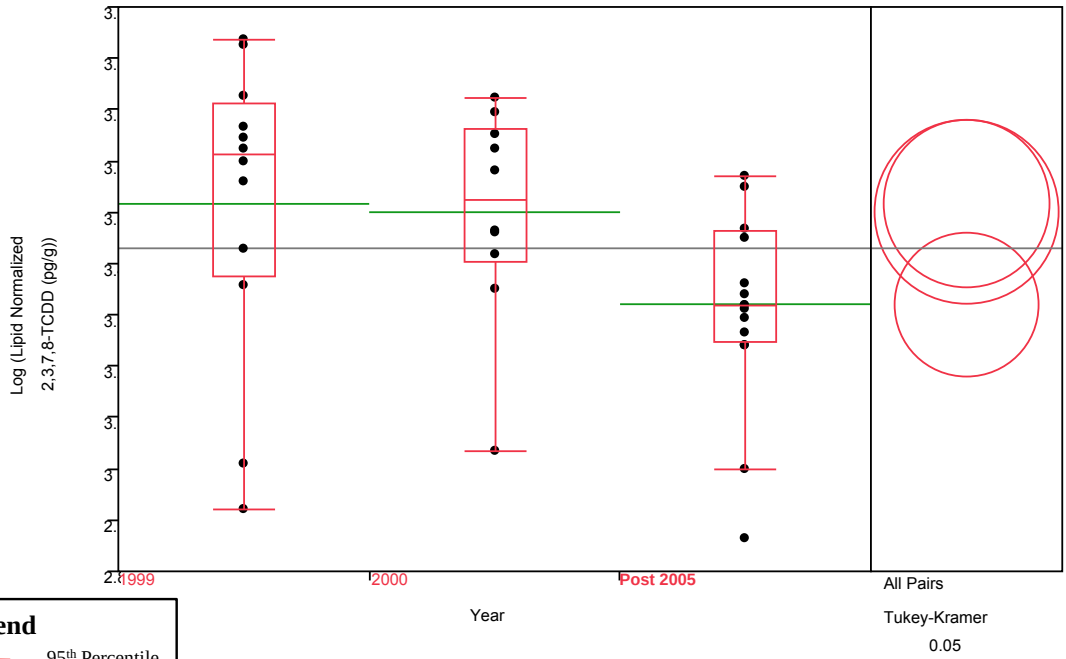


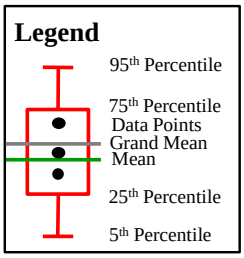


Notes:
1. Different colored circles indicate a statistically significant difference in the mean concentrations.
2. Tissue type: whole body

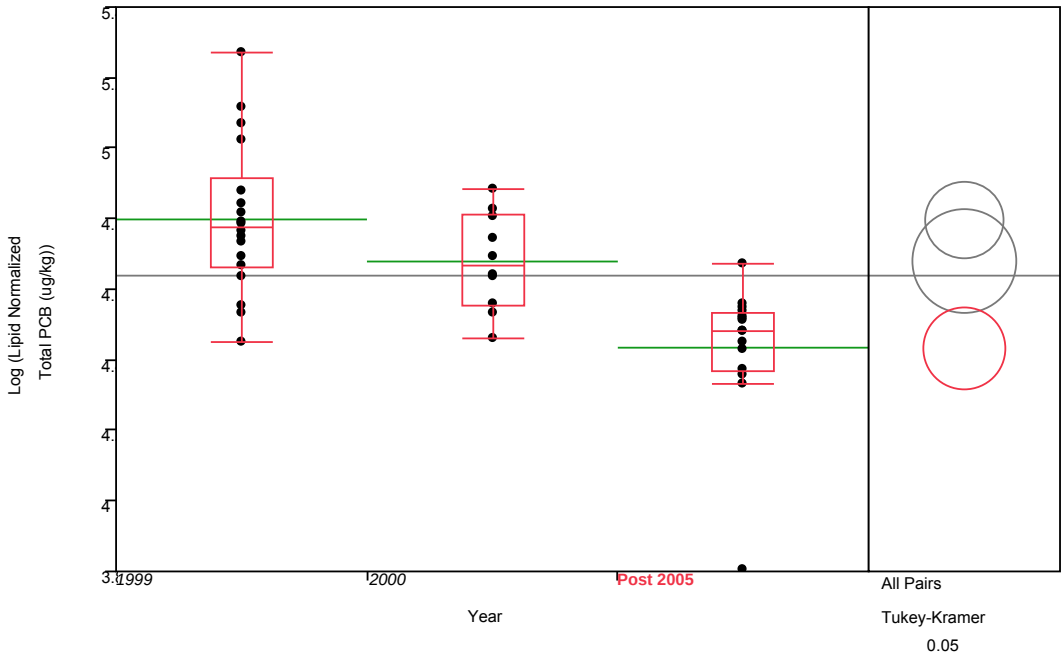
	Mummichog Mercury *vs.* Year *Lower Eight Miles of the Lower Passaic River*	Figure 2-9e 2014

R2-0027633





Notes:
1. Different colored circles indicate a statistically significant difference in the mean concentrations.
2. Tissue type: whole body-head&viscera and fillet with skin on



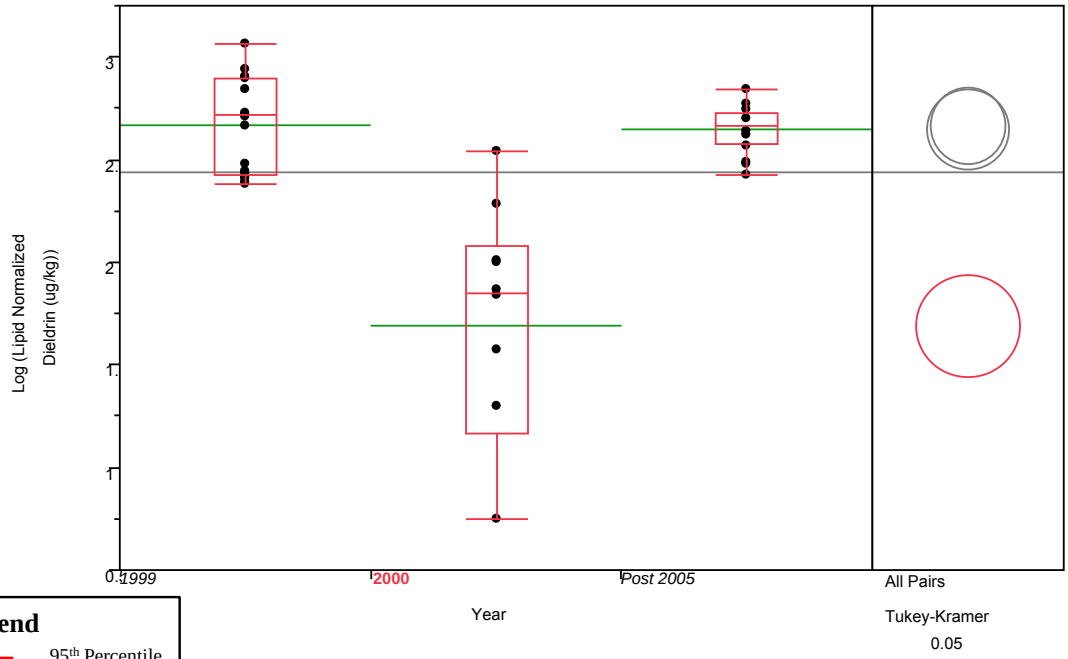
White Perch 2,3,7,8-TCDD and Total PCB *vs.* Year

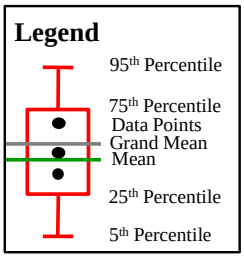
Lower Eight Miles of the Lower Passaic River

Figure 2-10a

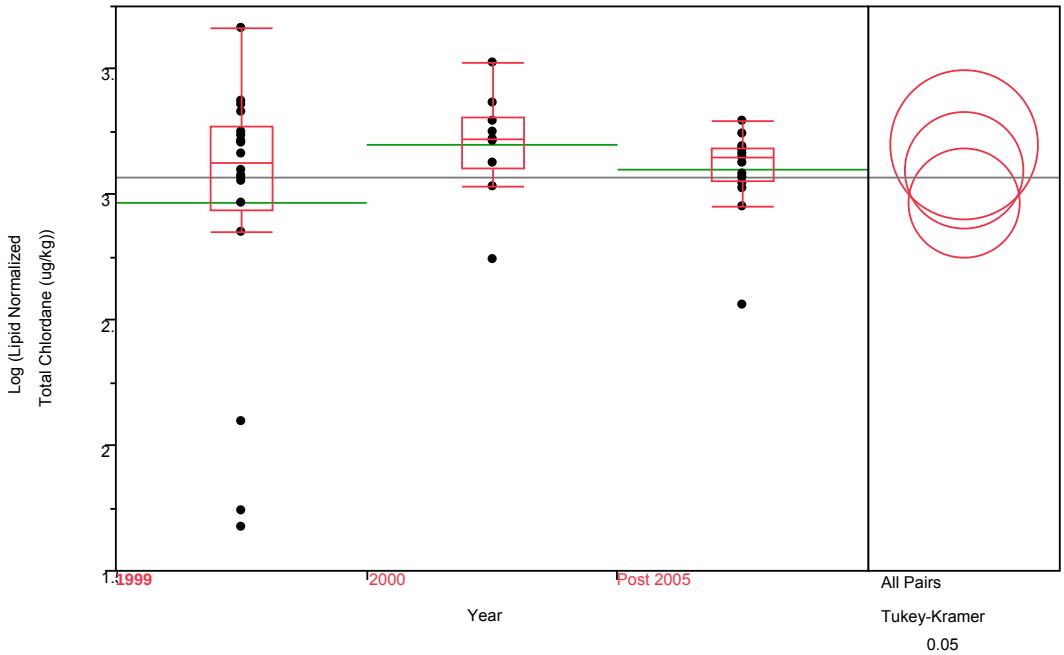
2014

R2-0027634



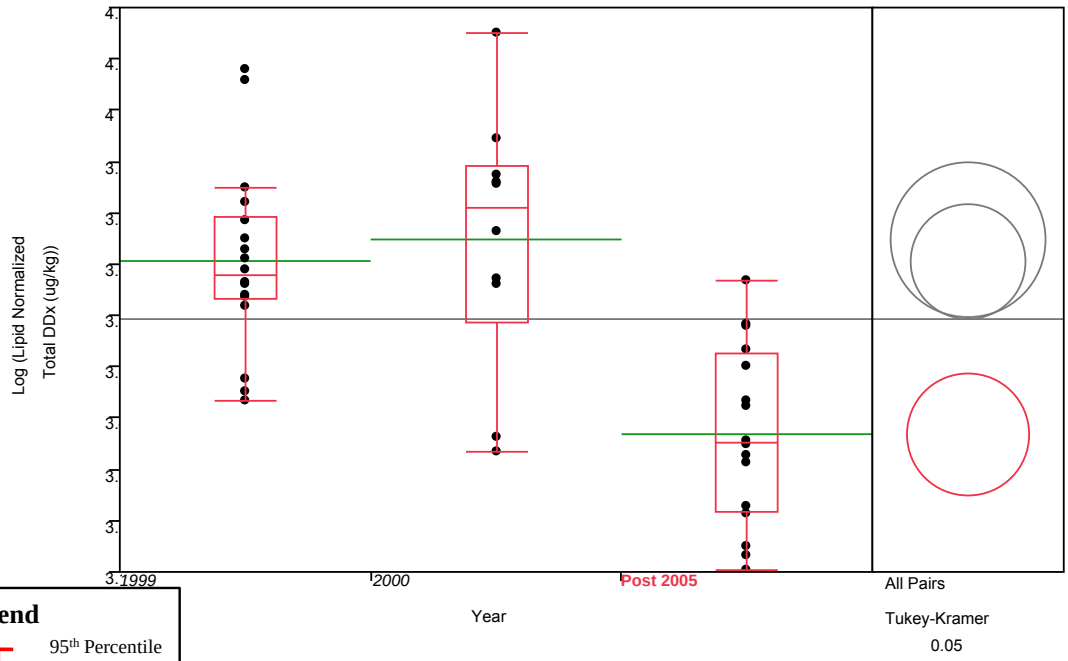


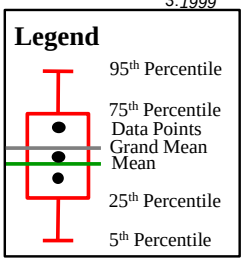
Notes:
1. Different colored circles indicate a statistically significant difference in the mean concentrations.
2. Tissue type: whole body-head&viscera and fillet with skin on



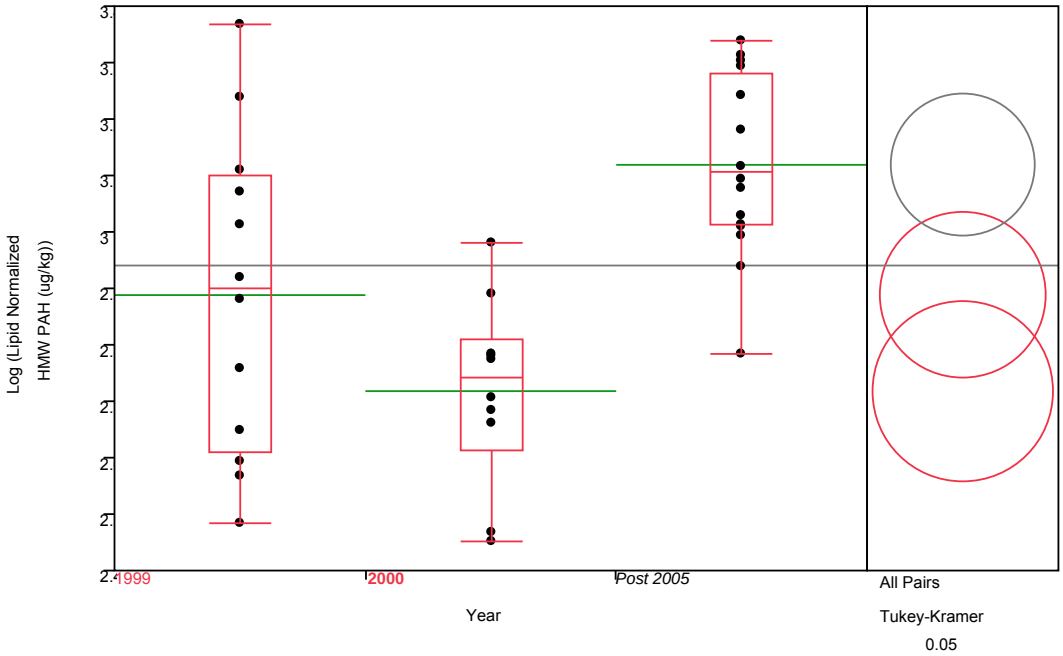
	White Perch Dieldrin and Total Chlordane *vs.* Year *Lower Eight Miles of the Lower Passaic River*	Figure 2-10b 2014

R2-0027635





Notes:
1. Different colored circles indicate a statistically significant difference in the mean concentrations.
2. Tissue type: whole body-head&viscera and fillet with skin on



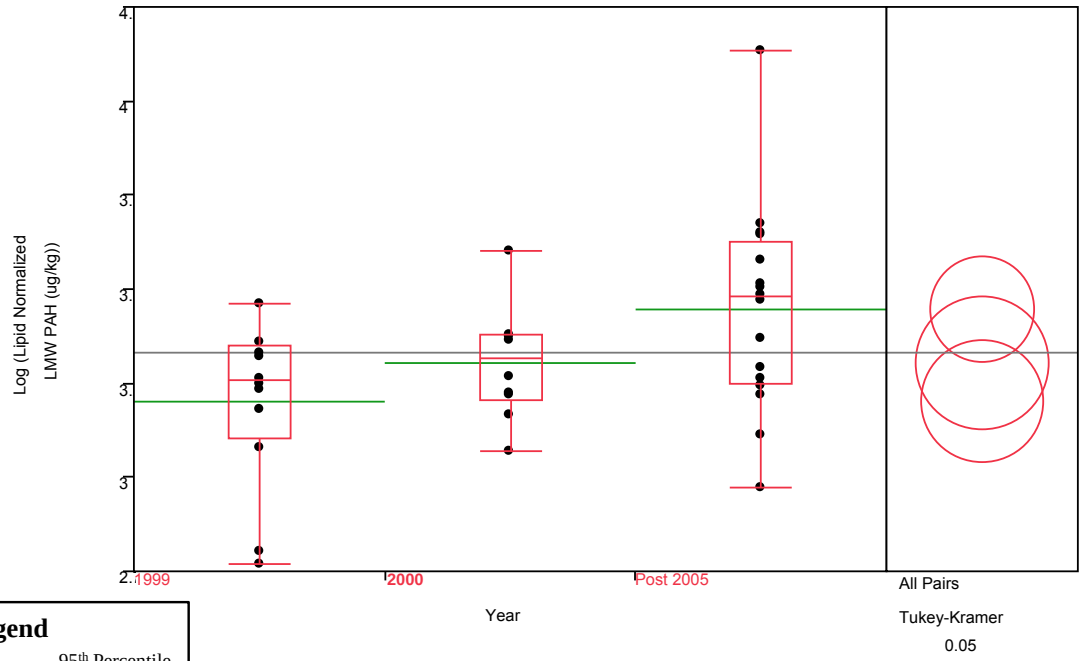
White Perch Total DDx and High Molecular Weight PAH *vs*. Year

Lower Eight Miles of the Lower Passaic River

Figure 2-10c

2014

R2-0027636



Legend

95th Percentile

75th Percentile

Data Points

Grand Mean

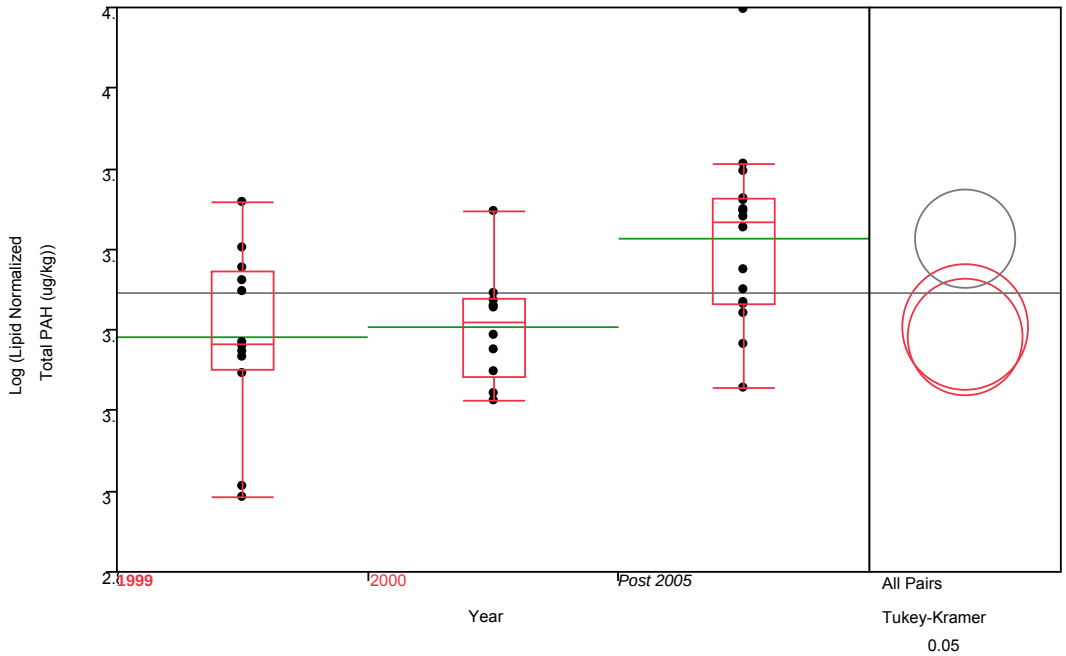
Mean

25th Percentile

5th Percentile

Notes:

1. Different colored circles indicate a statistically significant difference in the mean concentrations.
2. Tissue type: whole body-head&viscera and fillet with skin on



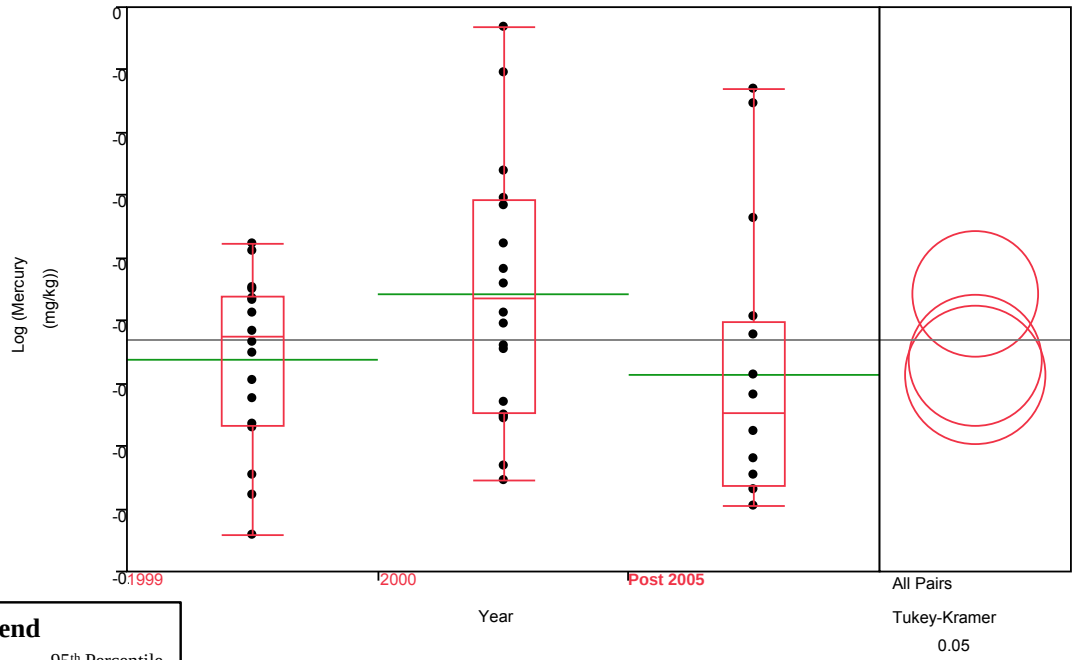
White Perch Low Molecular Weight PAH and Total PAH *vs*. Year

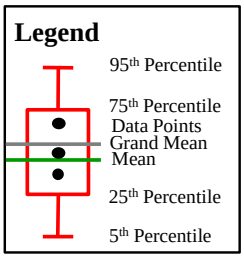
Lower Eight Miles of the Lower Passaic River

Figure 2-10d

2014

R2-0027637

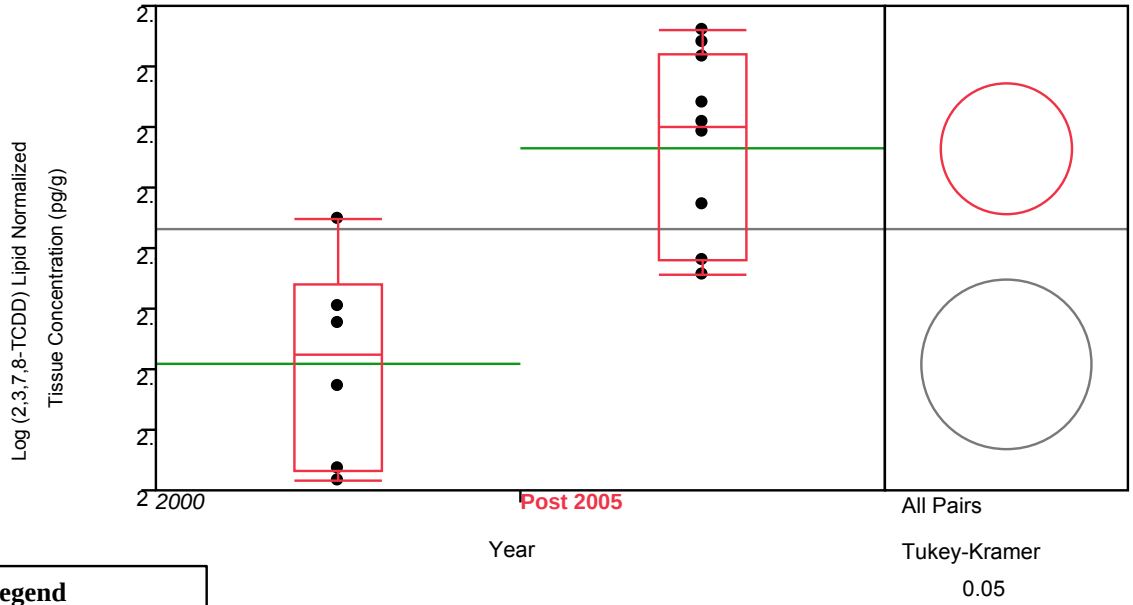


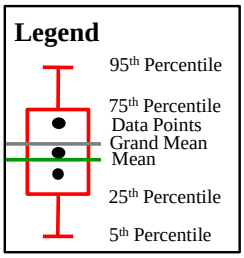


Notes:
1. Different colored circles indicate a statistically significant difference in the mean concentrations.
2. Tissue type: whole body-head&viscera and fillet with skin on

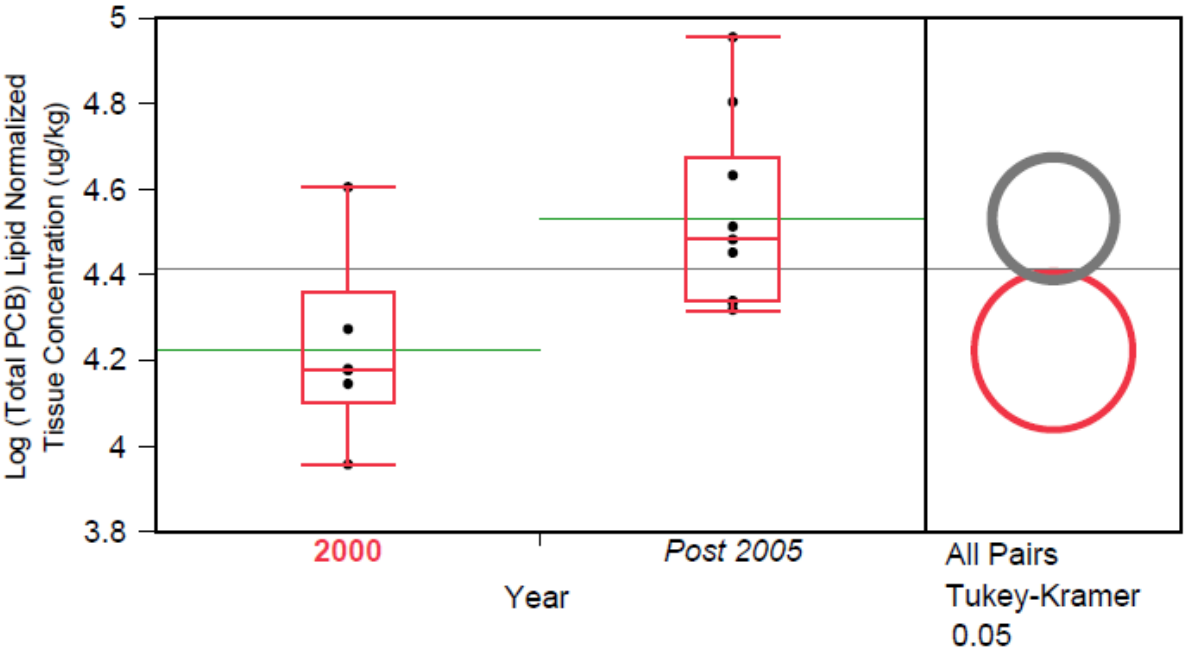
	White Perch Mercury *vs.* Year *Lower Eight Miles of the Lower Passaic River*	Figure 2-10e 2014

R2-0027638



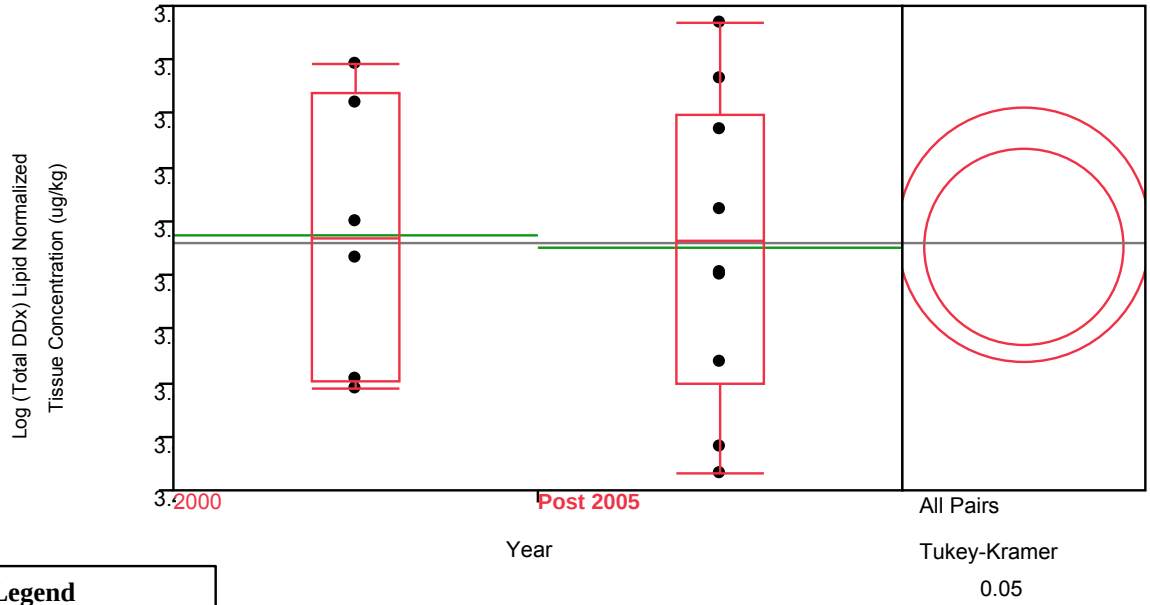


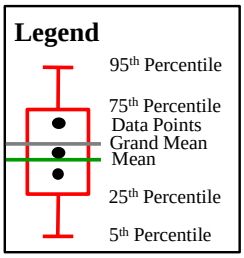
Notes:
1. Different colored circles indicate a statistically significant difference in the mean concentrations.
2. Tissue type: whole body



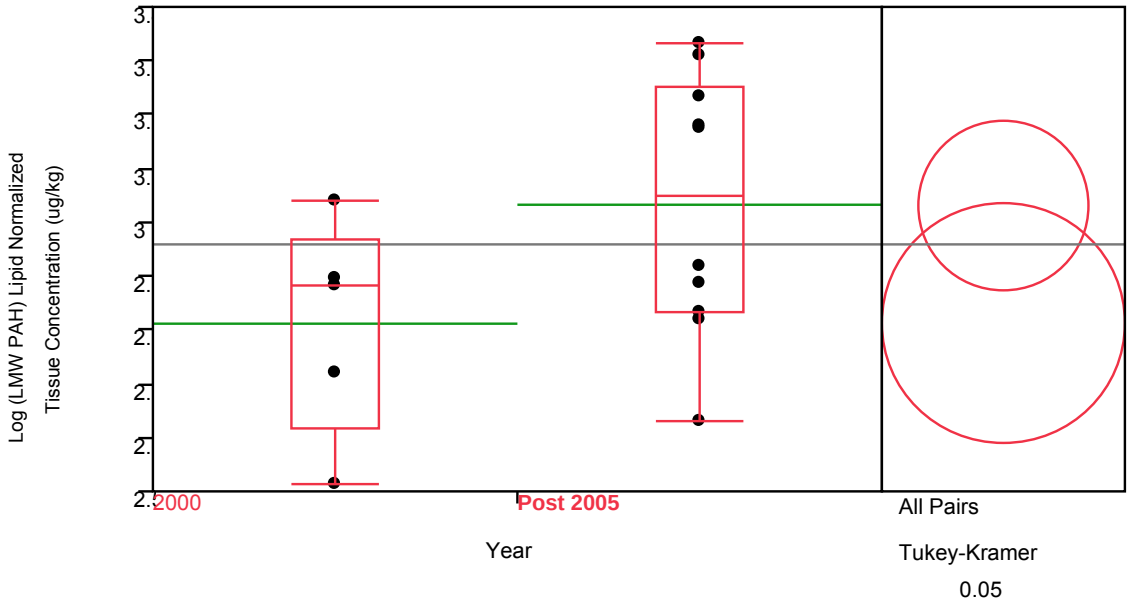
	American Eel 2,3,7,8-TCDD and Total PCB *vs.* Year *Lower Eight Miles of the Lower Passaic River*	Figure 2-11a 2014

R2-0027639



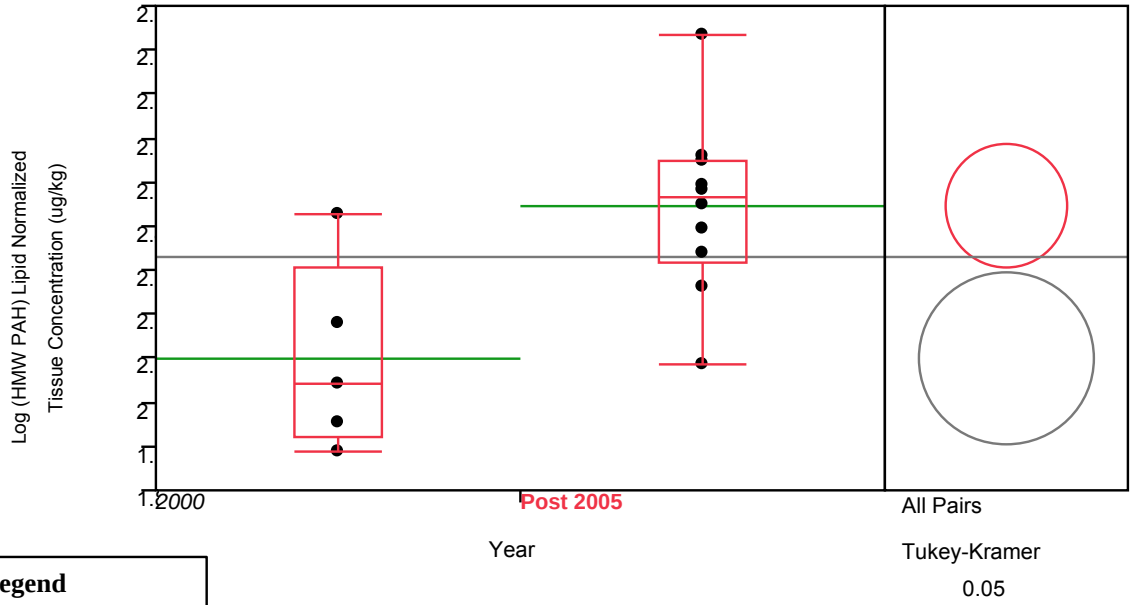


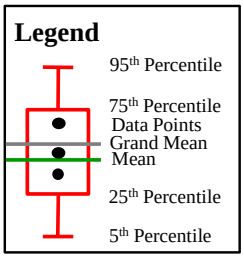
Notes:
1. Different colored circles indicate a statistically significant difference in the mean concentrations.
2. Tissue type: whole body



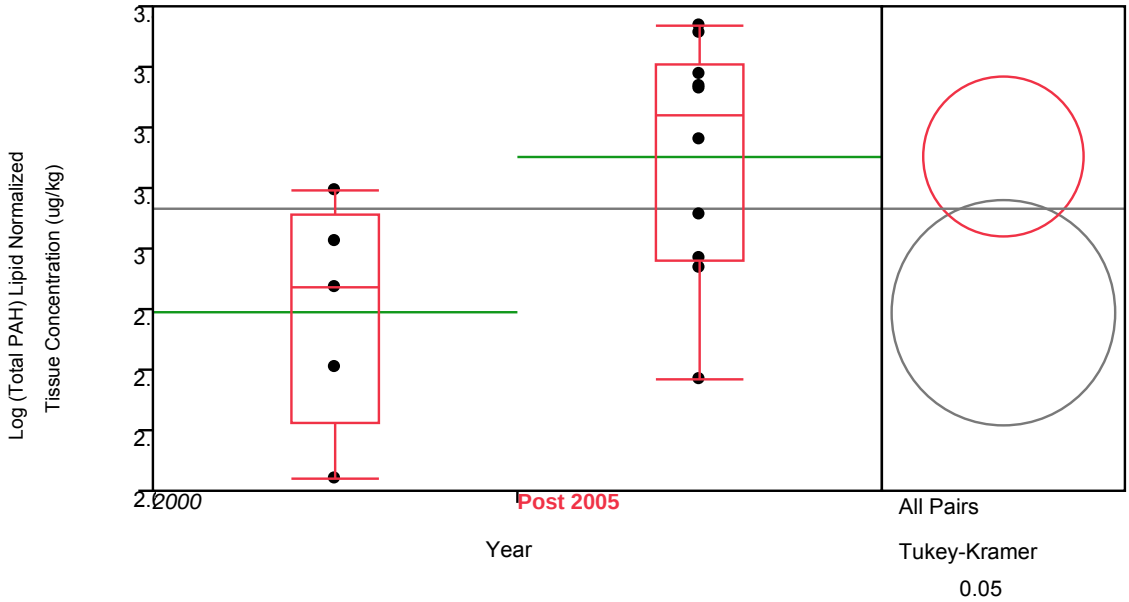
	American Eel Total DDx and Low Molecular Weight PAH *vs*. Year *Lower Eight Miles of the Lower Passaic River*	Figure 2-11b 2014

R2-0027640





Notes:
1. Different colored circles indicate a statistically significant difference in the mean concentrations.
2. Tissue type: whole body



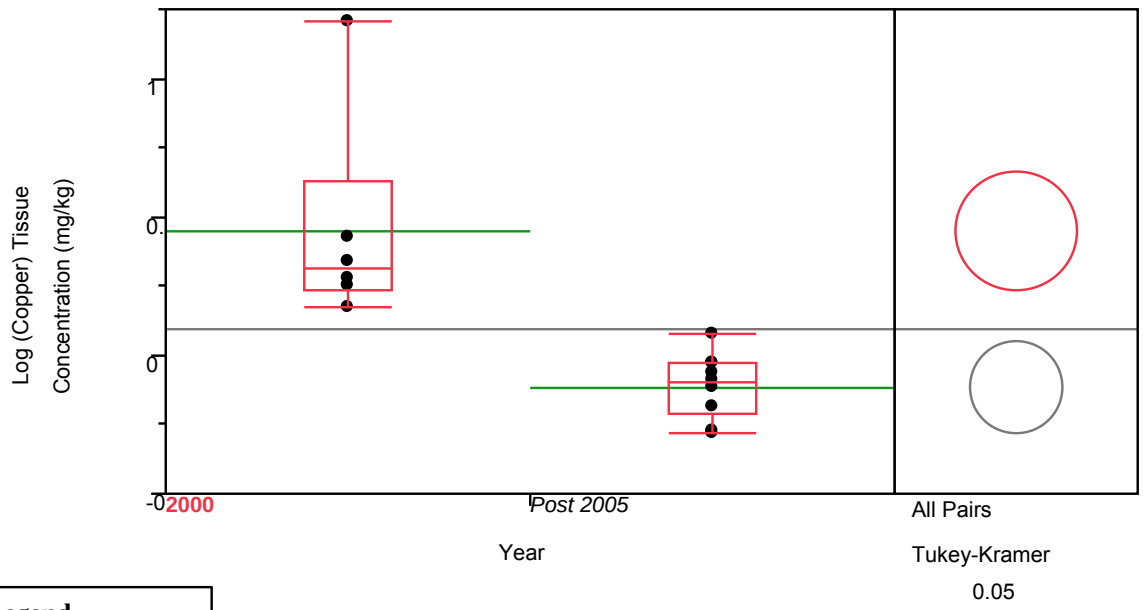
American Eel High Molecular Weight PAH and Total PAH *vs*. Year

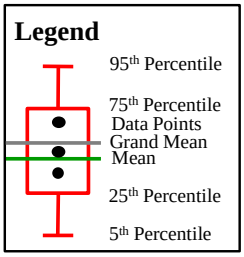
Lower Eight Miles of the Lower Passaic River

Figure 2-11c

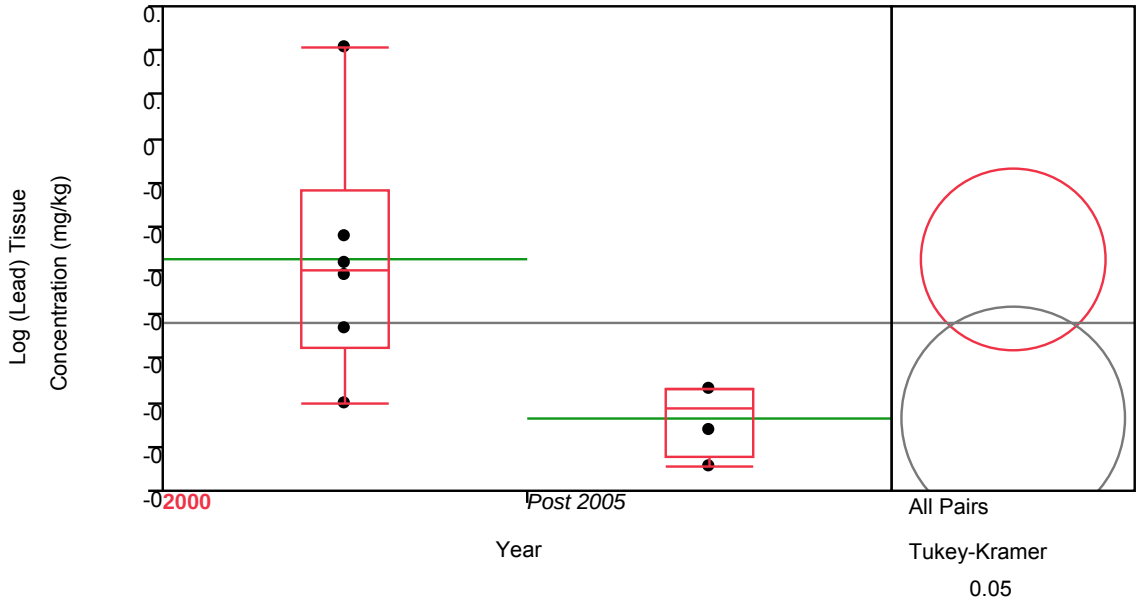
2014

R2-0027641





Notes:
1. Different colored circles indicate a statistically significant difference in the mean concentrations.
2. Tissue type: whole body



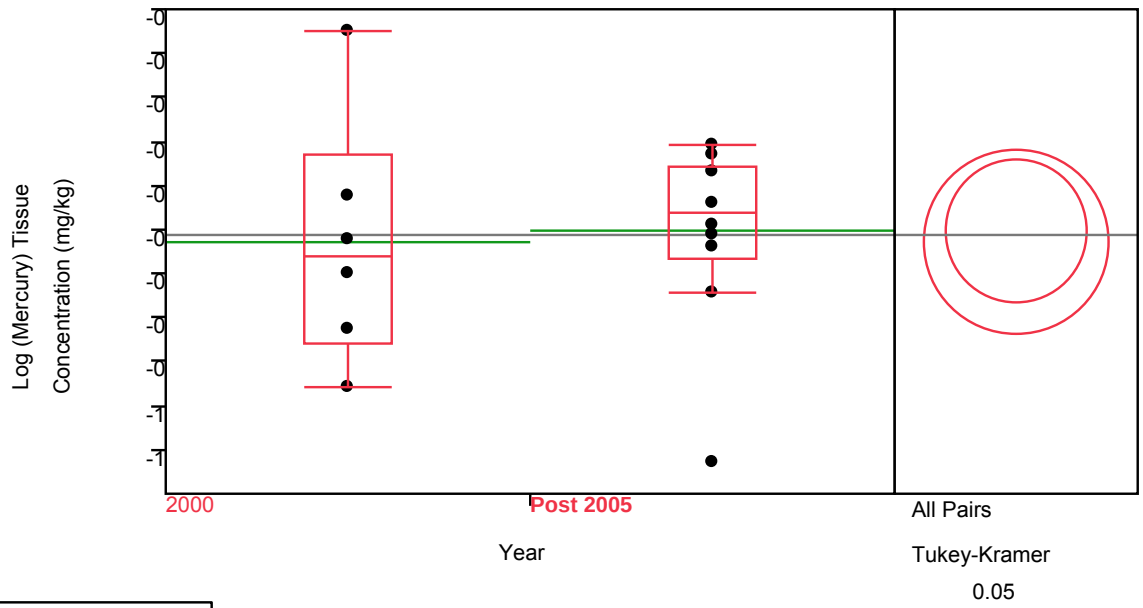
American Eel Copper and Lead *vs.* Year

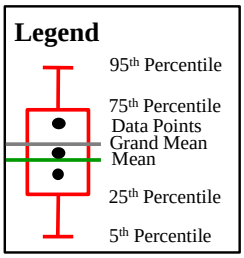
Lower Eight Miles of the Lower Passaic River

Figure 2-11d

2014

R2-0027642

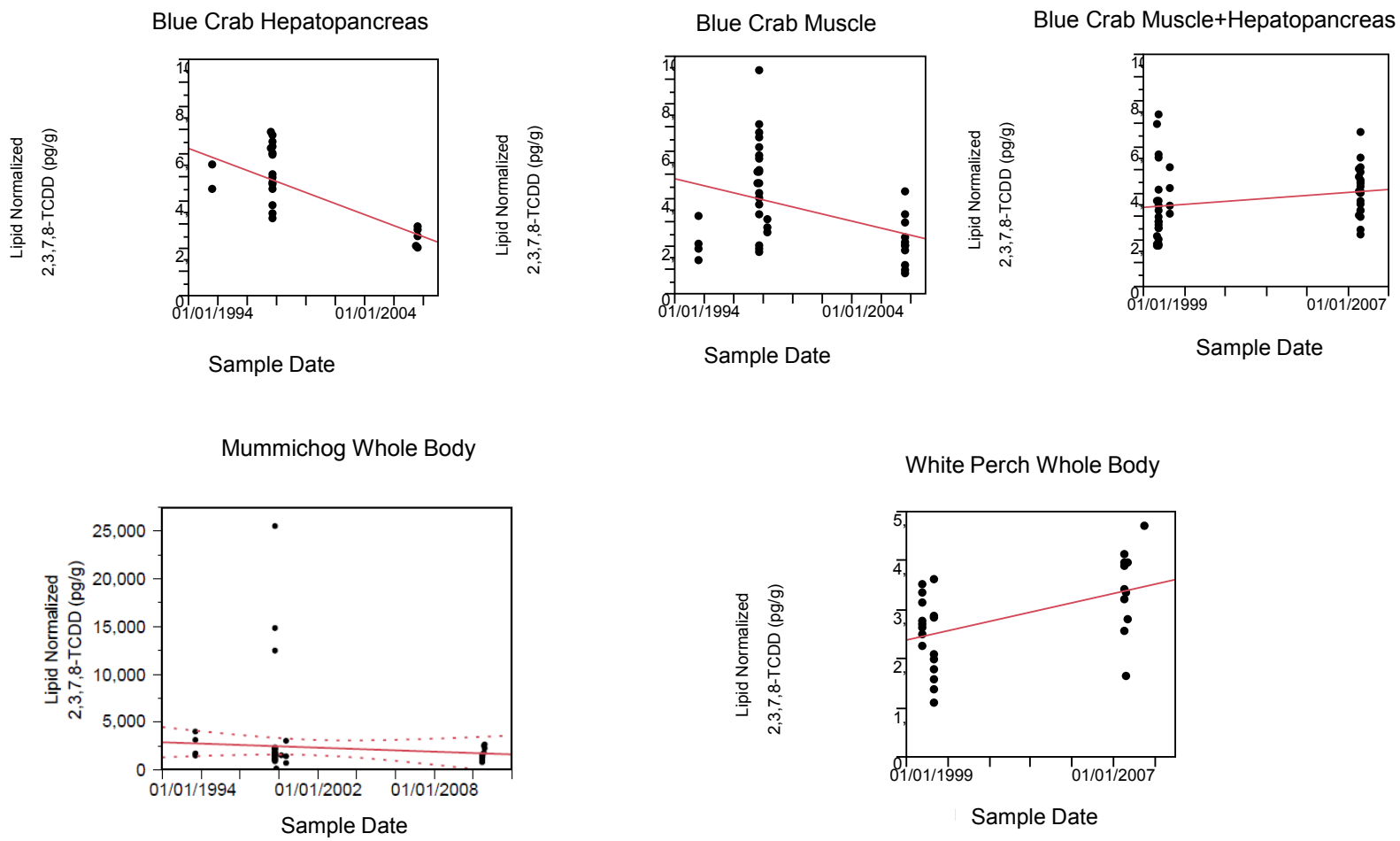




Notes:
1. Different colored circles indicate a statistically significant difference in the mean concentrations.
2. Tissue type: whole body

	American Eel Mercury *vs.* Year *Lower Eight Miles of the Lower Passaic River*	Figure 2-11e 2014

R2-0027643



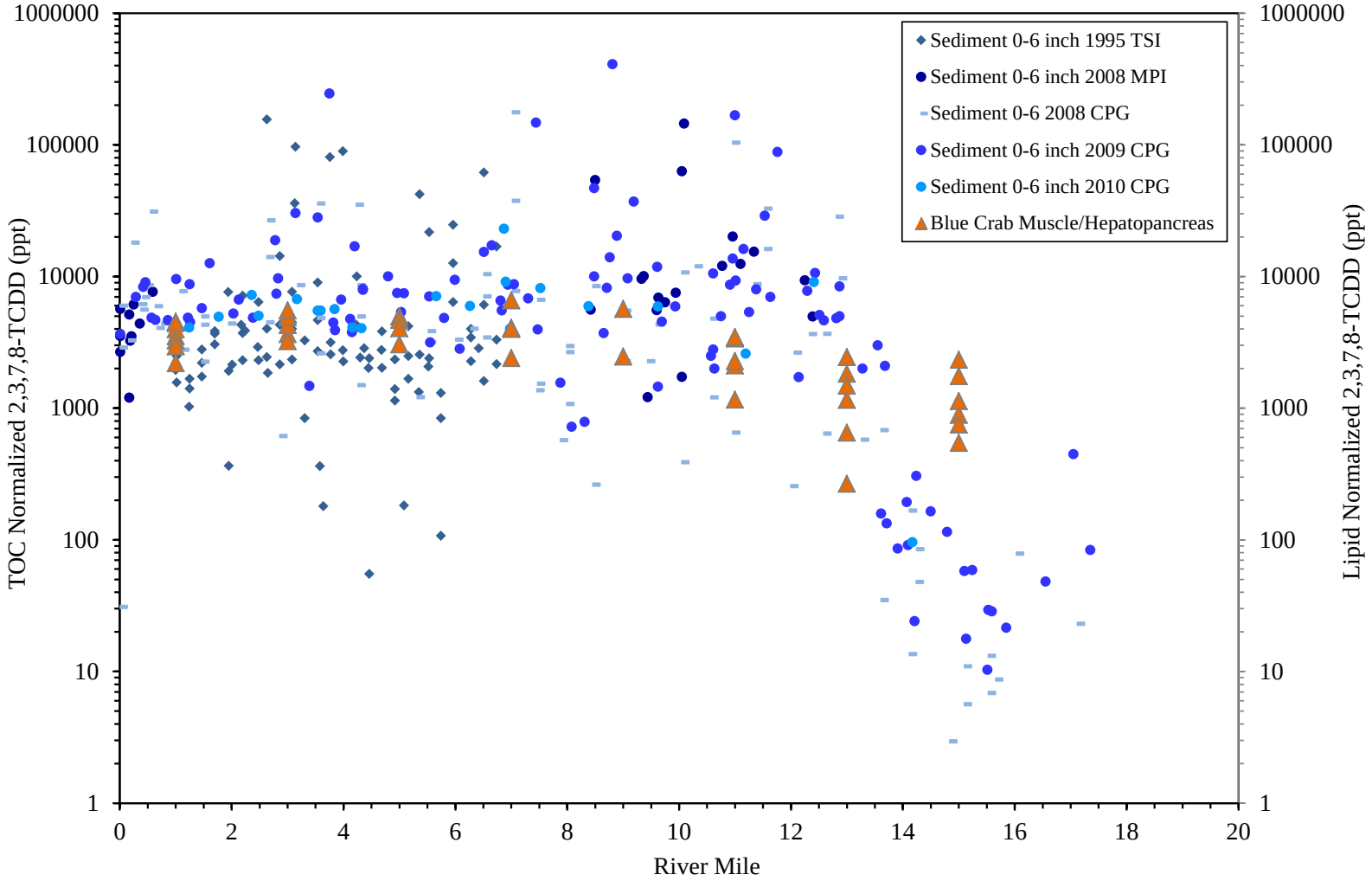
Lipid Normalized 2,3,7,8-TCDD Tissue Concentration *vs.* Time

Lower Eight Miles of the Lower Passaic River

Figure 2-12

2014

R2-0027644



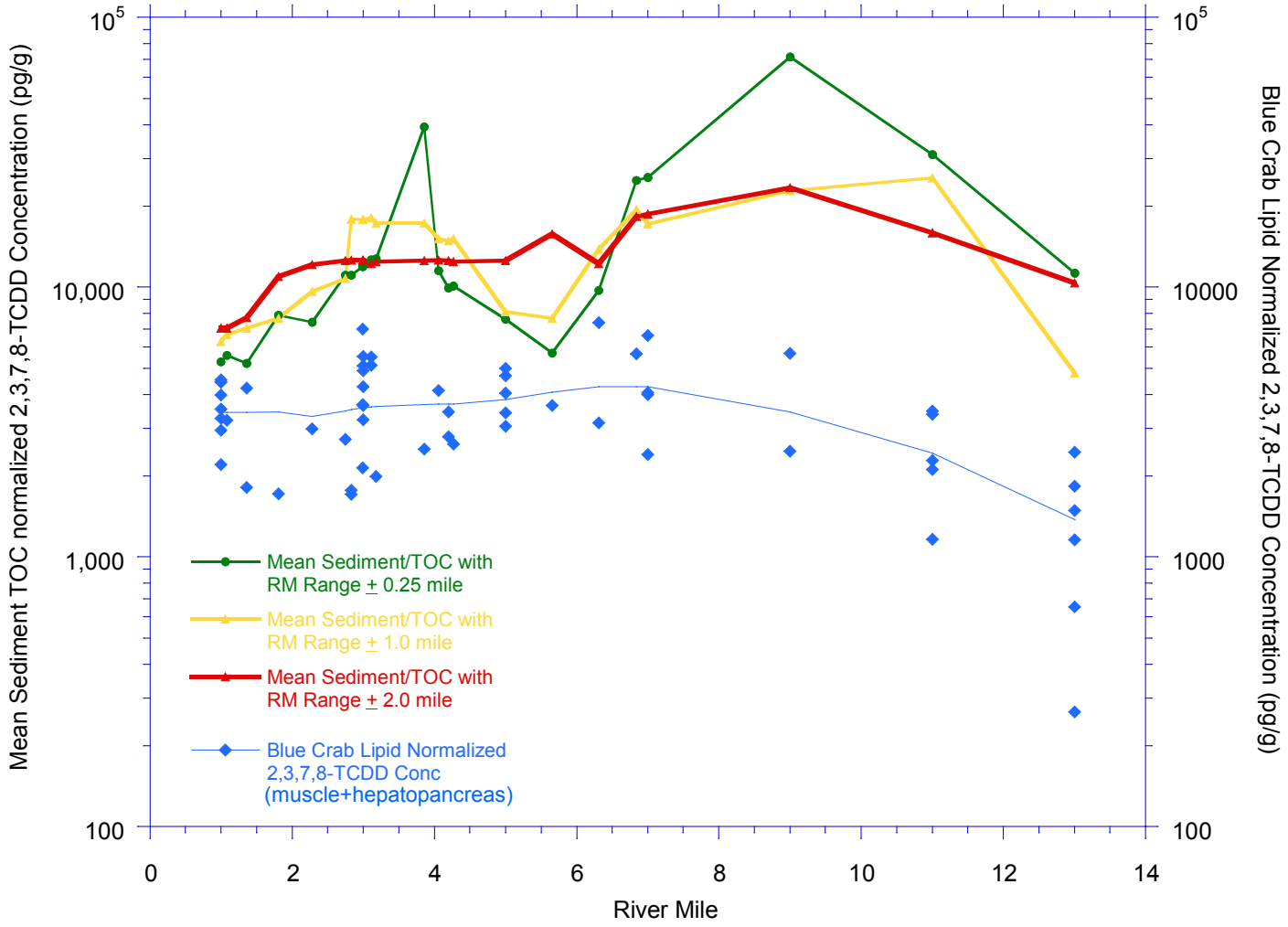
TOC-Normalized 2,3,7,8-TCDD Concentration in Sediment and Lipid-Normalized 2,3,7,8-TCDD Concentration in Blue Crab *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 3-2

2014

R2-0027645



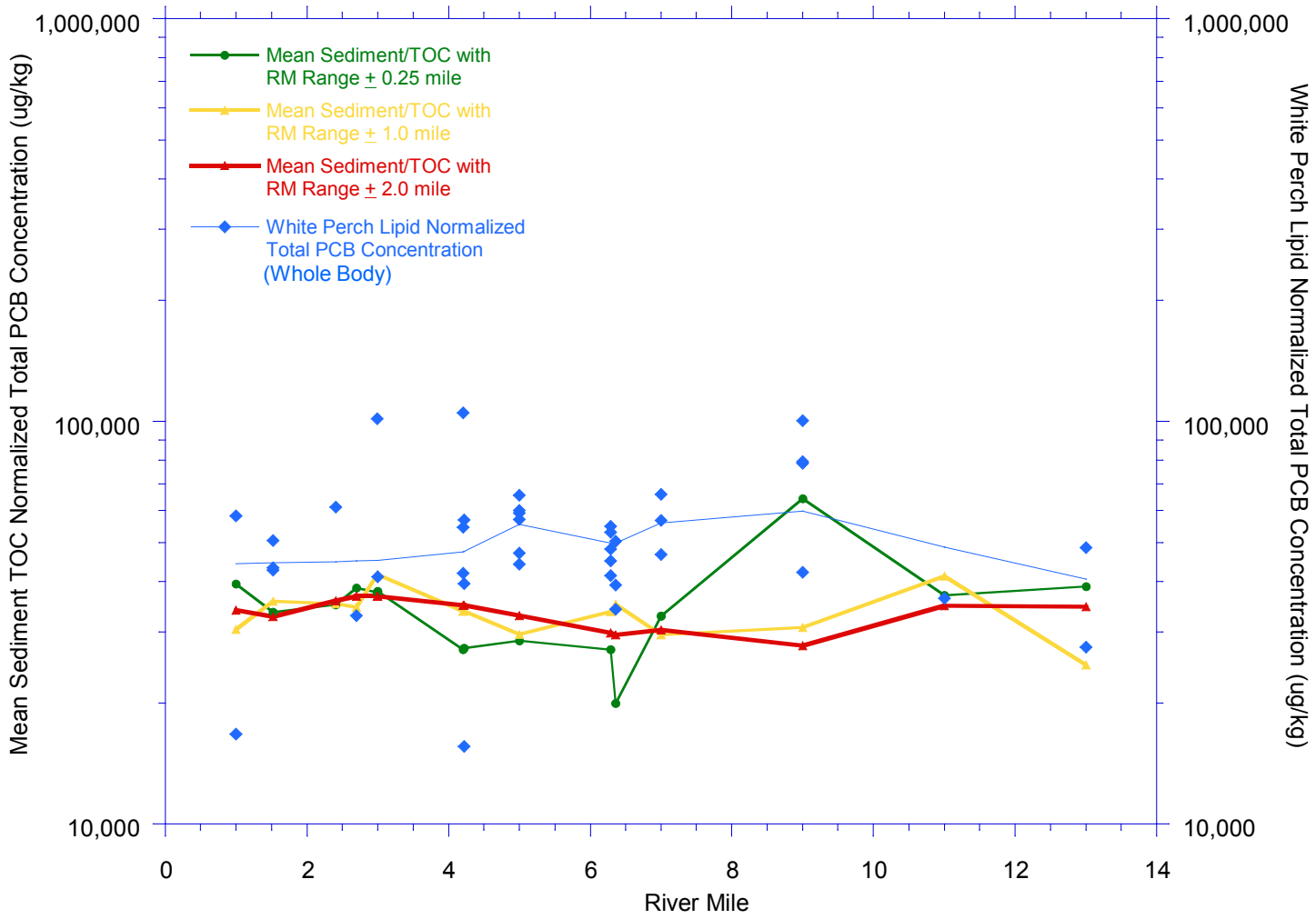
Mean TOC-Normalized 2,3,7,8-TCDD Concentration in Sediment and Mean Lipid-Normalized 2,3,7,8-TCDD Concentration in Blue Crab *vs.* River Mile

Lower Eight Miles of the Lower Passaic River

Figure 3-3

2014

R2-0027646



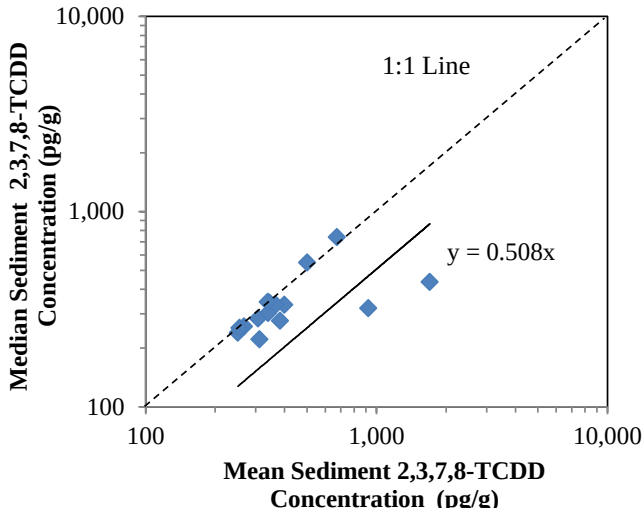
Mean TOC-Normalized Total PCB Concentration in Sediment and Mean Lipid-Normalized Total PCB Concentration in White Perch *vs.* River Mile

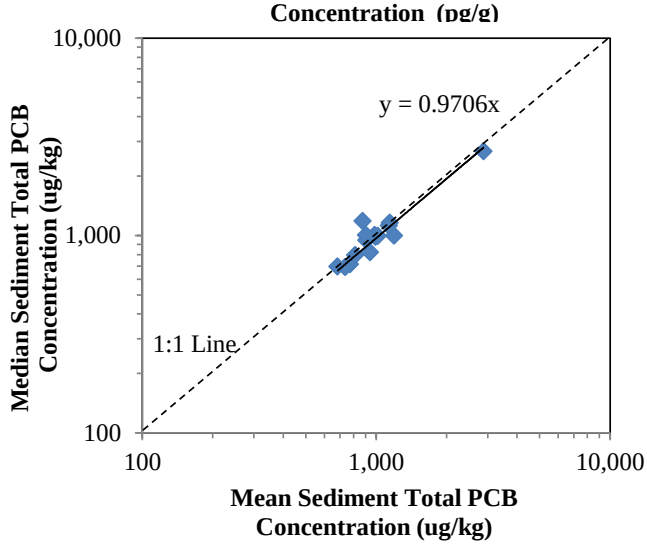
Lower Eight Miles of the Lower Passaic River

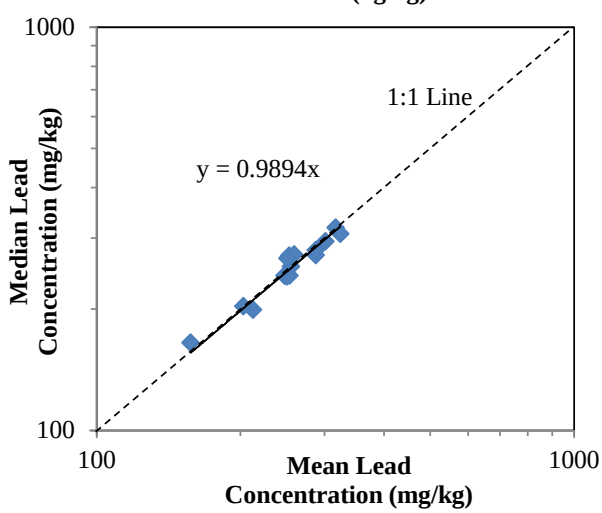
Figure 3-4

2014

R2-0027647

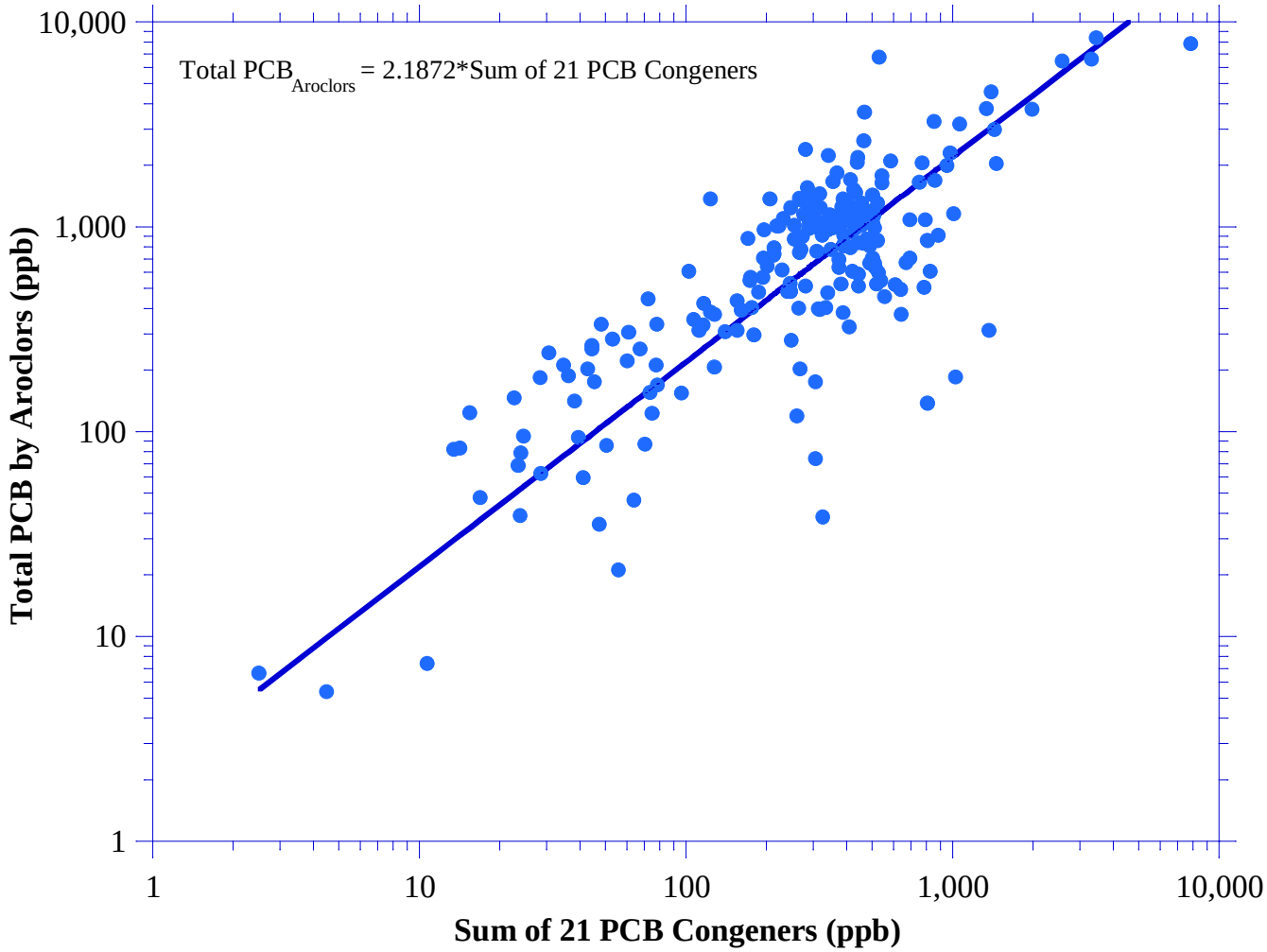






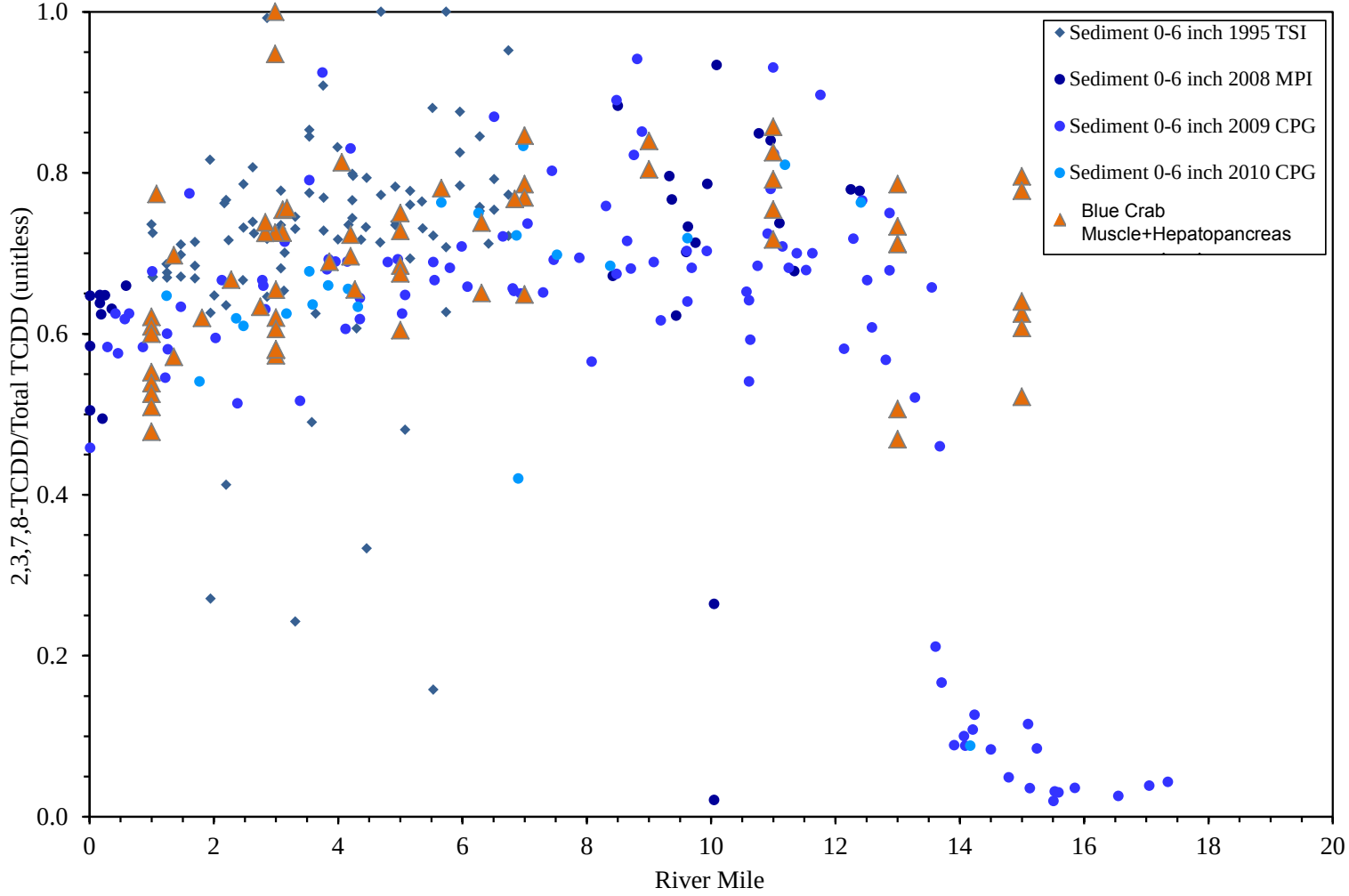
	Mean and Median Contaminant Concentration Comparison at 1999 Mummichog Sampling Stations *Lower Eight Miles of the Lower Passaic River*	Figure 3-5 2014

R2-0027648



	Comparison of Paired 21 PCB Congeners Sum and Total Aroclors Analytical Results *Lower Eight Miles of the Lower Passaic River*	Figure 3-6 2014

R2-0027649



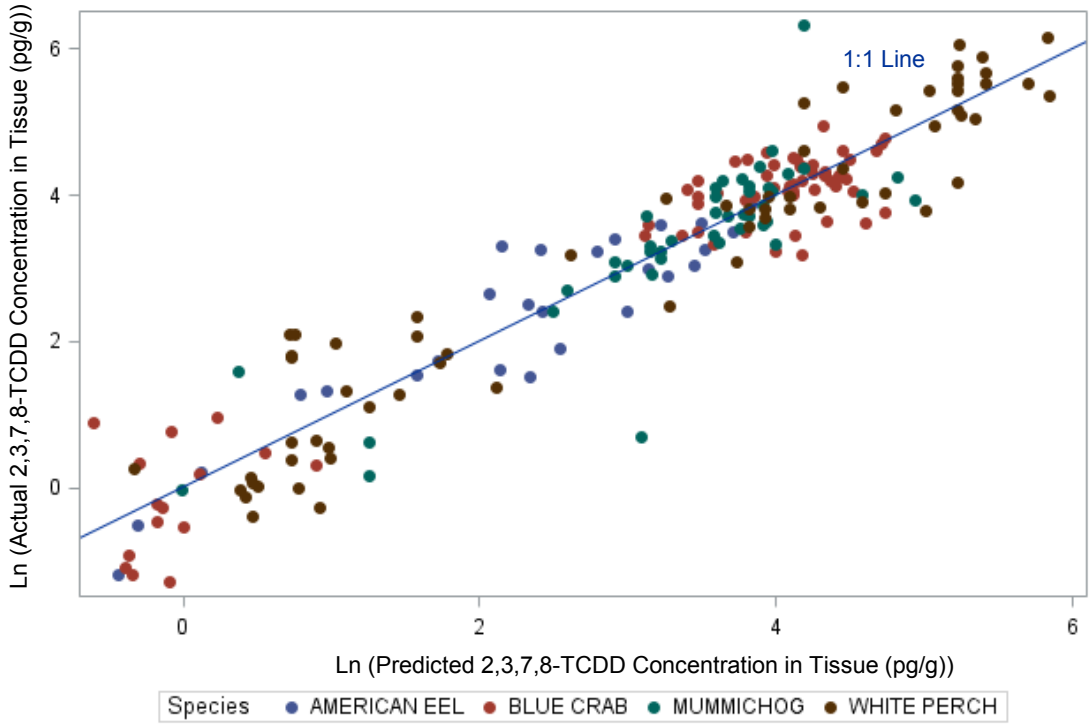
Ratio of 2,3,7,8-TCDD/Total TCDD in Blue Crab and 0-6 inch Sediment vs. River Mile

Lower Eight Miles of the Lower Passaic River

Figure 3-7

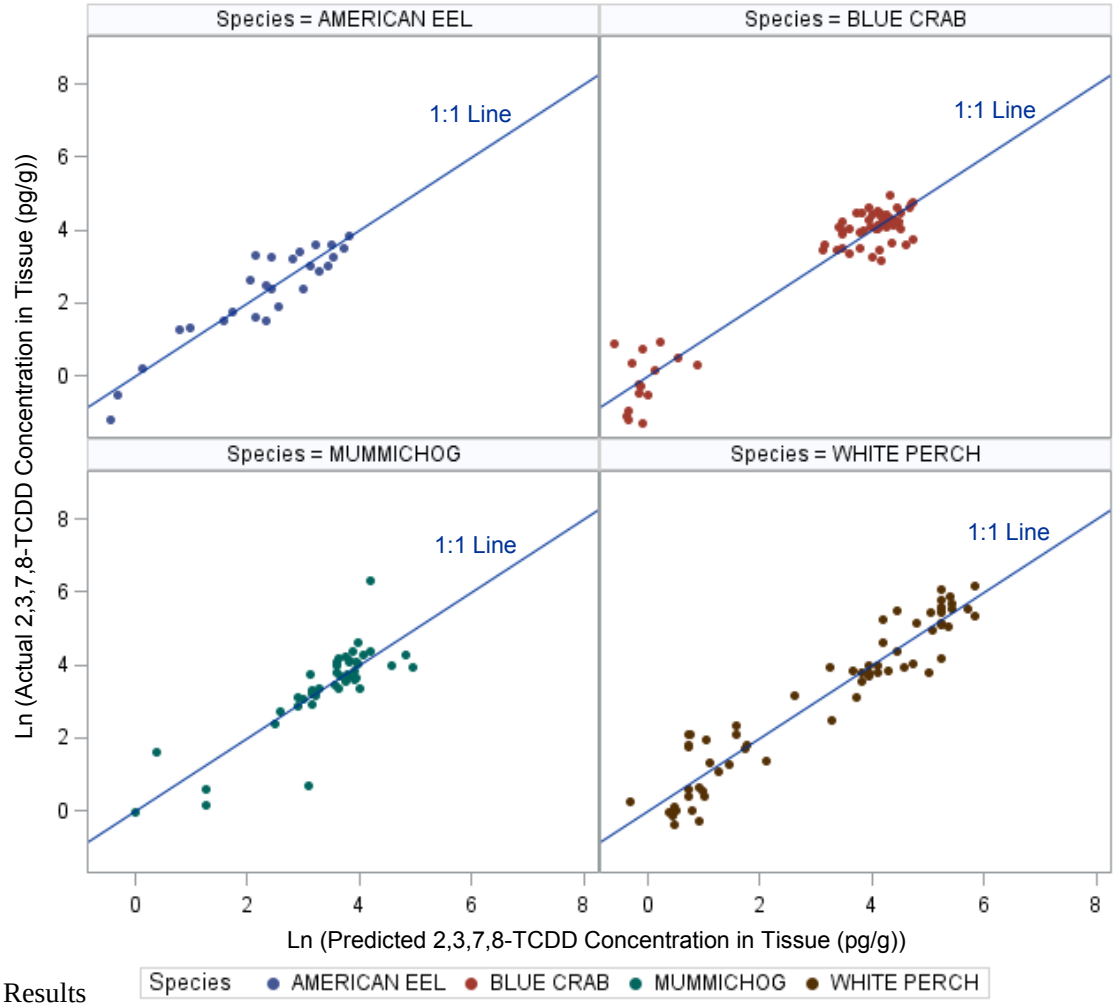
2014

R2-0027650



Regression Model Results

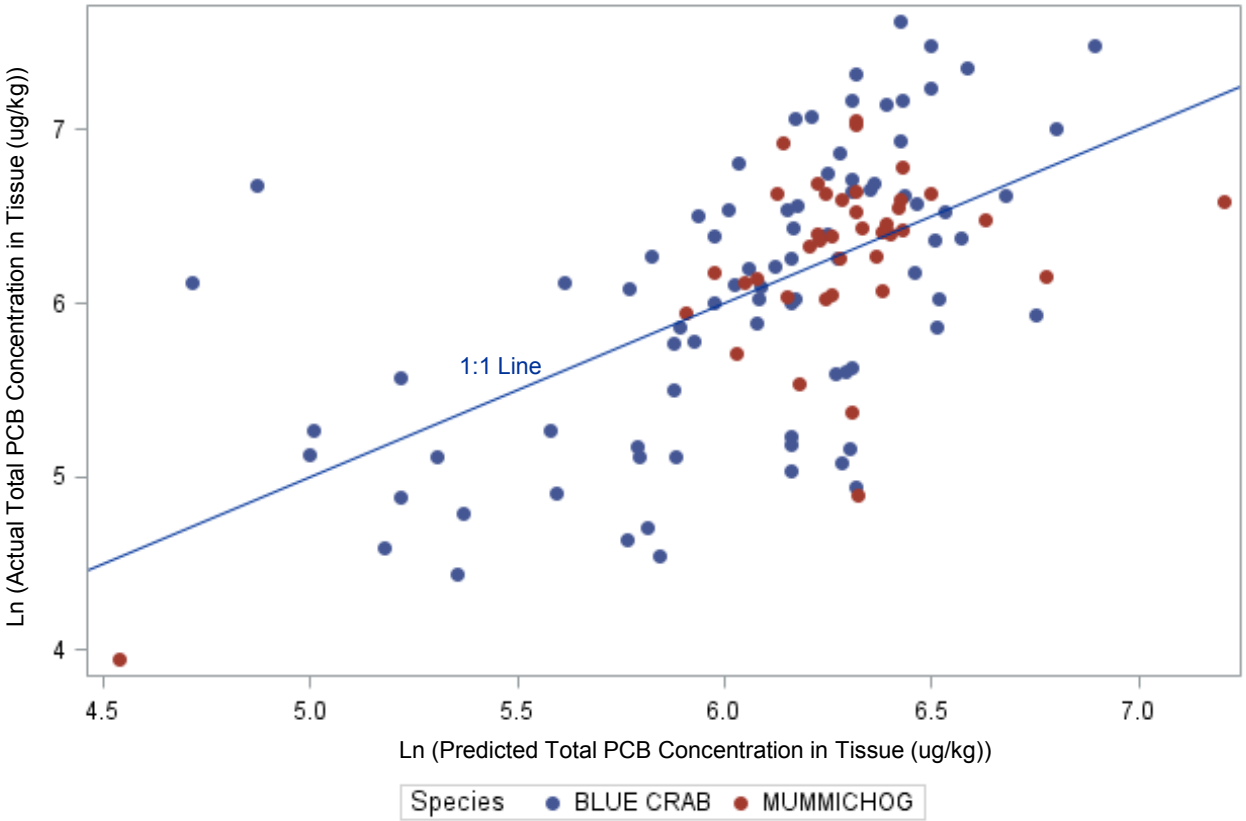
	Actual 2,3,7,8-TCDD Concentration *vs.* Predicted 2,3,7,8-TCDD Concentration in Tissue *Lower Eight Miles of the Lower Passaic River*	Figure 3-8a 2014



Regression Model Results

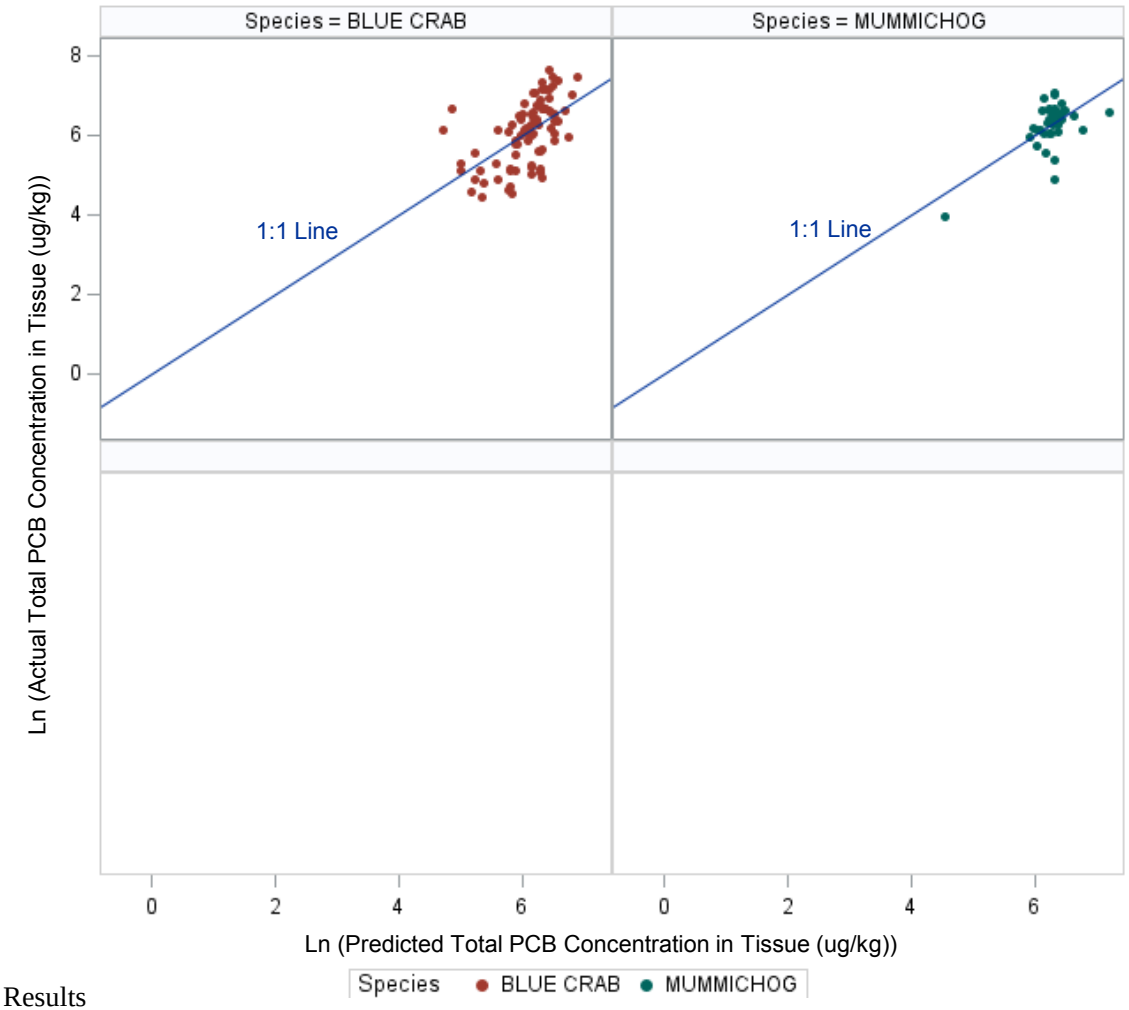
	Actual 2,3,7,8-TCDD Concentration *vs.* Predicted 2,3,7,8-TCDD Concentration in Tissue by Species *Lower Eight Miles of the Lower Passaic River*	Figure 3-8b 2014

R2-0027652



Regression Model Results

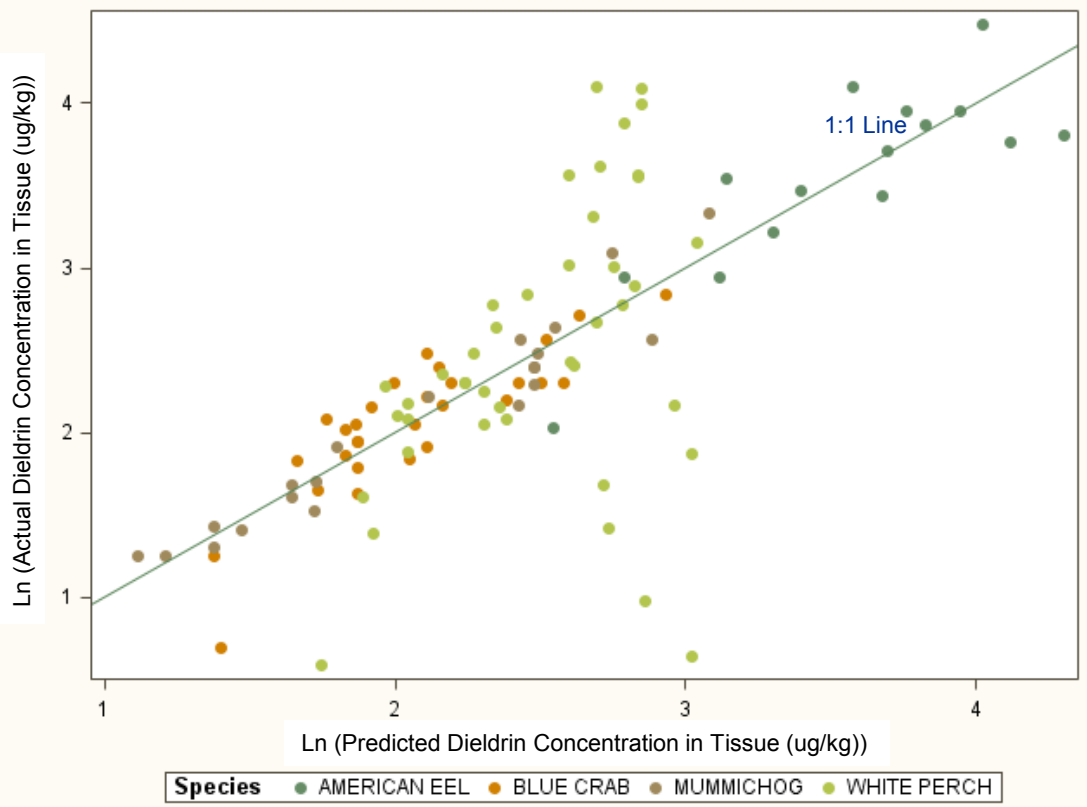
	Actual Total PCB Concentration *vs.* Predicted Total PCB Concentration in Tissue *Lower Eight Miles of the Lower Passaic River*	Figure 3-9a 2014



Regression Model Results

	Actual Total PCB Concentration *vs.* Predicted Total PCB Concentration in Tissue by Species *Lower Eight Miles of the Lower Passaic River*	Figure 3-9b 2014

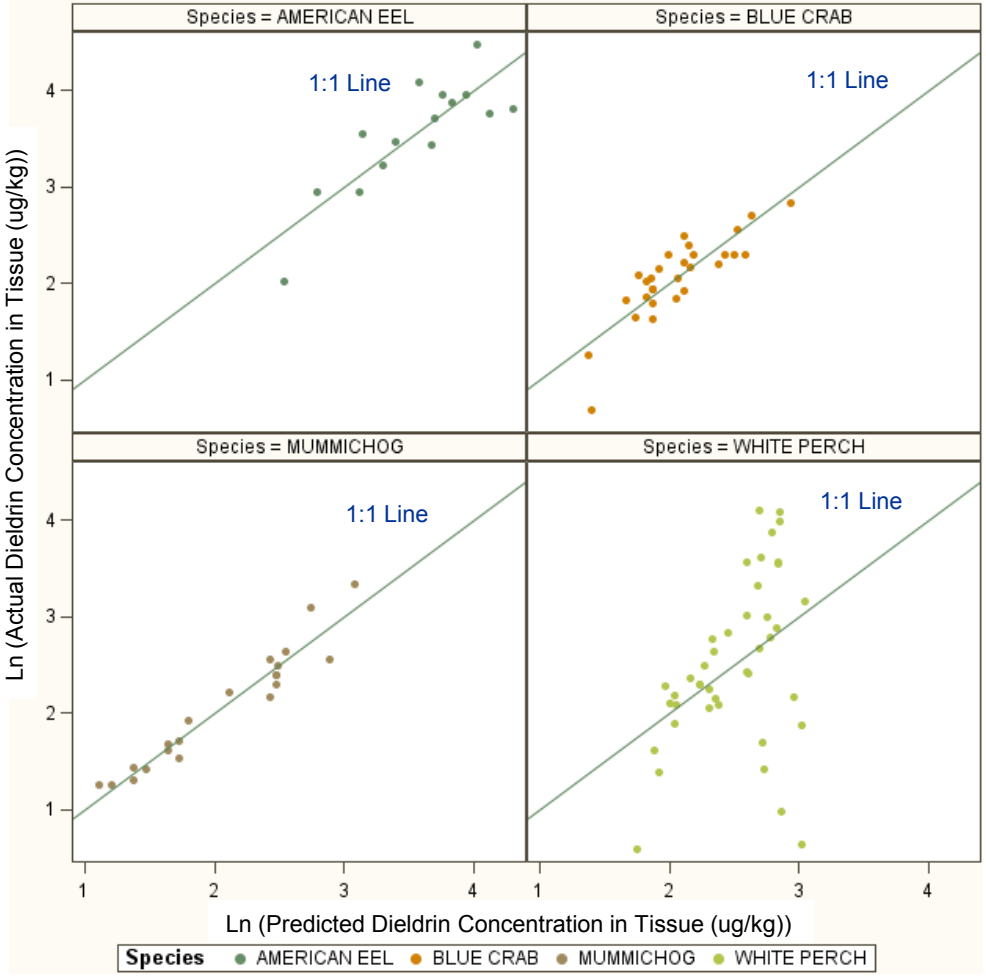
R2-0027654



Regression Model Results

	Actual Dieldrin Concentration *vs.* Predicted Dieldrin Concentration in Tissue *Lower Eight Miles of the Lower Passaic River*	Figure 3-10a 2014

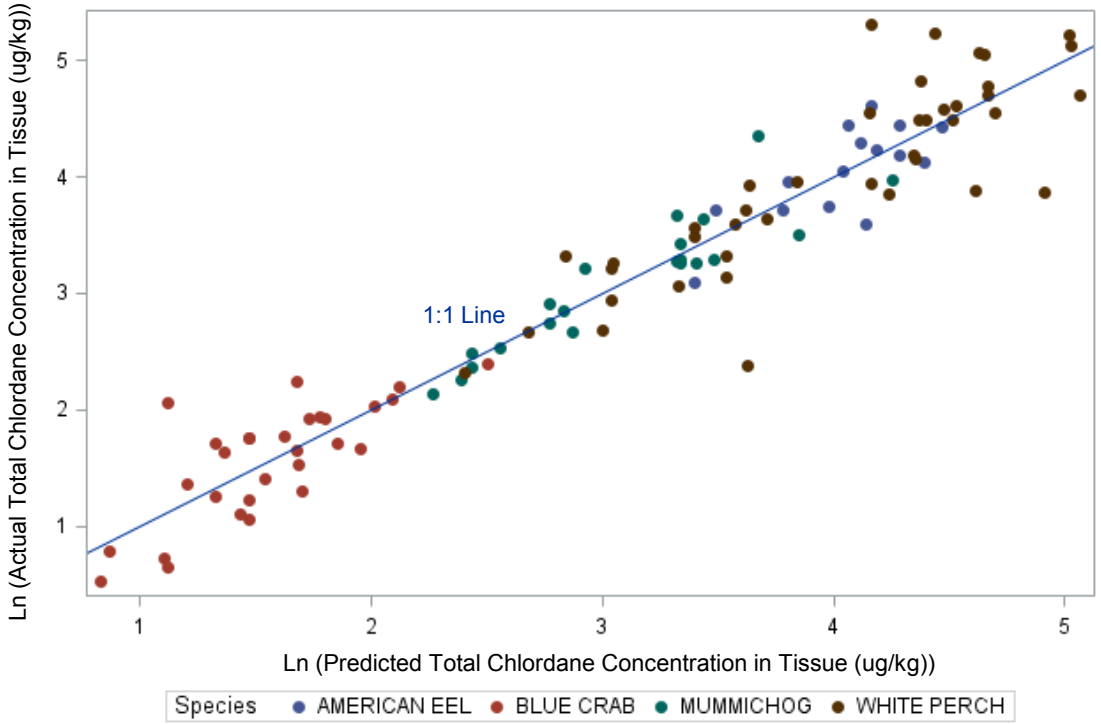
R2-0027655



Regression Model Results

	Actual Dieldrin Concentration *vs.* Predicted Dieldrin Concentration in Tissue by Species *Lower Eight Miles of the Lower Passaic River*	Figure 3-10b 2014

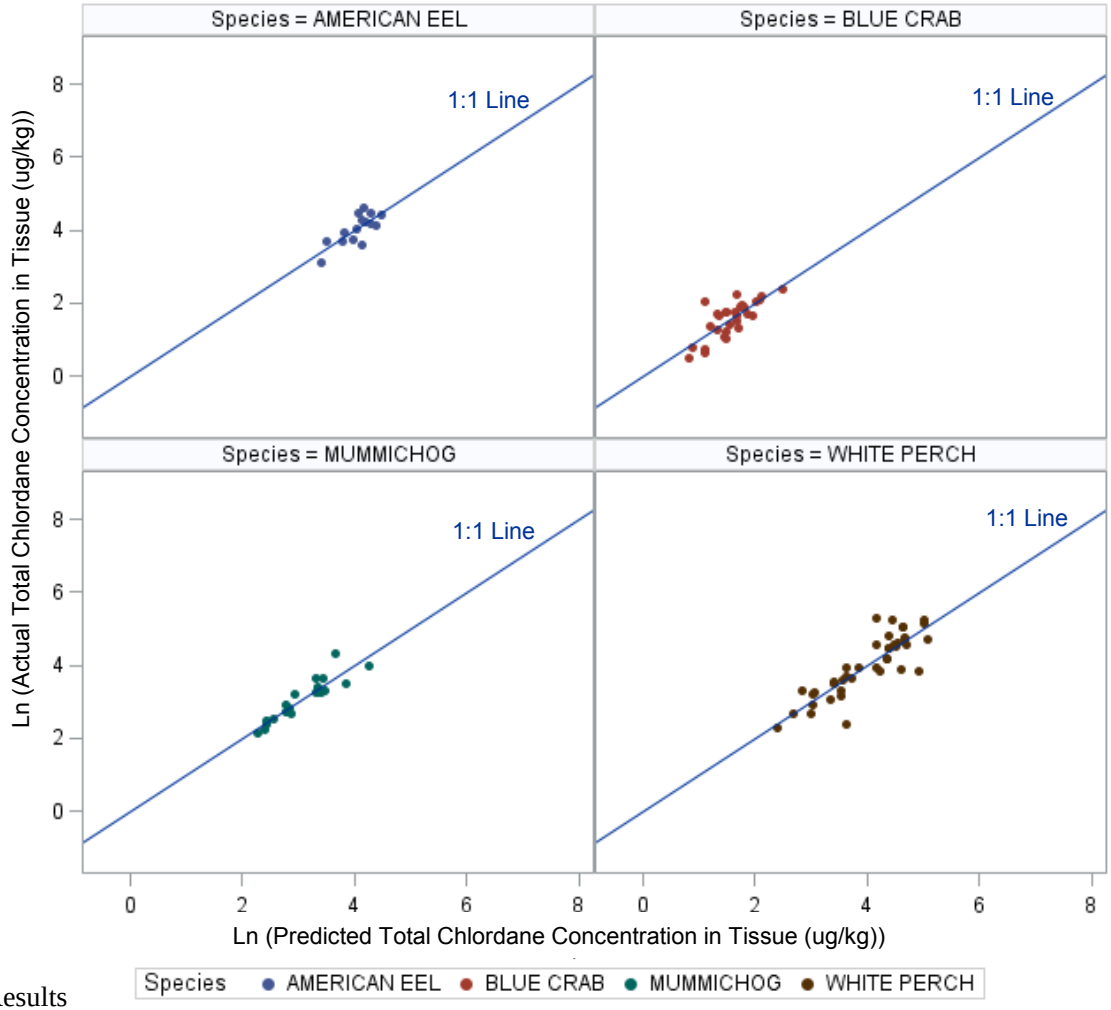
R2-0027656



Regression Model Results

	Actual Total Chlordane Concentration *vs.* Predicted Total Chlordane Concentration in Tissue *Lower Eight Miles of the Lower Passaic River*	Figure 3-11a 2014

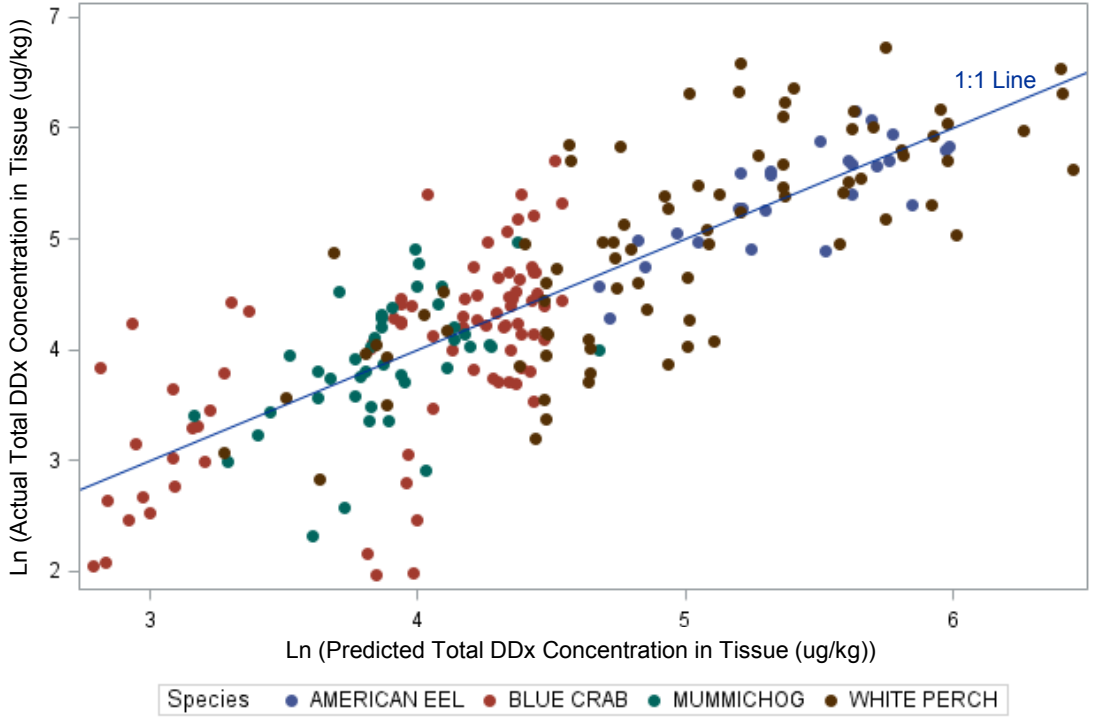
R2-0027657



Regression Model Results

	Actual Total Chlordane Concentration *vs.* Predicted Total Chlordane Concentration in Tissue by Species *Lower Eight Miles of the Lower Passaic River*	Figure 3-11b 2014

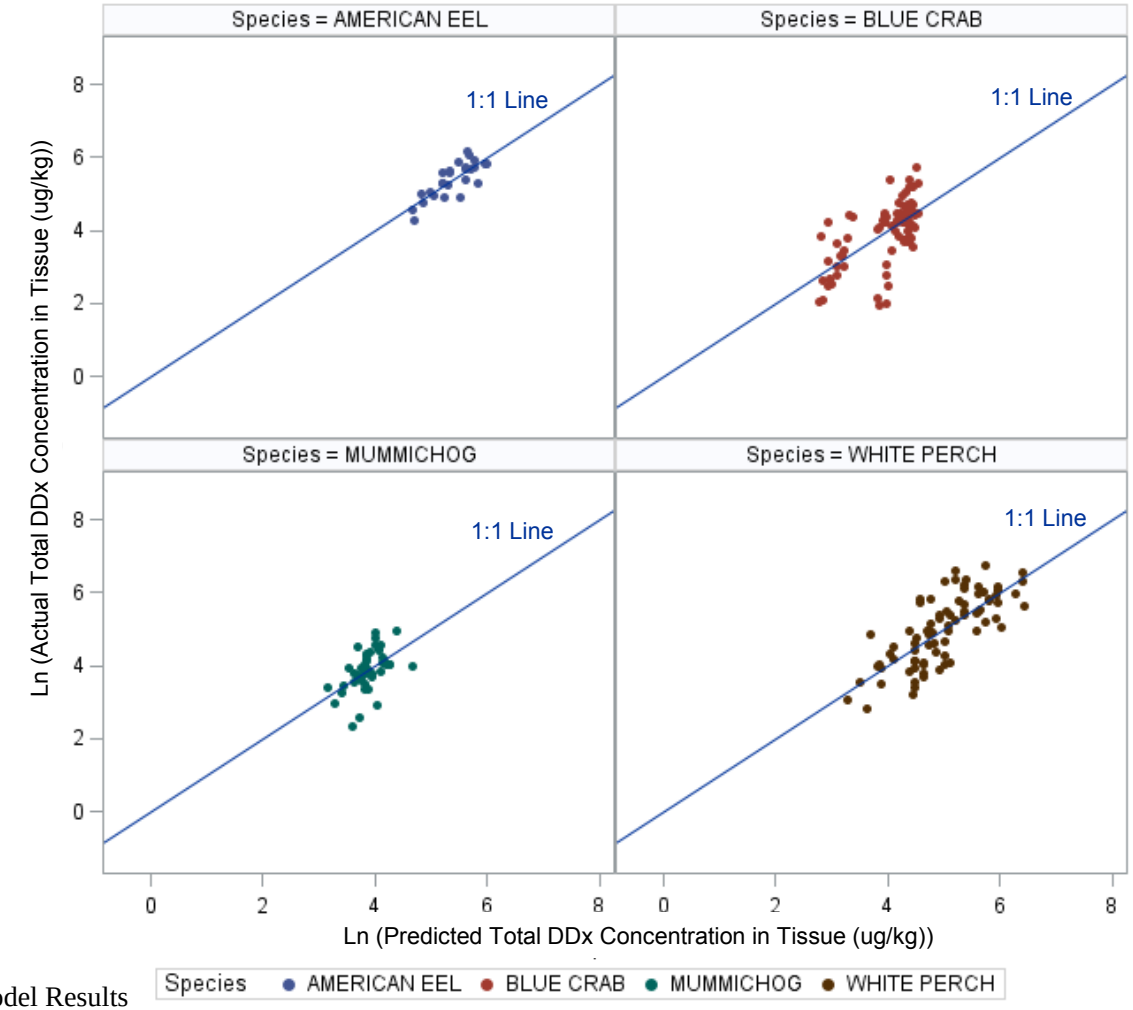
R2-0027658



Regression Model Results

	Actual Total DDx Concentration *vs.* Predicted Total DDx Concentration in Tissue *Lower Eight Miles of the Lower Passaic River*	Figure 3-12a 2014

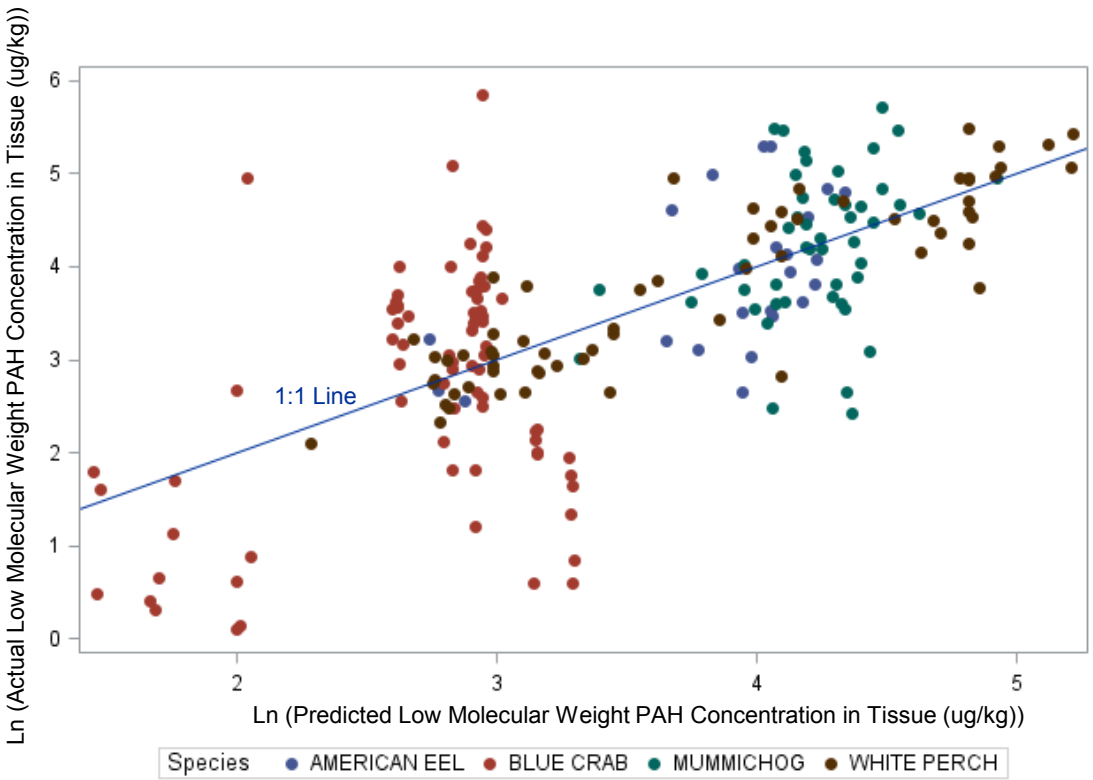
R2-0027659



Regression Model Results

	Actual Total DDx Concentration *vs.* Predicted Total DDx Concentration in Tissue by Species *Lower Eight Miles of the Lower Passaic River*	Figure 3-12b 2014

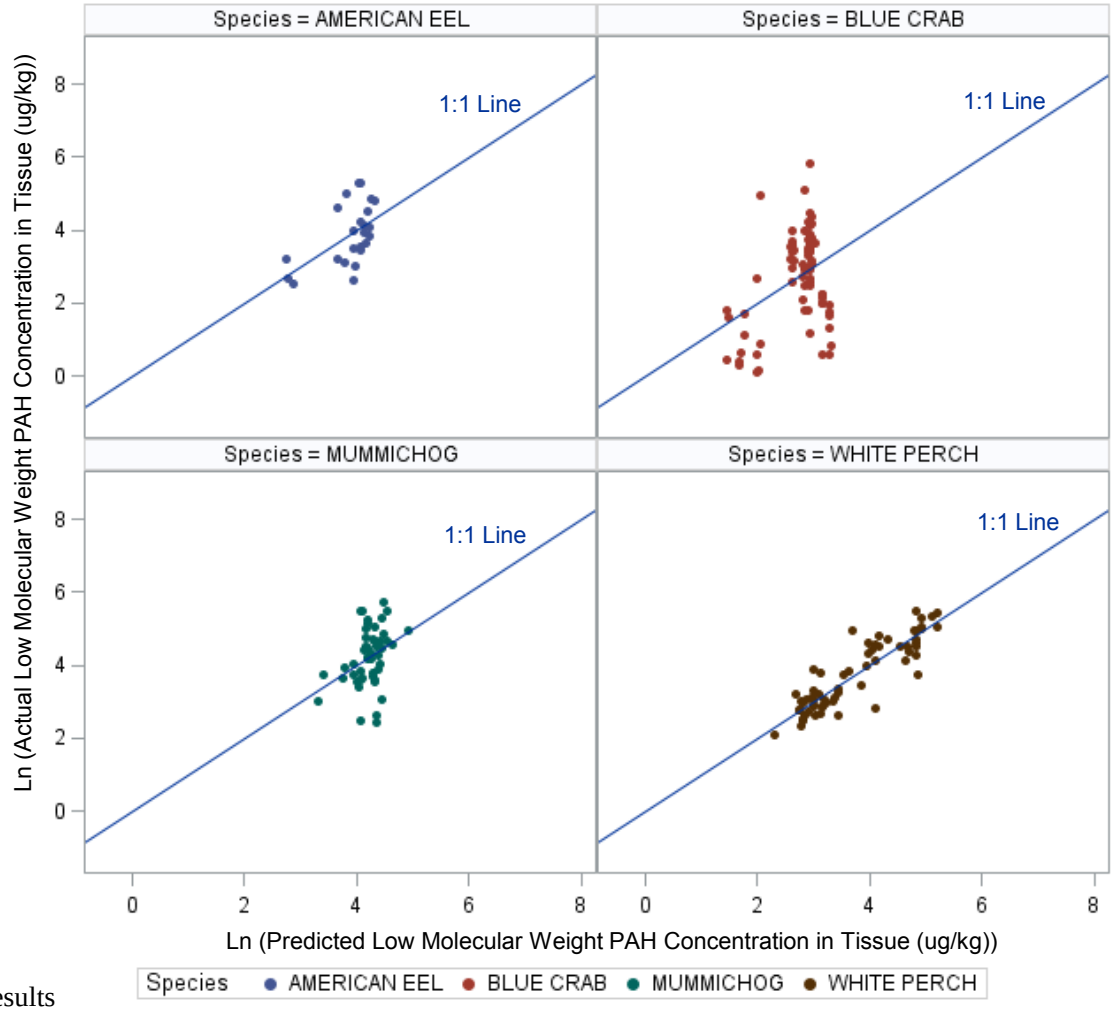
R2-0027660



Regression Model Results

	Actual Low Molecular Weight PAH Concentration *vs.* Predicted Low Molecular Weight PAH Concentration in Tissue *Lower Eight Miles of the Lower Passaic River*	Figure 3-13a 2014

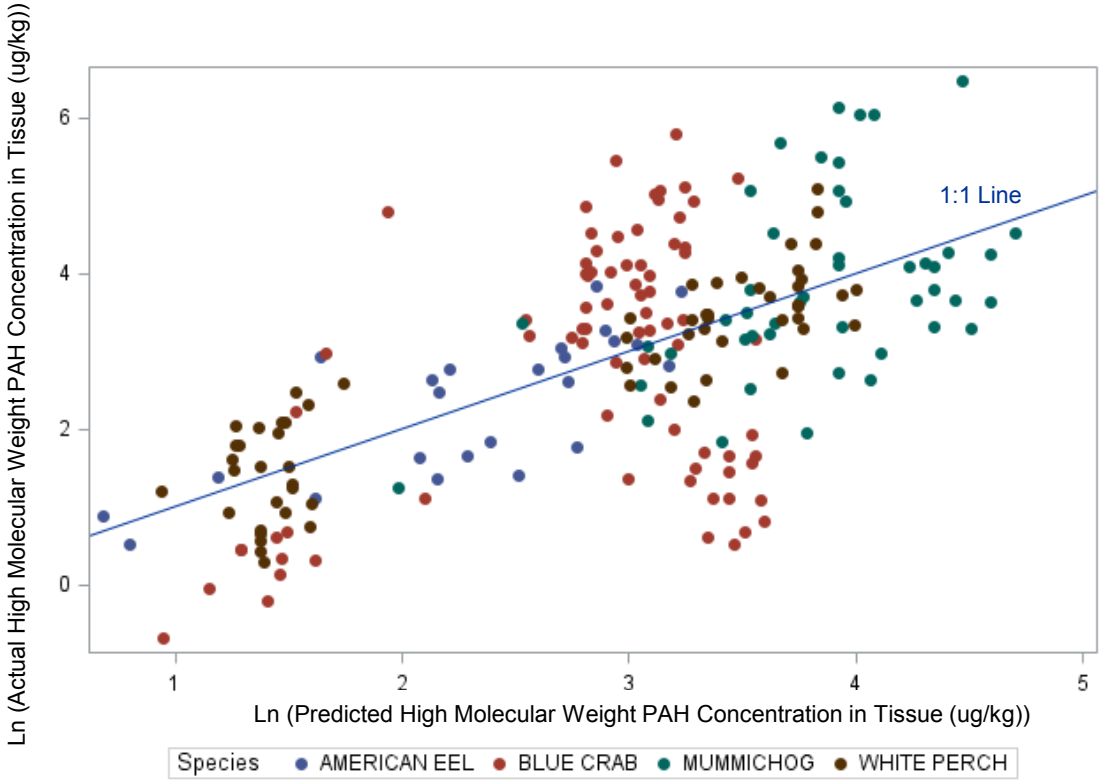
R2-0027661



Regression Model Results

	Actual Low Molecular Weight PAH Concentration *vs.* Predicted Low Molecular Weight PAH Concentration in Tissue by Species *Lower Eight Miles of the Lower Passaic River*	Figure 3-13b 2014

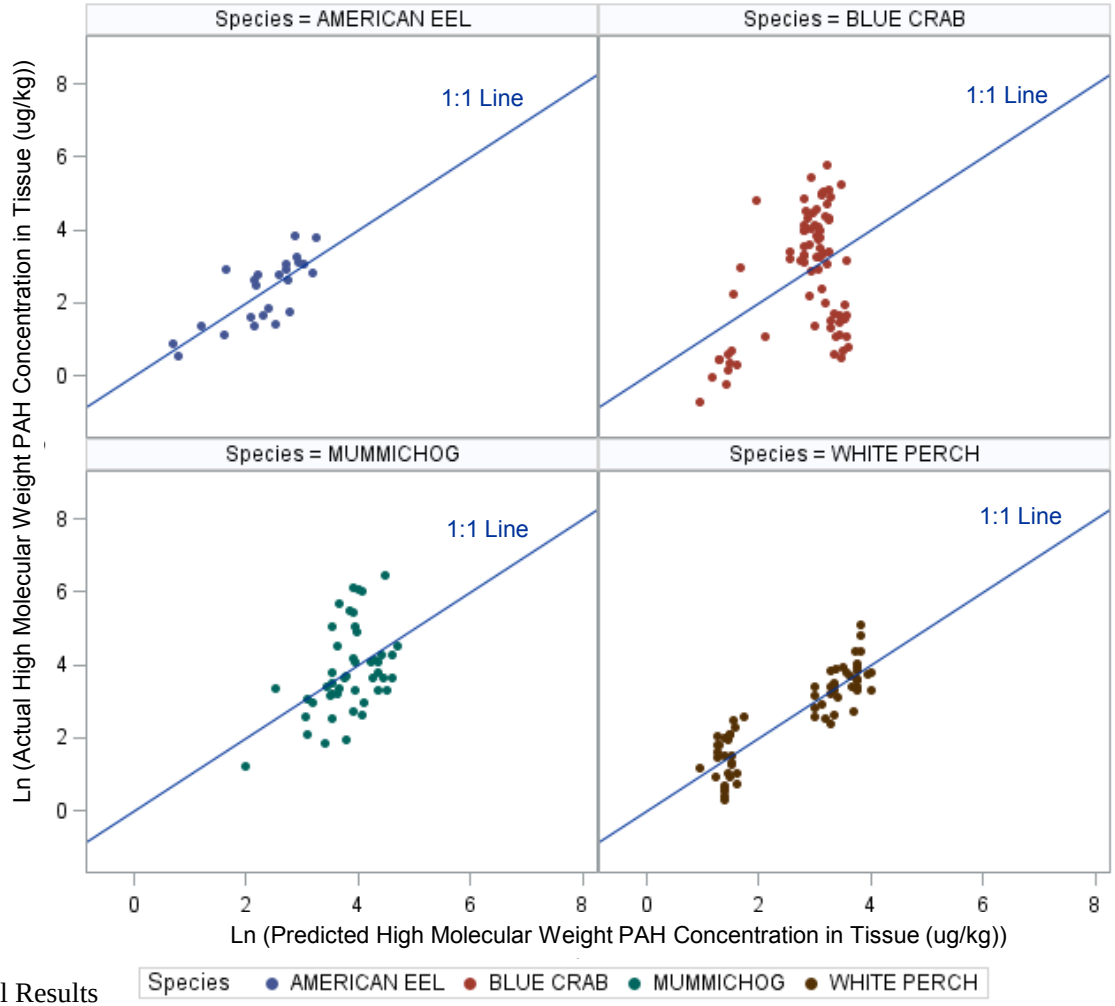
R2-0027662



Regression Model Results

	Actual High Molecular Weight PAH Concentration *vs.* Predicted High Molecular Weight PAH Concentration in Tissue *Lower Eight Miles of the Lower Passaic River*	Figure 3-14a 2014

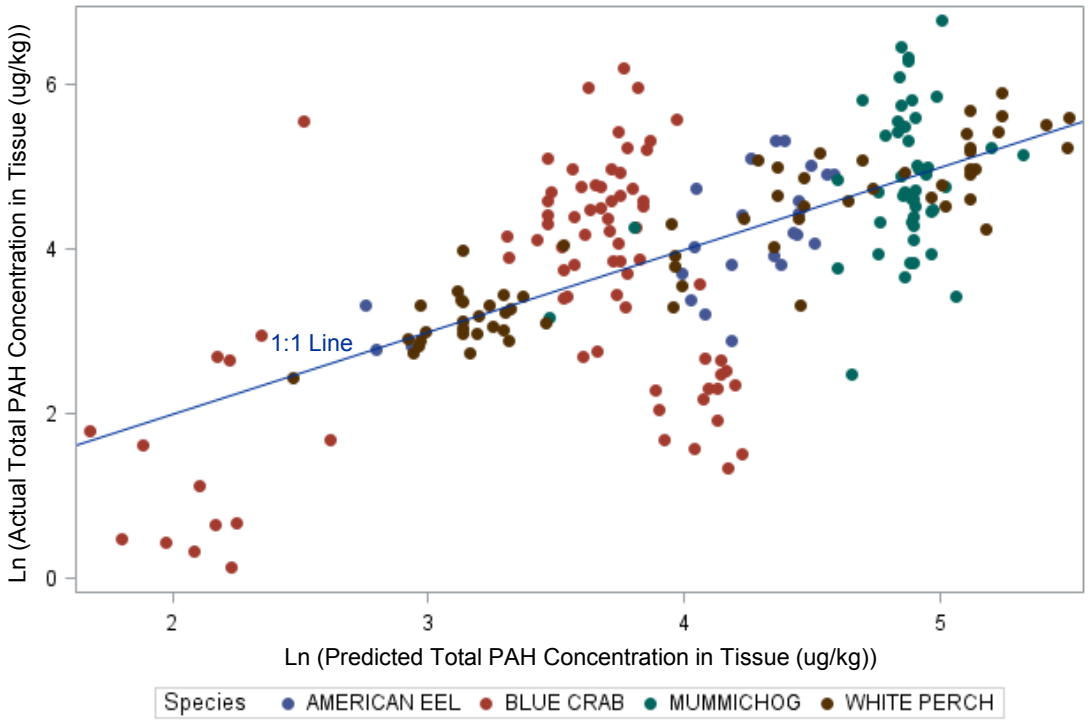
R2-0027663



Regression Model Results

	Actual High Molecular Weight PAH Concentration *vs.* Predicted High Molecular Weight PAH Concentration in Tissue by Species *Lower Eight Miles of the Lower Passaic River*	Figure 3-14b 2014

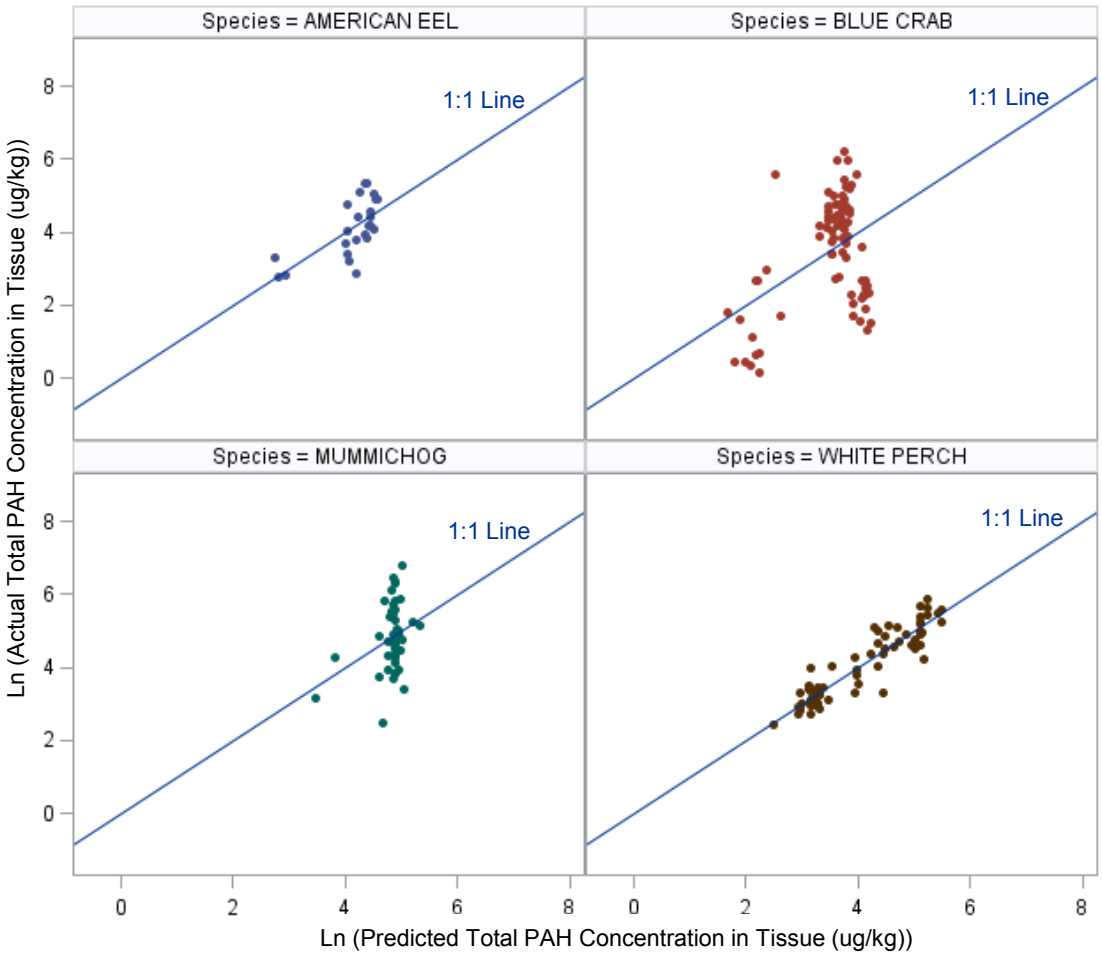
R2-0027664



Regression Model Results

	Actual Total PAH Concentration *vs.* Predicted Total PAH Concentration in Tissue *Lower Eight Miles of the Lower Passaic River*	Figure 3-15a 2014

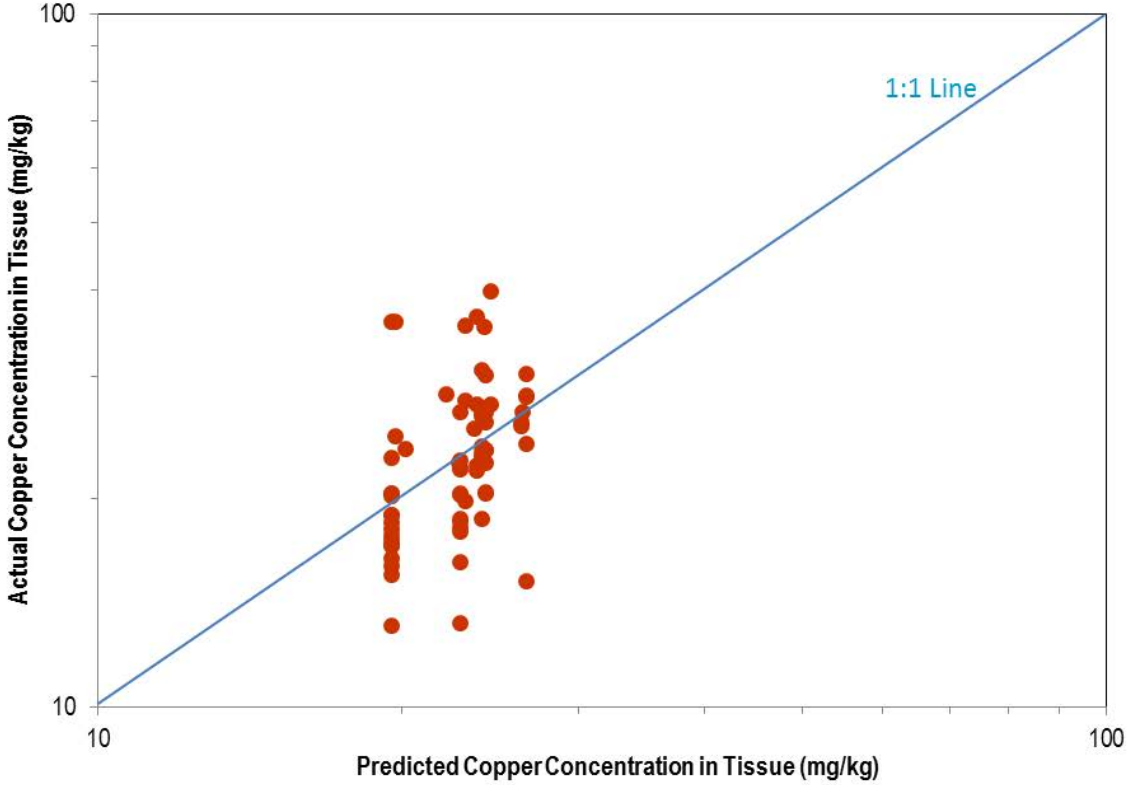
R2-0027665



Regression Model Results

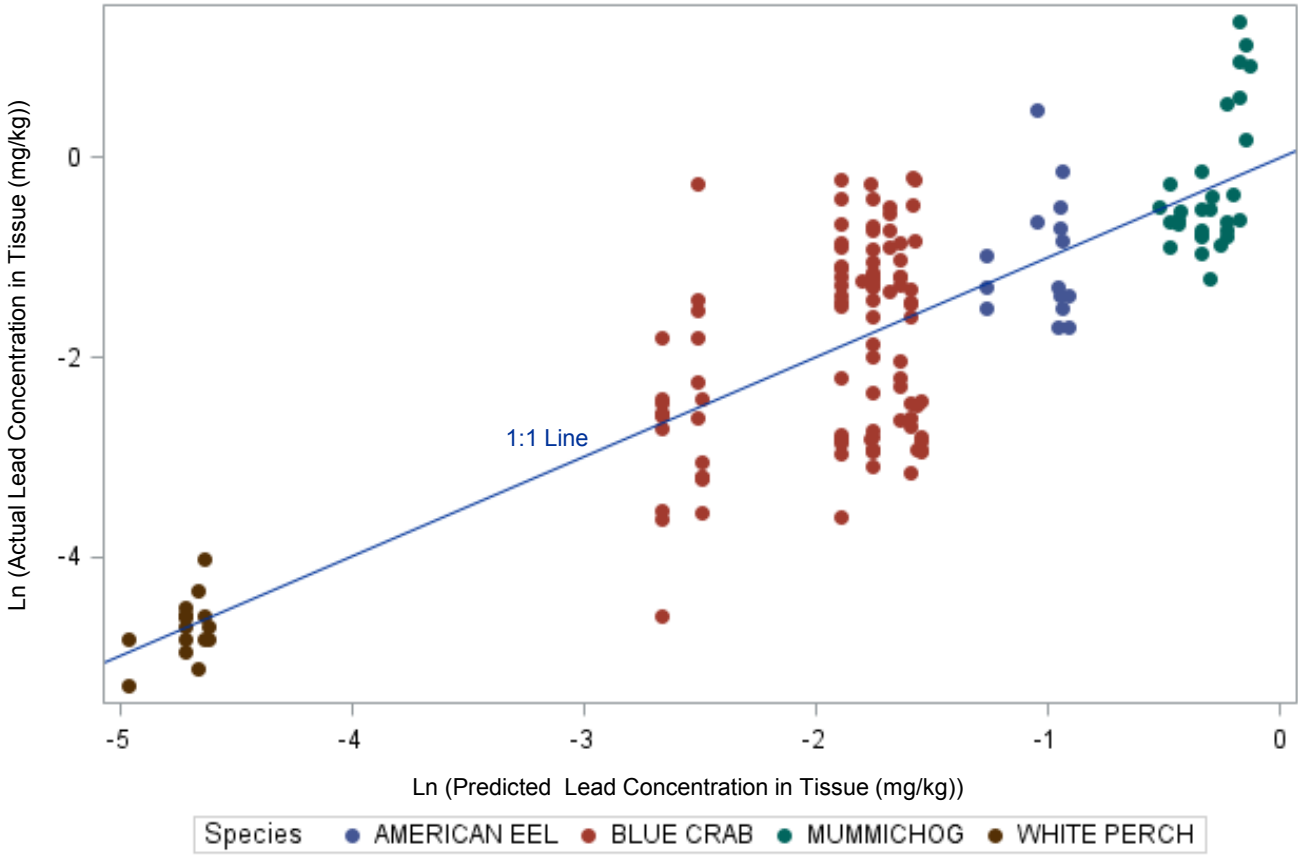
	Actual Total PAH Concentration *vs.* Predicted Total PAH Concentration in Tissue by Species *Lower Eight Miles of the Lower Passaic River*	Figure 3-15b 2014

R2-0027666



Regression Model Results

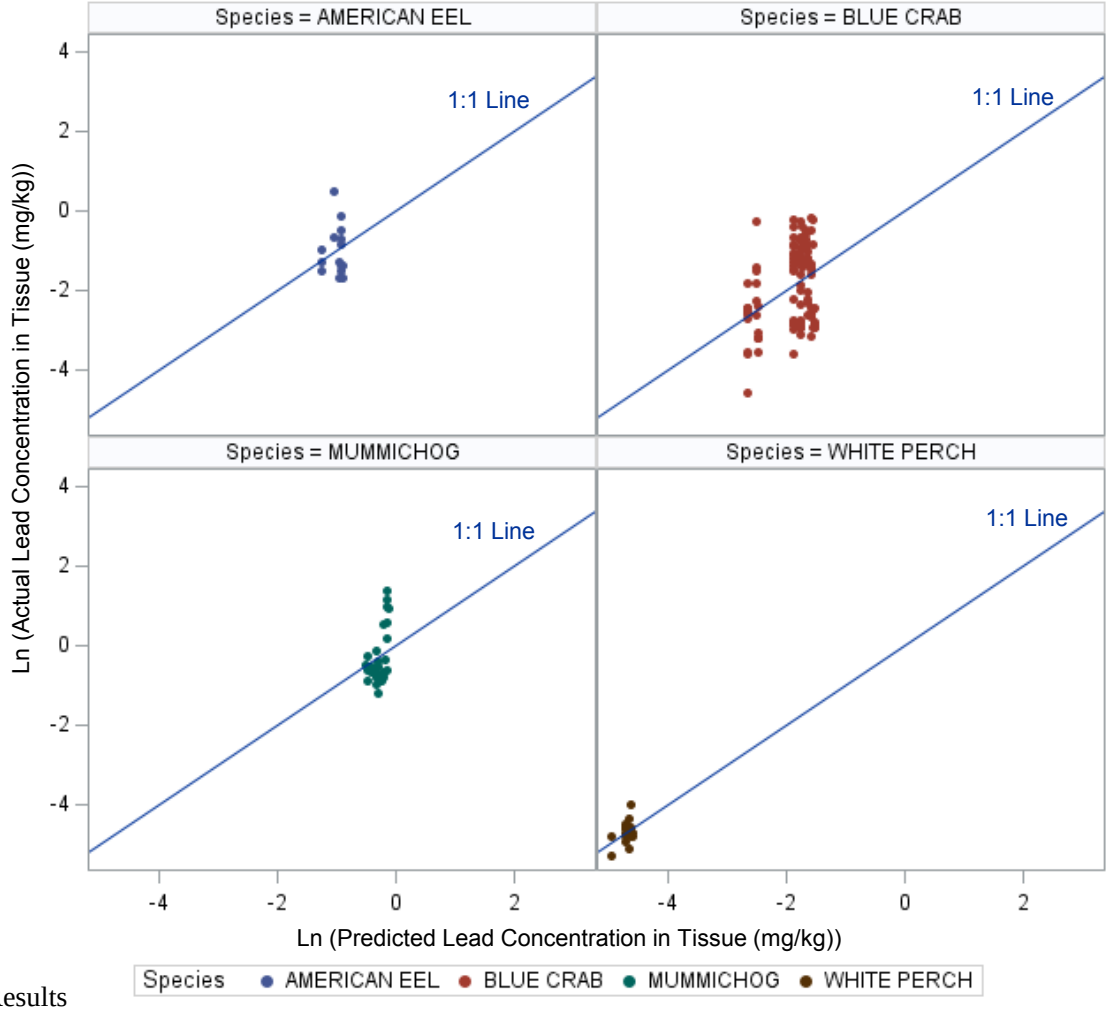
	Blue Crab Actual Copper Concentration *vs.* Predicted Copper Concentration in Tissue *Lower Eight Miles of the Lower Passaic River*	Figure 3-16 2014



Regression Model Results

	Actual Lead Concentration *vs.* Predicted Lead Concentration in Tissue *Lower Eight Miles of the Lower Passaic River*	Figure 3-17a 2014

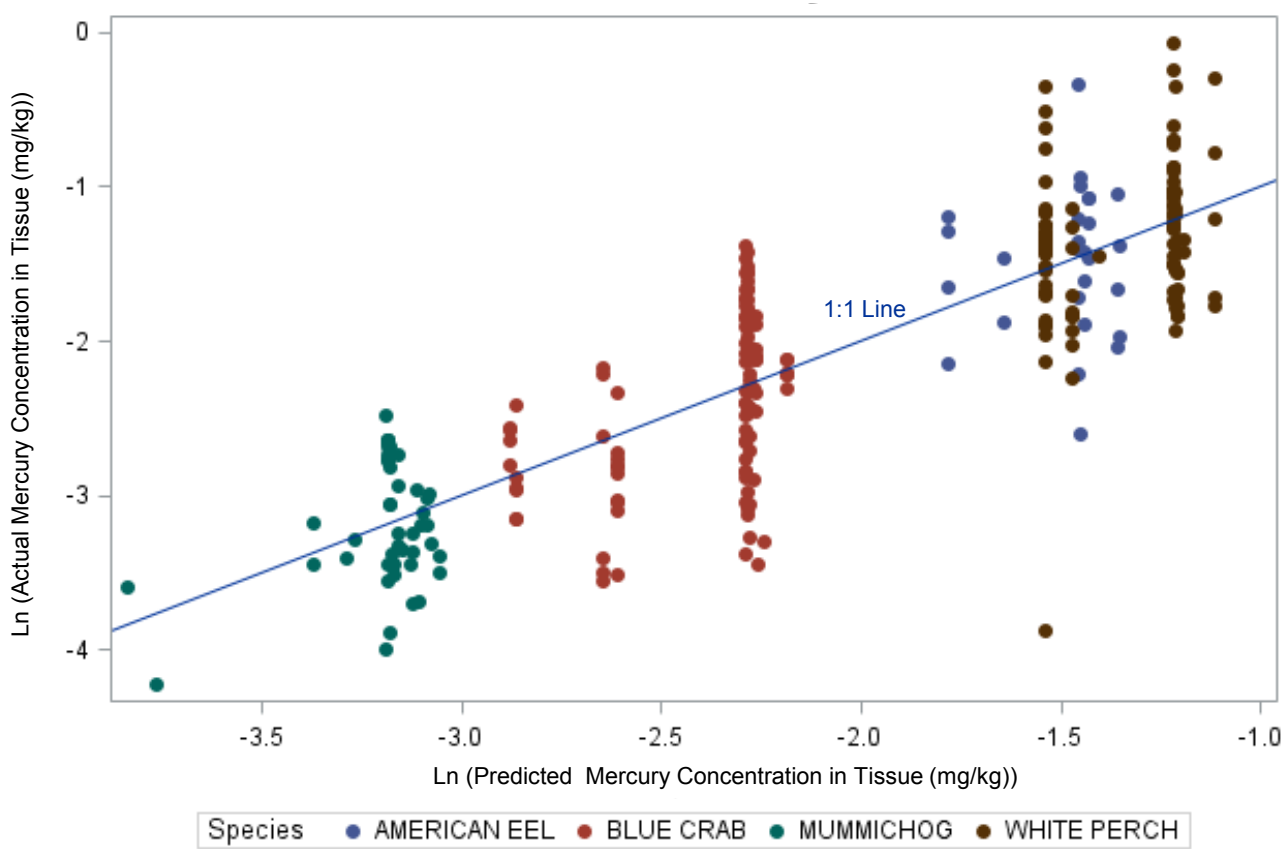
R2-0027668



Regression Model Results

	Actual Lead Concentration *vs.* Predicted Lead Concentration in Tissue by Species *Lower Eight Miles of the Lower Passaic River*	Figure 3-17b 2014

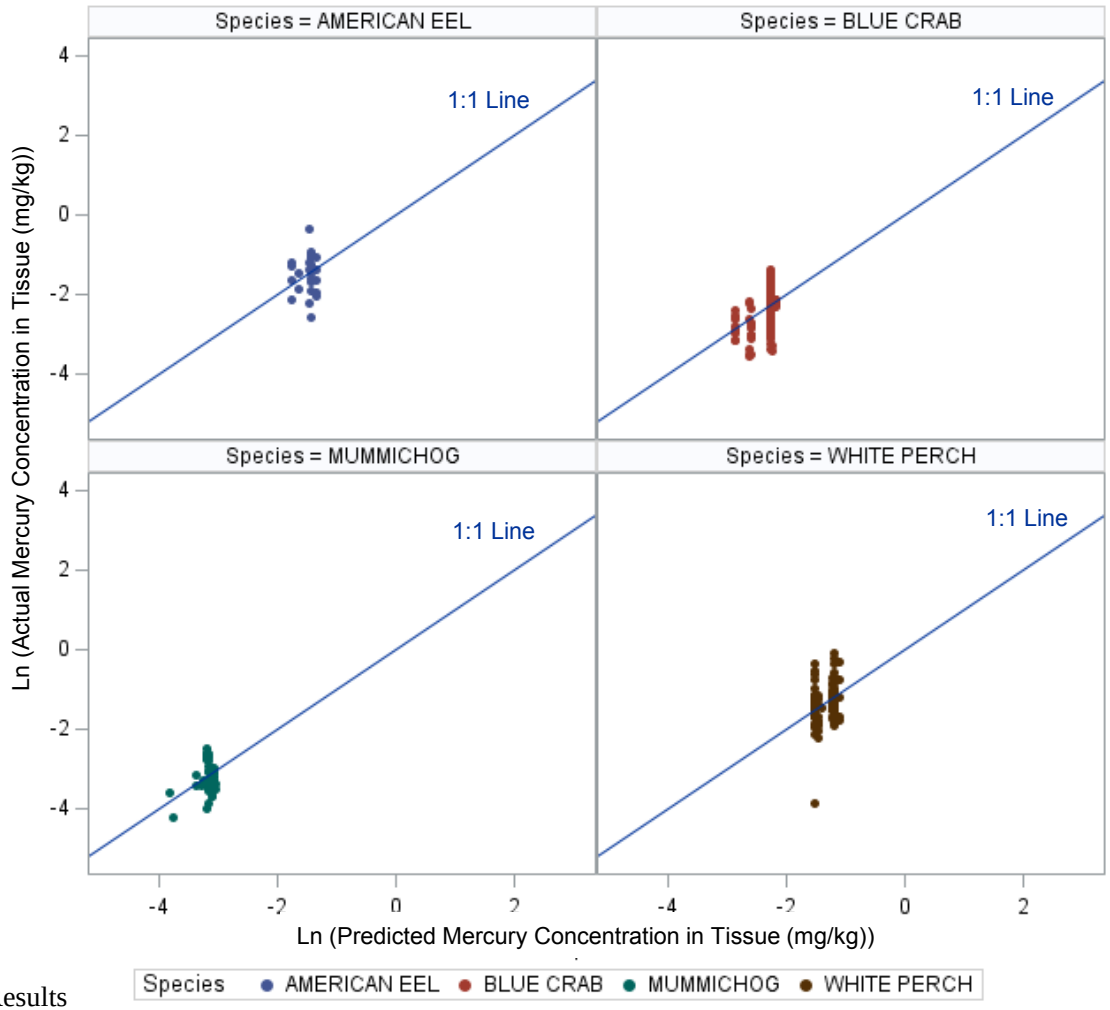
R2-0027669



Regression Model Results

	Actual Mercury Concentration *vs.* Predicted Mercury Concentration in Tissue *Lower Eight Miles of the Lower Passaic River*	Figure 3-18a 2014

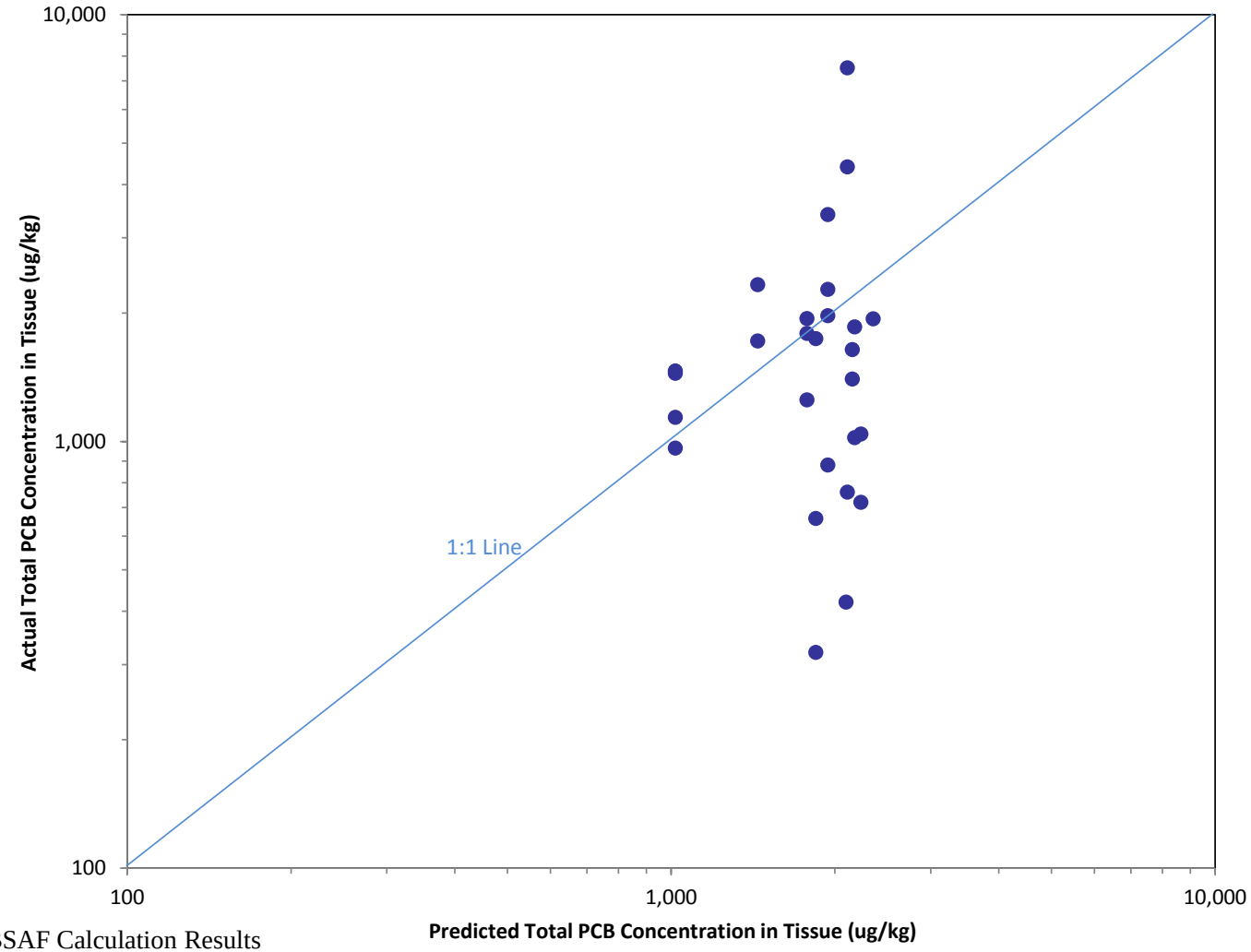
R2-0027670



Regression Model Results

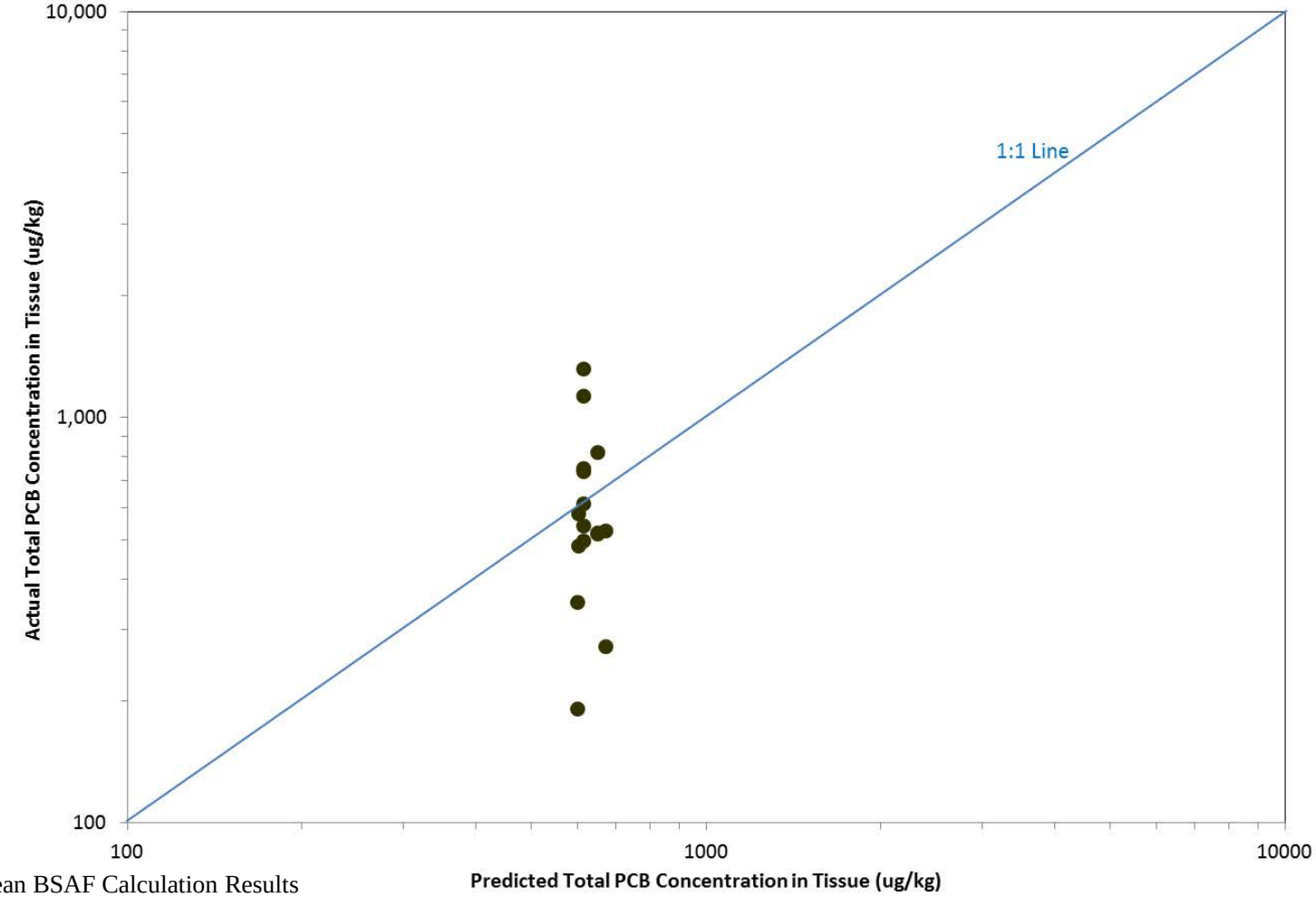
	Actual Mercury Concentration *vs.* Predicted Mercury Concentration in Tissue by Species *Lower Eight Miles of the Lower Passaic River*	Figure 3-18b 2014

R2-0027671



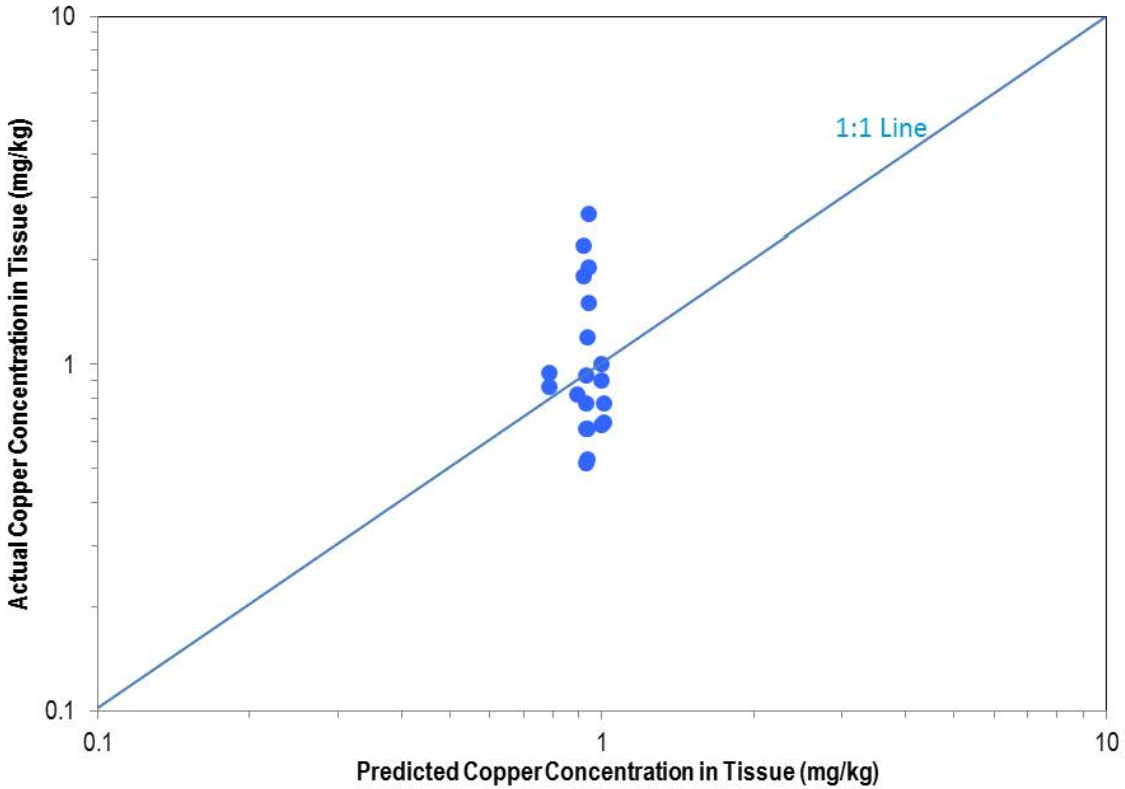
Mean BSAF Calculation Results

	American Eel Actual Total PCB Concentration *vs.* Predicted Total PCB Concentration in Tissue *Lower Eight Miles of the Lower Passaic River*	Figure 3-19a 2014



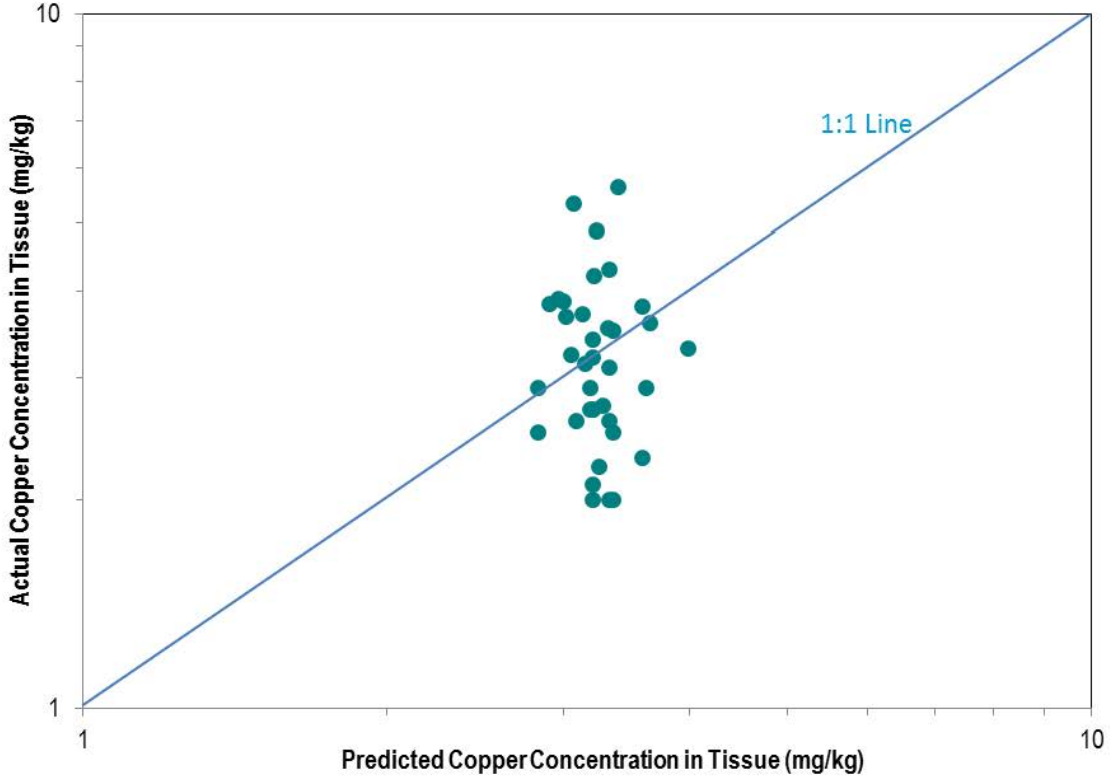
Mean BSAF Calculation Results

	White Perch Actual Total PCB Concentration *vs.* Predicted Total PCB Concentration in Tissue *Lower Eight Miles of the Lower Passaic River*	Figure 3-19b 2014



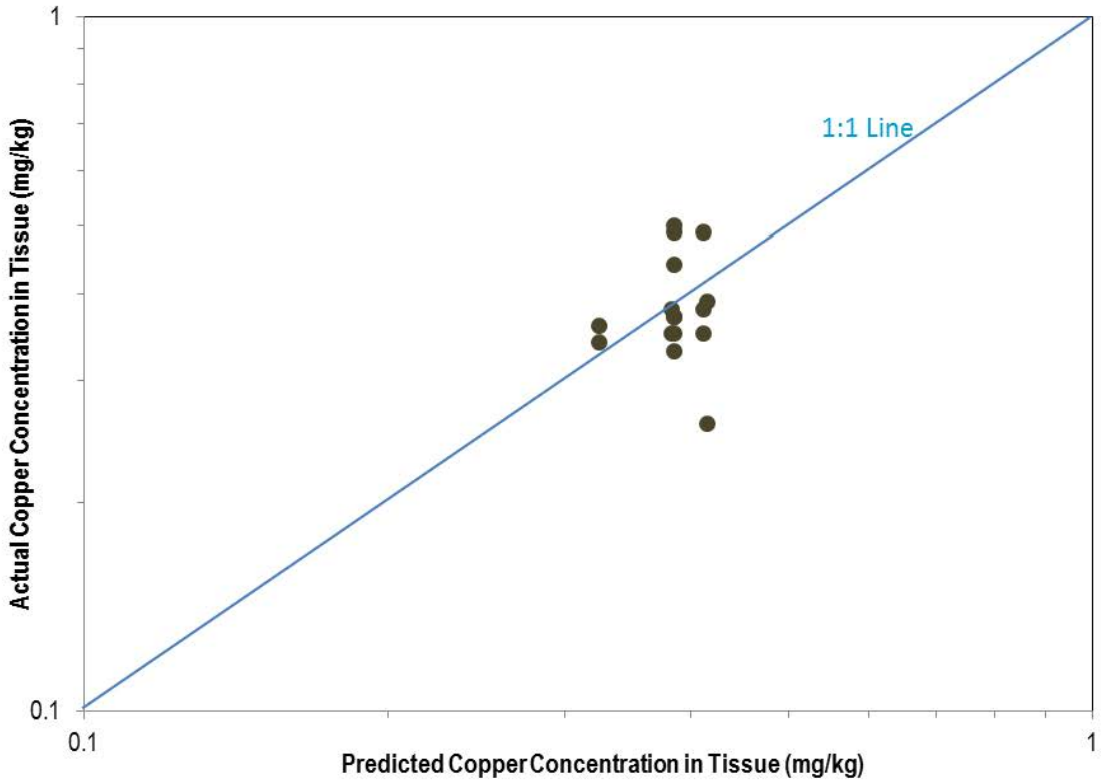
Median BAF Calculation Results

	American Eel Actual Copper Concentration *vs.* Predicted Copper Concentration in Tissue *Lower Eight Miles of the Lower Passaic River*	Figure 3-20a 2014



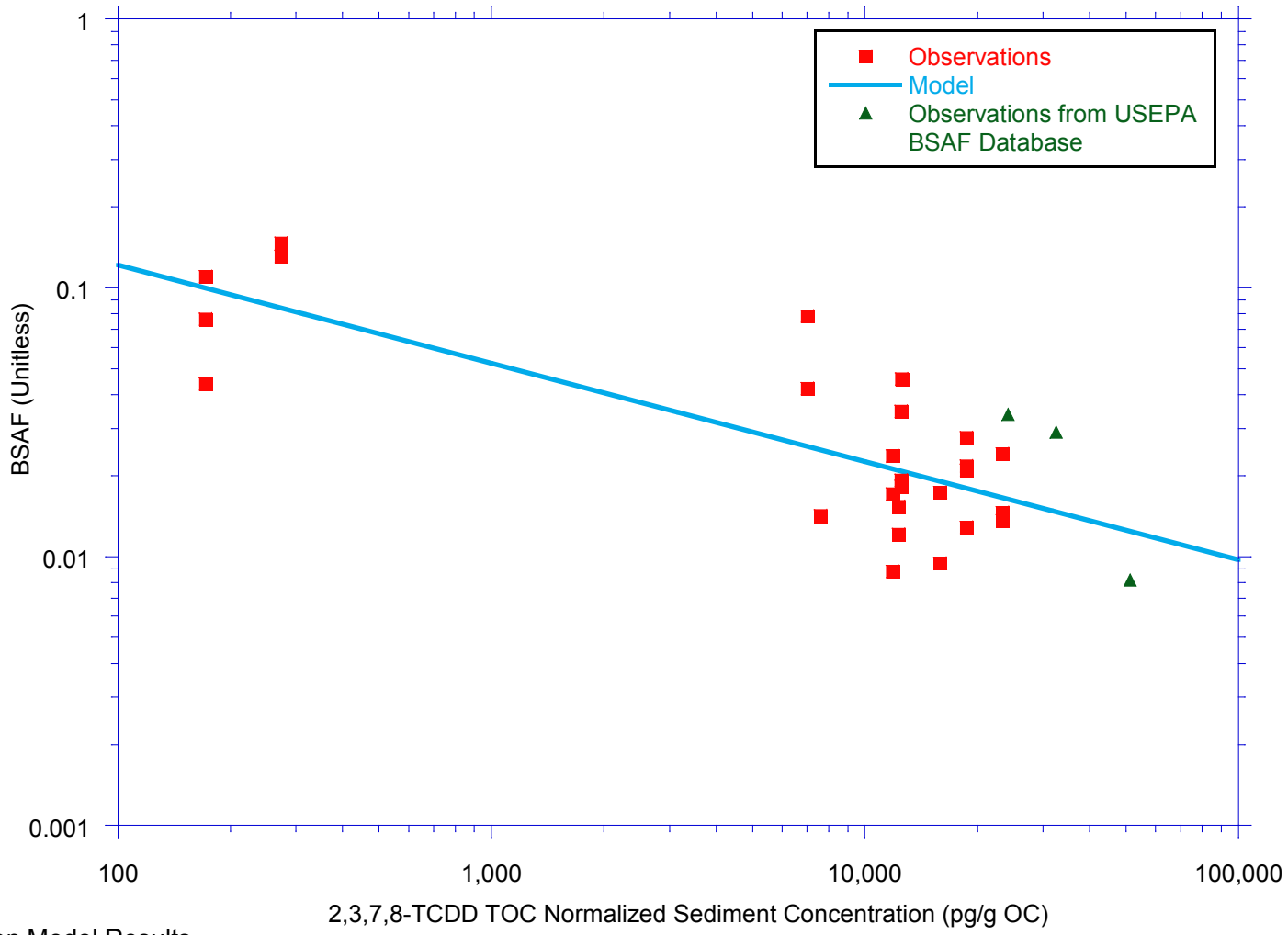
Mean BAF Calculation Results

	Mummichog Actual Copper Concentration *vs.* Predicted Copper Concentration in Tissue *Lower Eight Miles of the Lower Passaic River*	Figure 3-20b 2014



Mean BAF Calculation Results

	White Perch Actual Copper Concentration *vs.* Predicted Copper Concentration in Tissue *Lower Eight Miles of the Lower Passaic River*	Figure 3-20c 2014



Regression Model Results

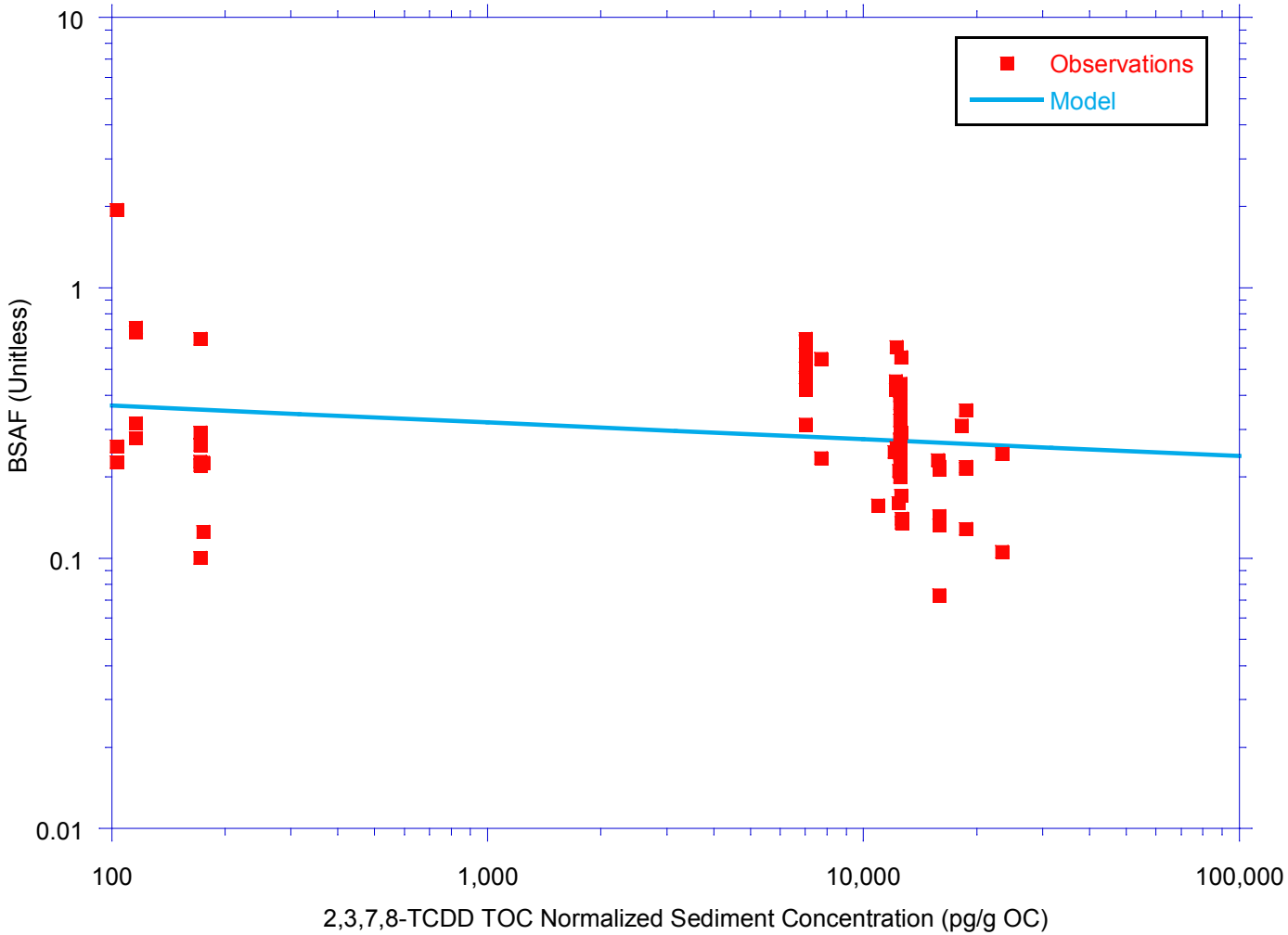
American Eel
BSAF *vs.* 2,3,7,8-TCDD TOC Normalized Sediment Concentration

Lower Eight Miles of the Lower Passaic River

Figure 3-21a

2014

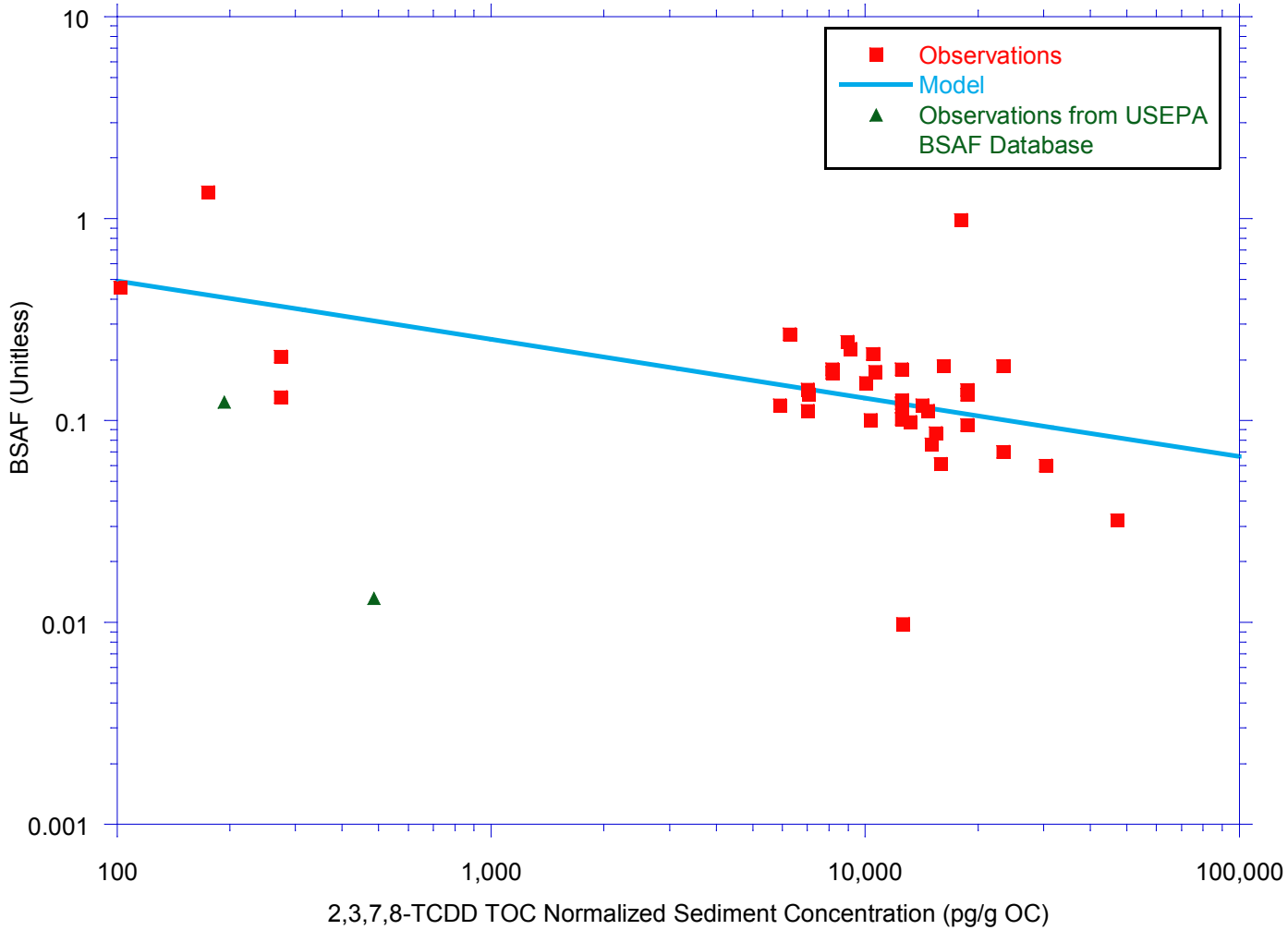
R2-0027677



Regression Model Results

	Blue Crab **BSAF *vs.* 2,3,7,8-TCDD TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-21b 2014

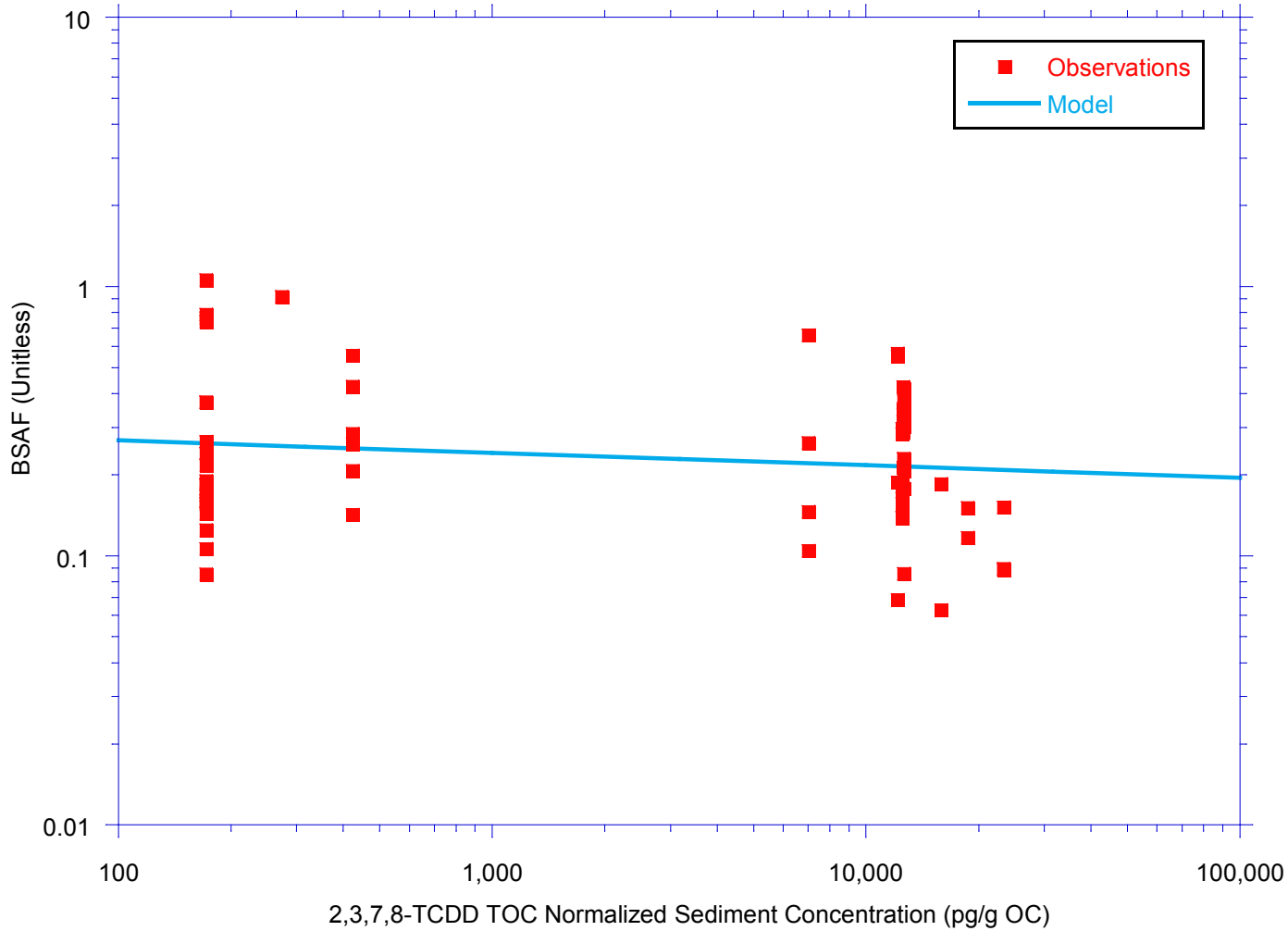
R2-0027678



Regression Model Results

	Mummichog **BSAF *vs.* 2,3,7,8-TCDD TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-21c 2014

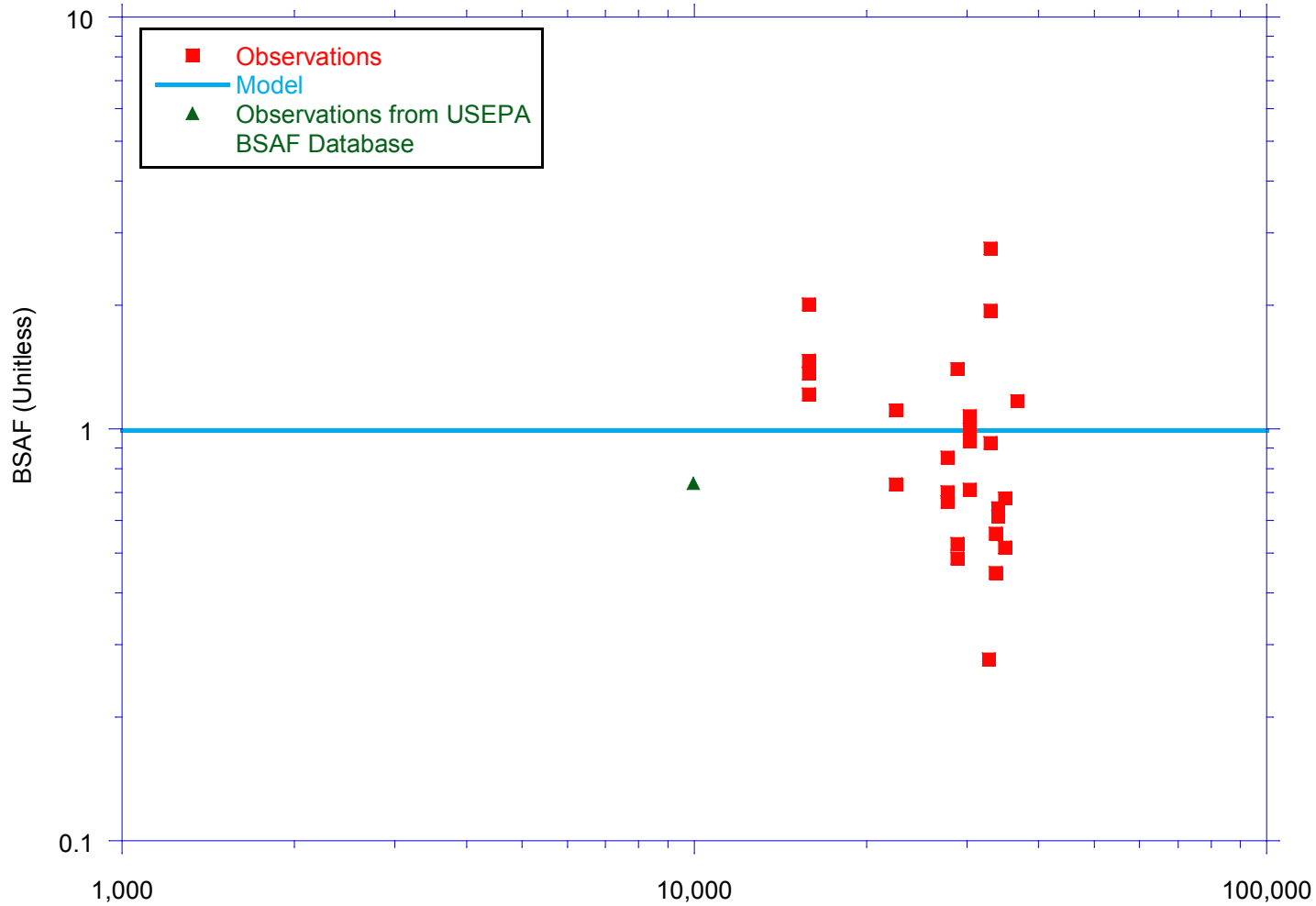
R2-0027679



Regression Model Results

	White Perch **BSAF *vs.* 2,3,7,8-TCDD TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-21d 2014

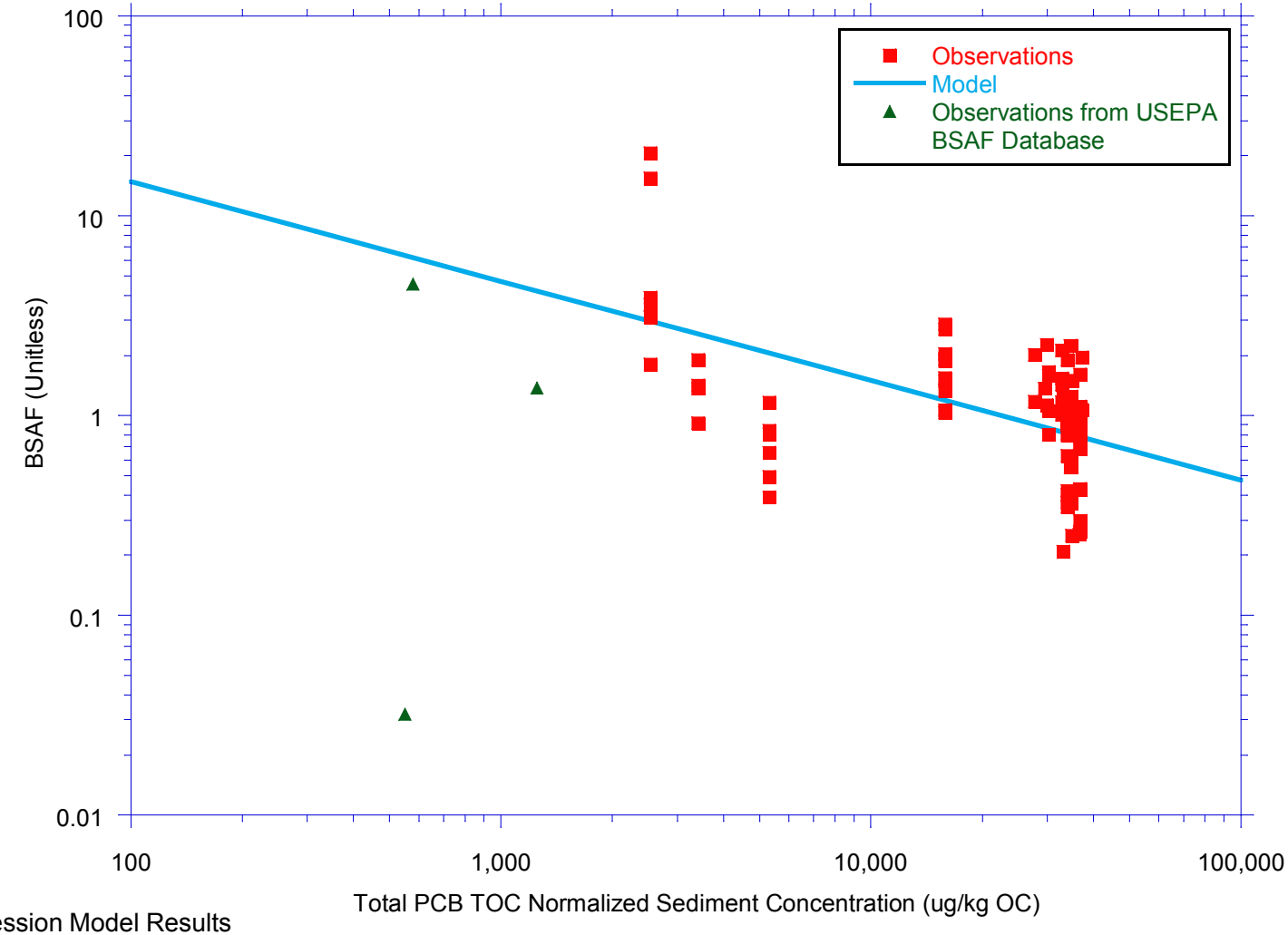
R2-0027680



Mean BSAF Calculation Results

	American Eel **BSAF *vs.* Total PCB TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-22a 2014

R2-0027681



Regression Model Results

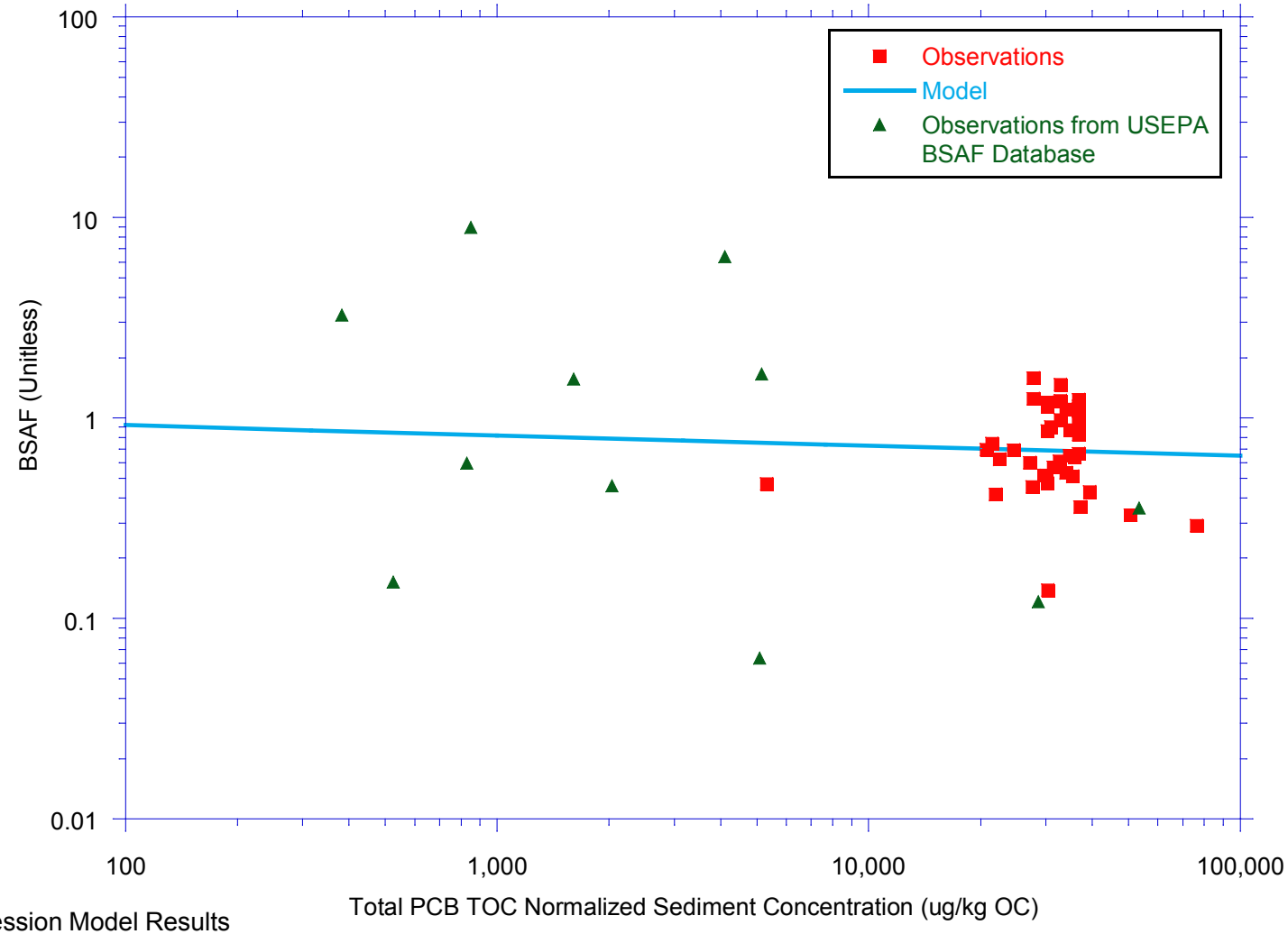
Blue Crab
BSAF *vs.* Total PCB TOC Normalized Sediment Concentration

Lower Eight Miles of the Lower Passaic River

Figure 3-22b

2014

R2-0027682



Regression Model Results

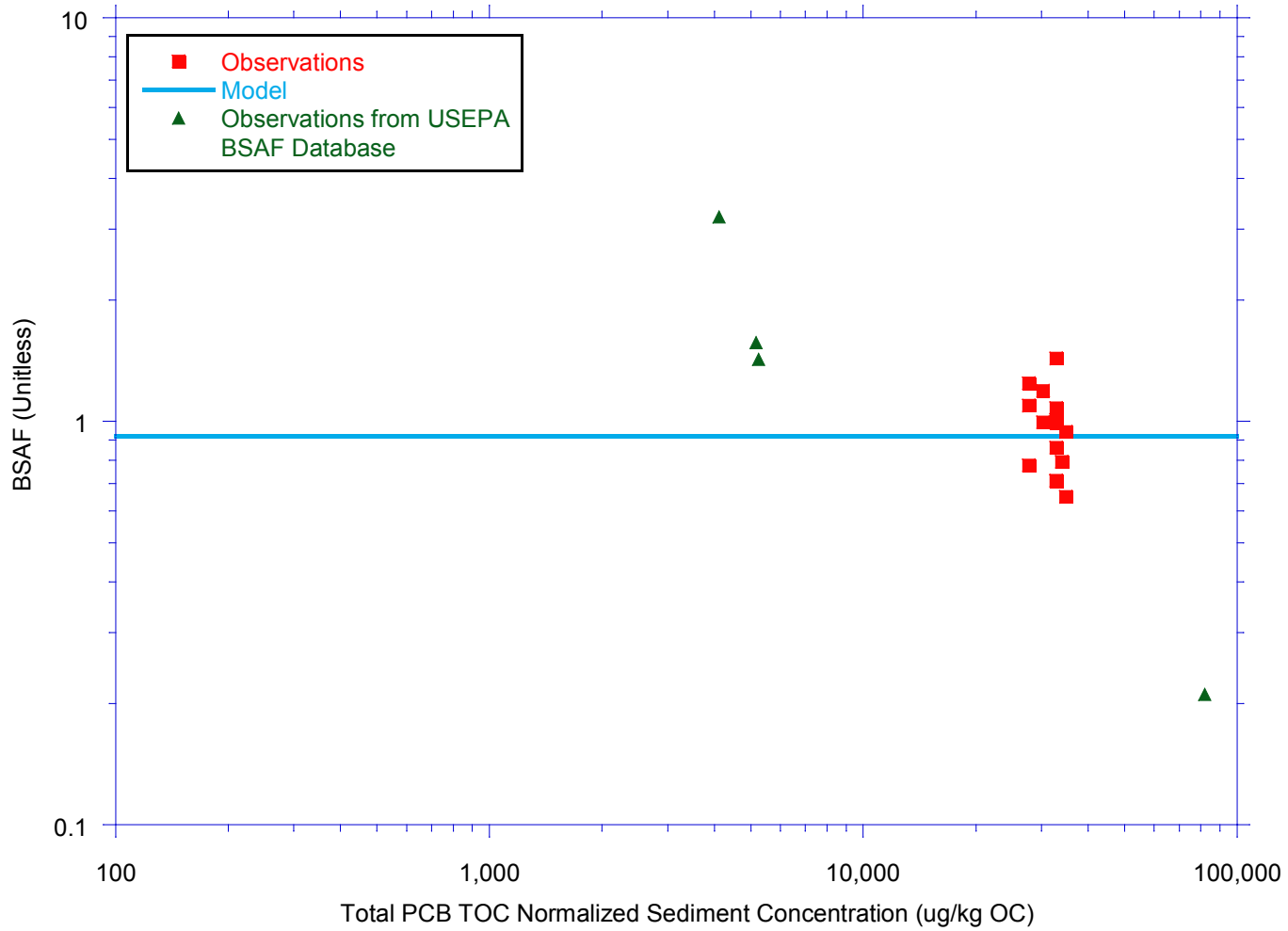
Mummichog
BSAF *vs.* Total PCB TOC Normalized Sediment Concentration

Lower Eight Miles of the Lower Passaic River

Figure 3-22c

2014

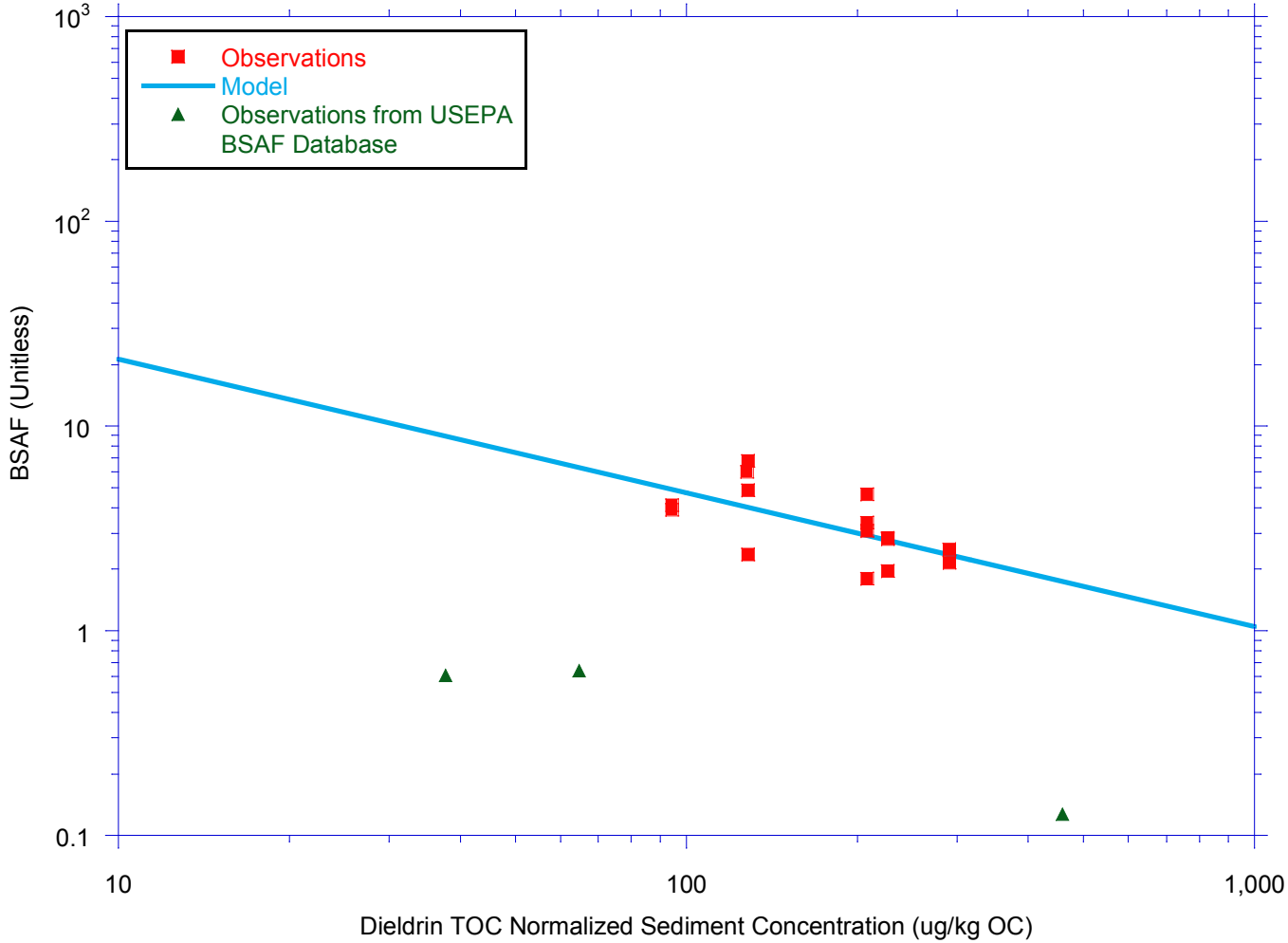
R2-0027683



Mean BSAF Calculation Results

	White Perch **BSAF *vs.* Total PCB TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-22d 2014

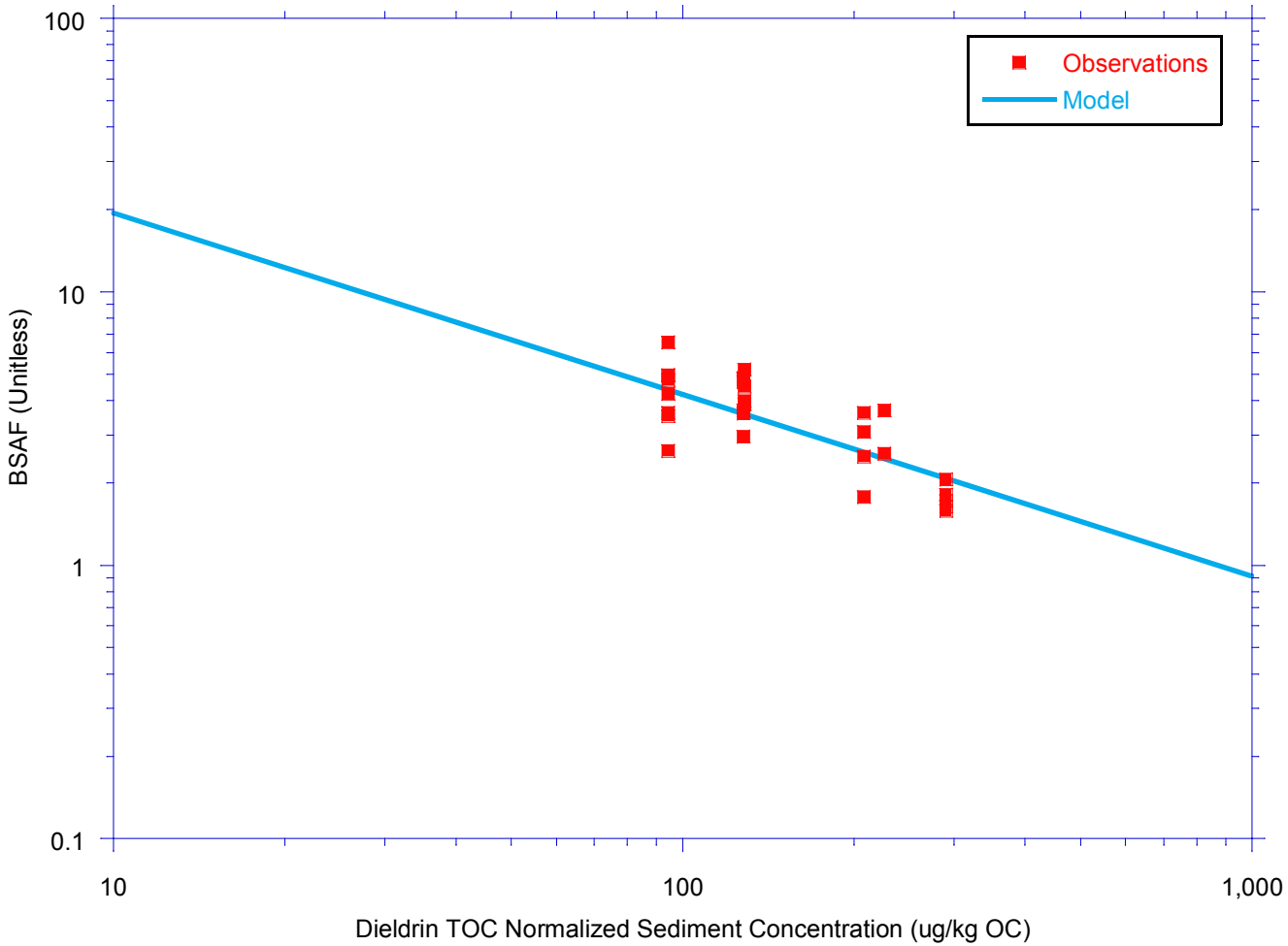
R2-0027684



Regression Model Results

	American Eel **BSAF *vs.* Dieldrin TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-23a 2014

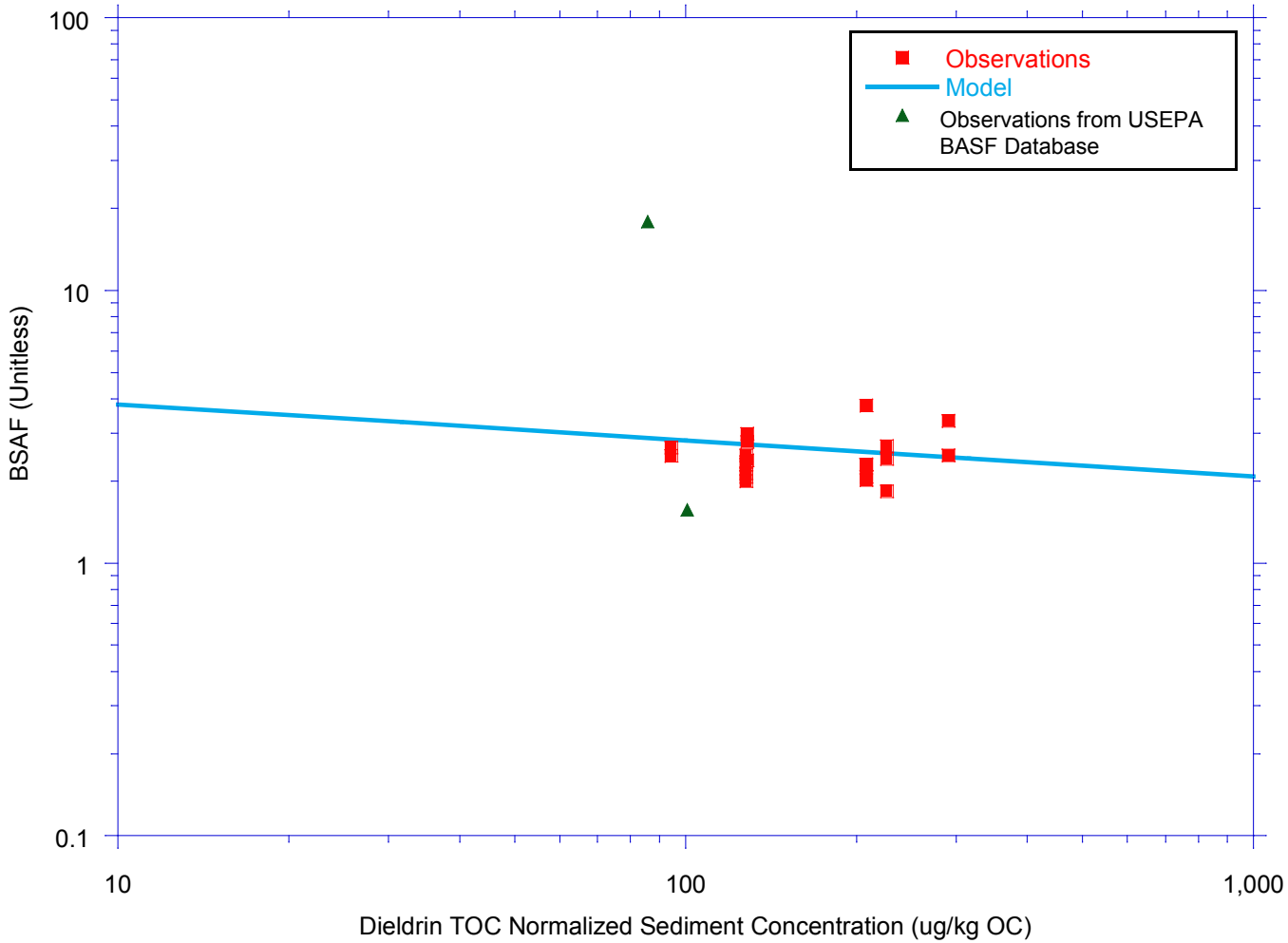
R2-0027685



Regression Model Results

	Blue Crab **BSAF *vs.* Dieldrin TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-23b 2014

R2-0027686



Regression Model Results

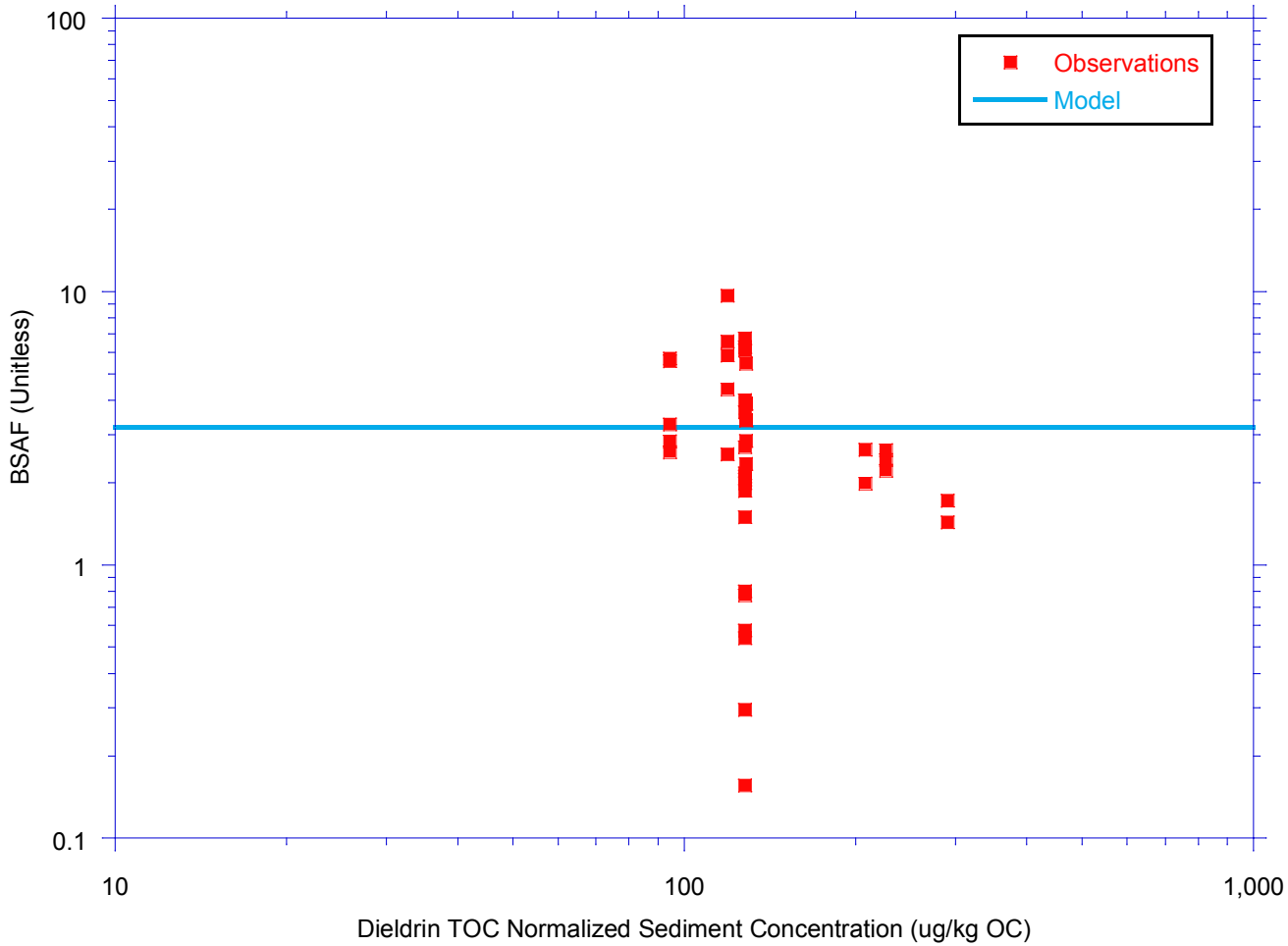
Mummichog
BSAF *vs.* Dieldrin TOC Normalized Sediment Concentration

Lower Eight Miles of the Lower Passaic River

Figure 3-23c

2014

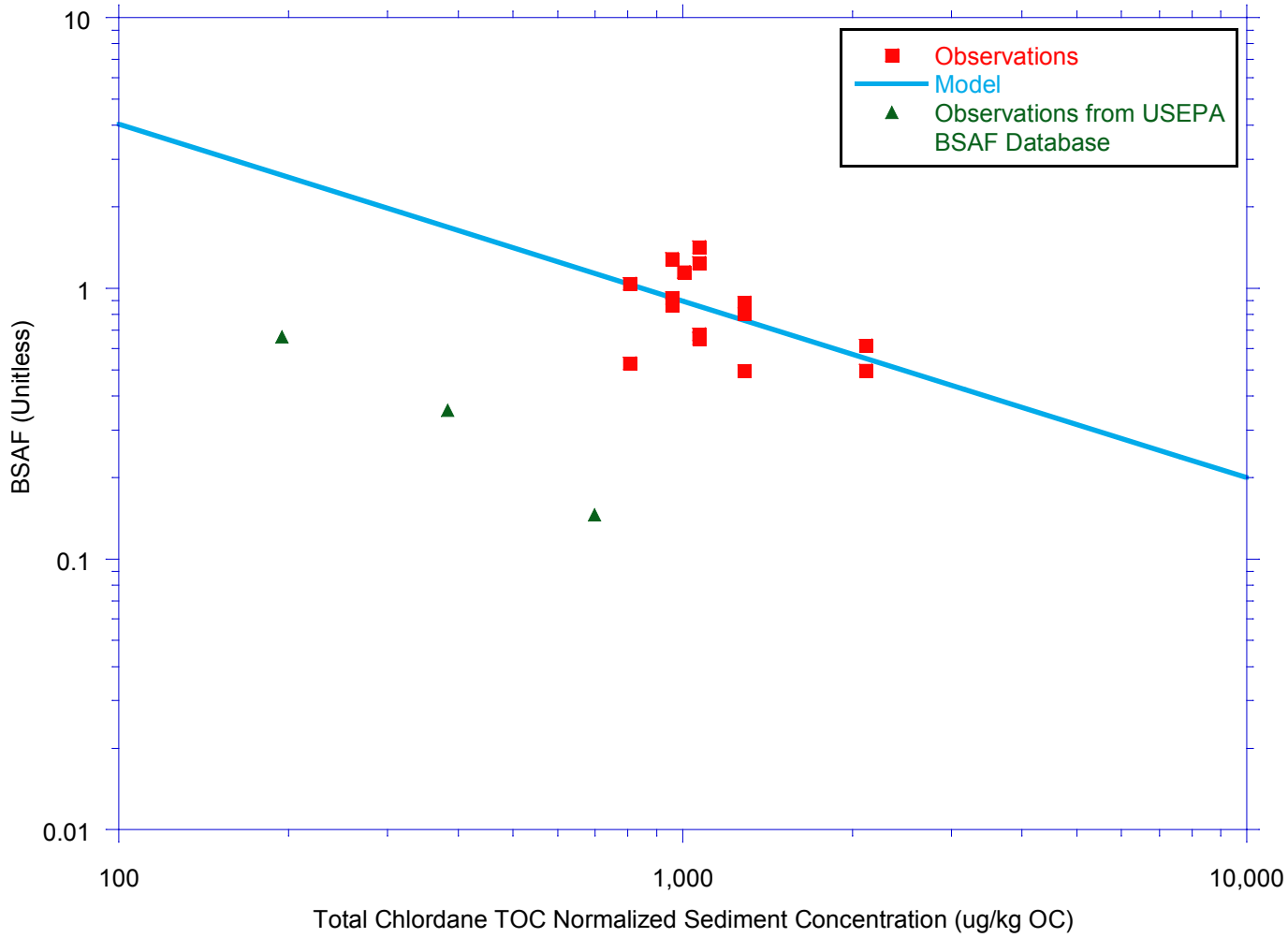
R2-0027687



Regression Model Results

	White Perch **BSAF *vs.* Dieldrin TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-23d 2014

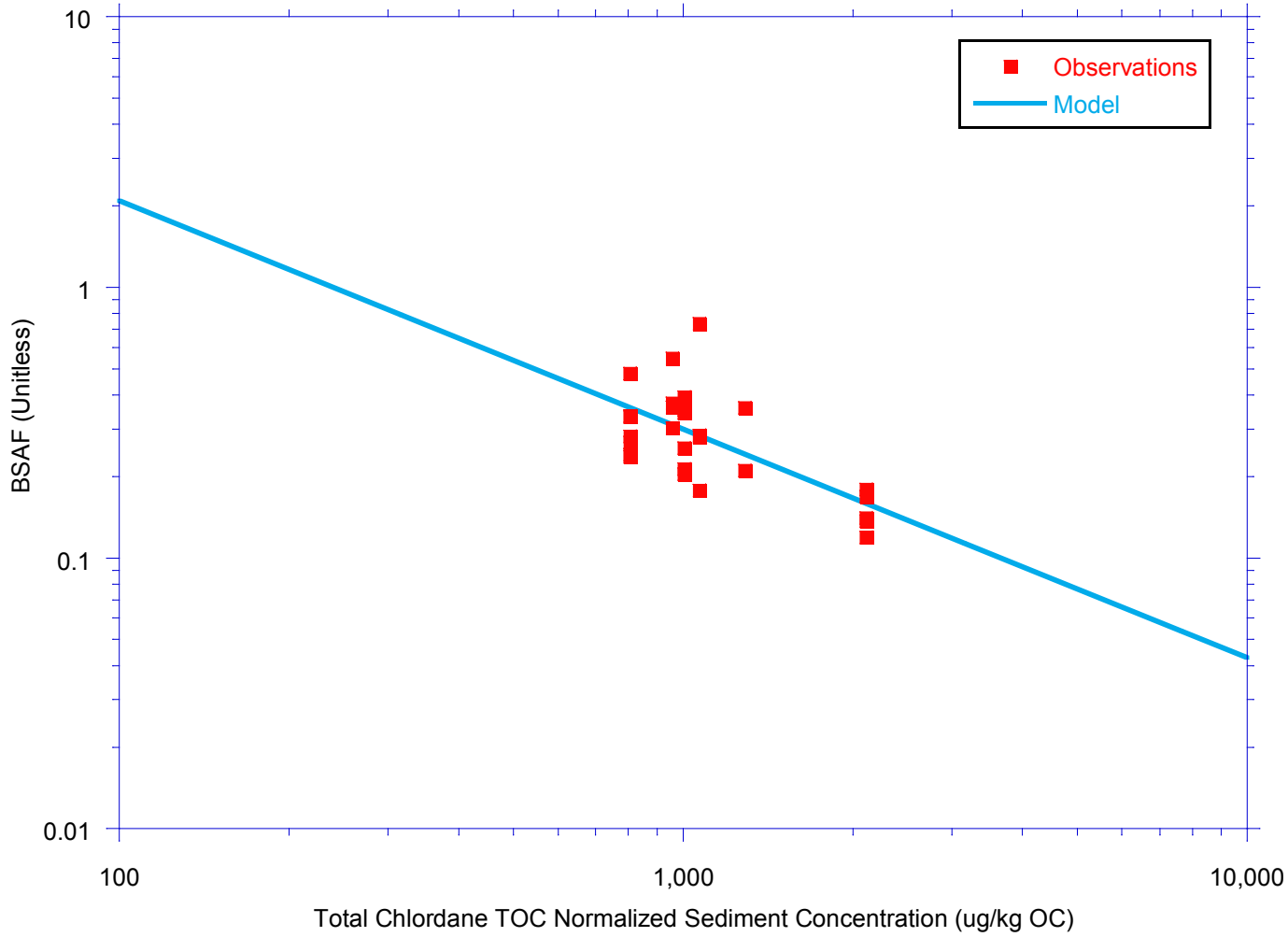
R2-0027688



Regression Model Results

	American Eel **BSAF *vs.* Total Chlordane TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-24a 2014

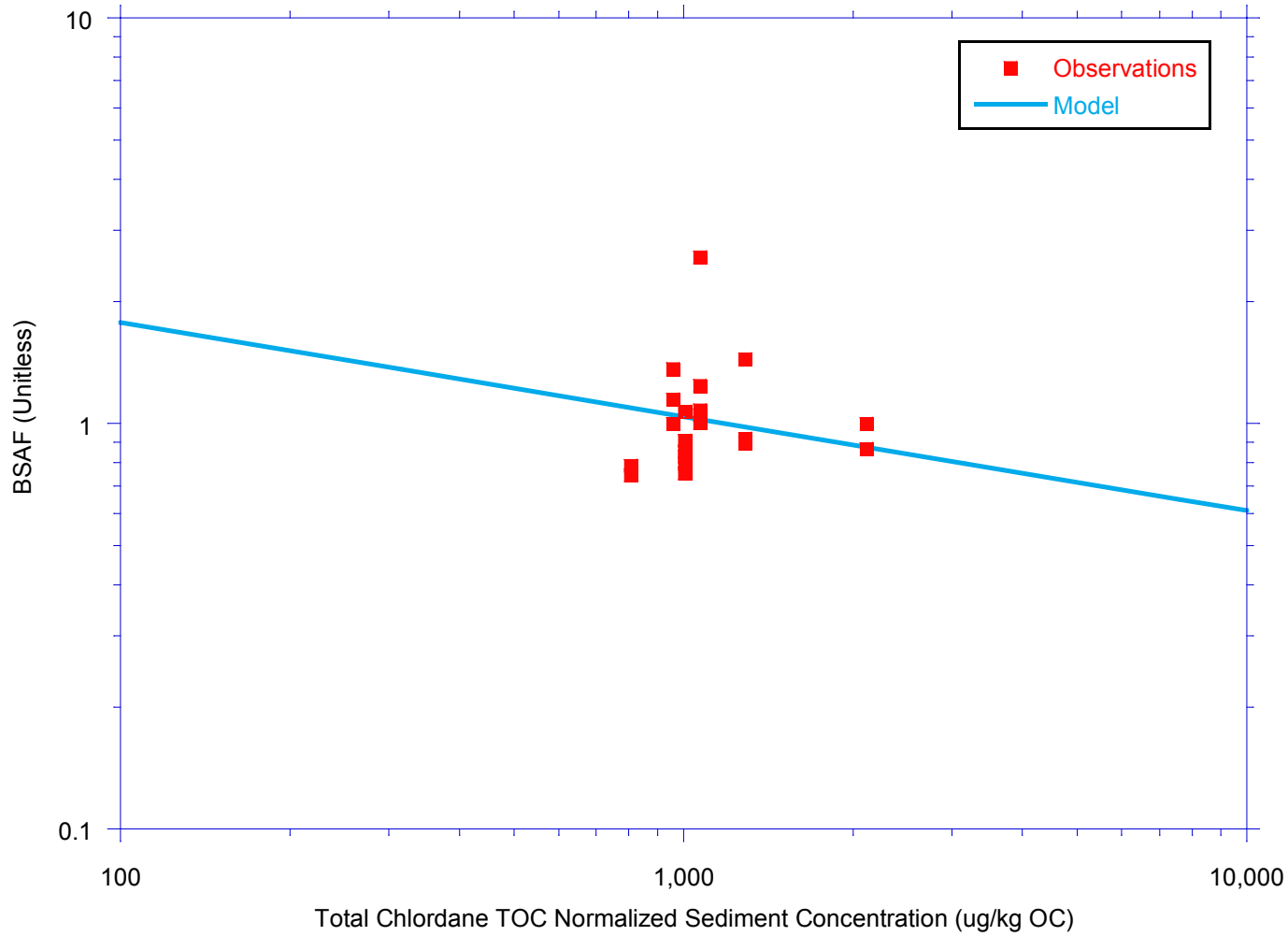
R2-0027689



Regression Model Results

	Blue Crab **BSAF *vs.* Total Chlordane TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-24b 2014

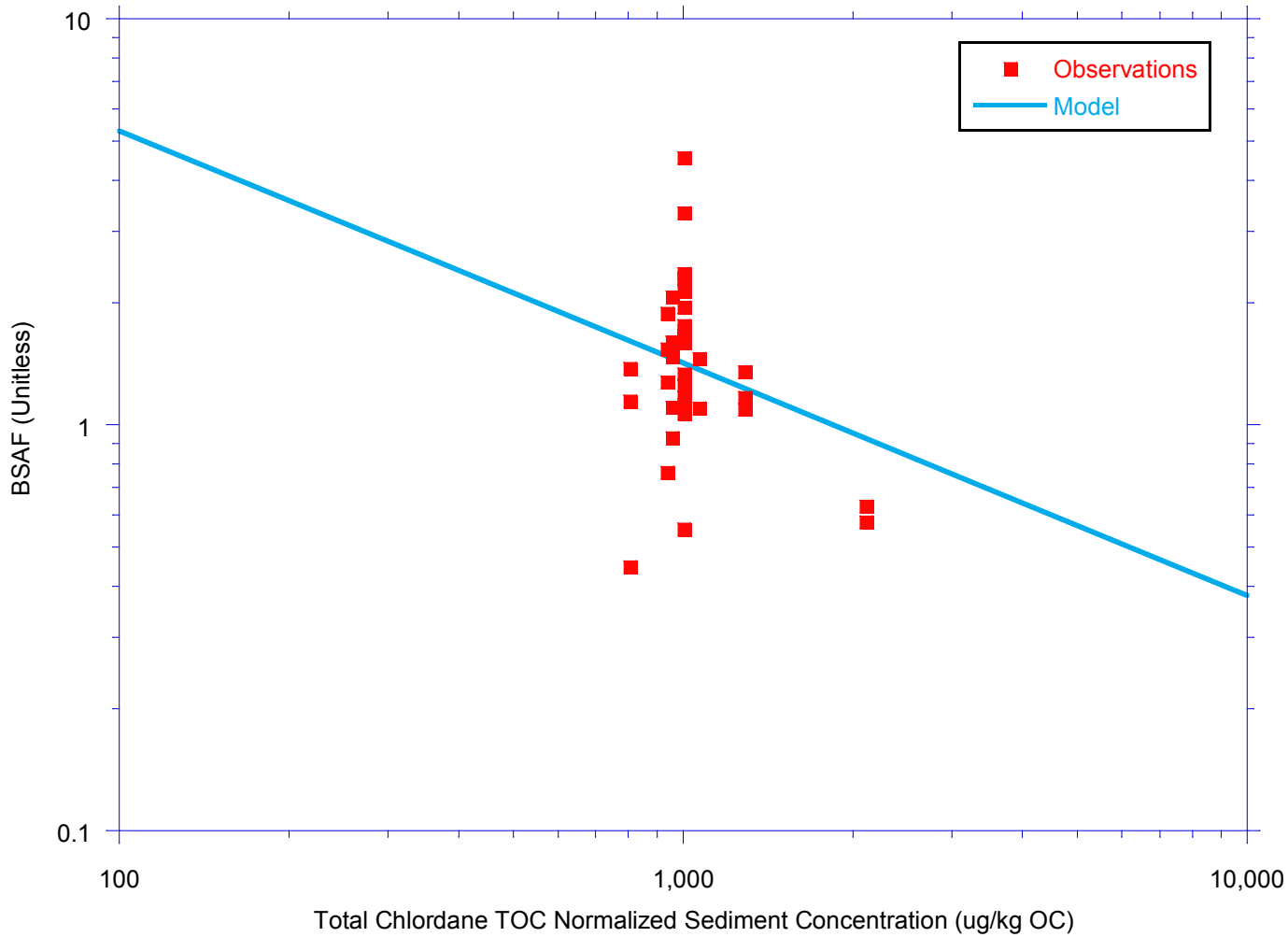
R2-0027690



Regression Model Results

	Mummichog **BSAF *vs.* Total Chlordane TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-24c 2014

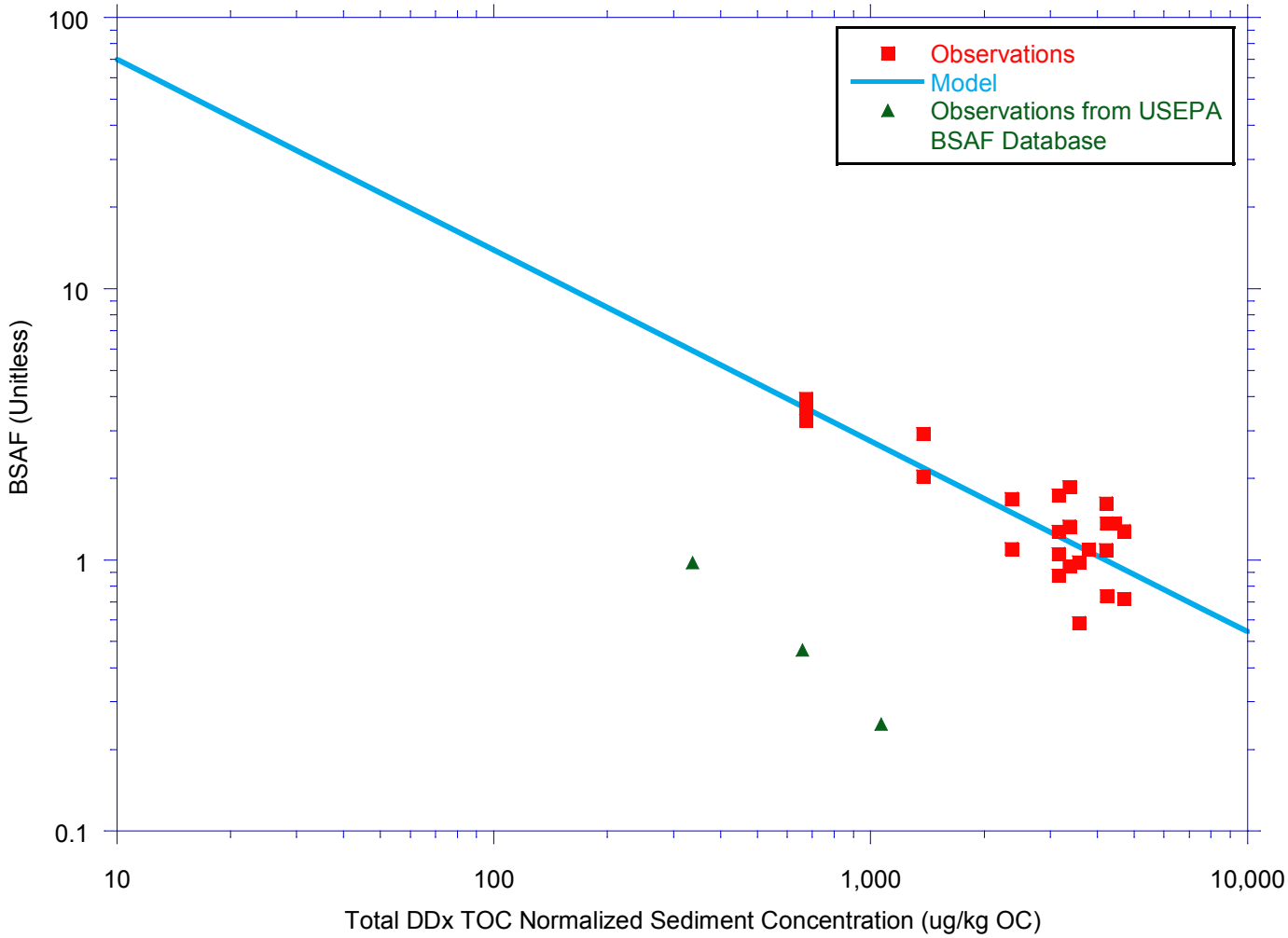
R2-0027691



Regression Model Results

	White Perch **BSAF *vs.* Total Chlordane TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-24d 2014

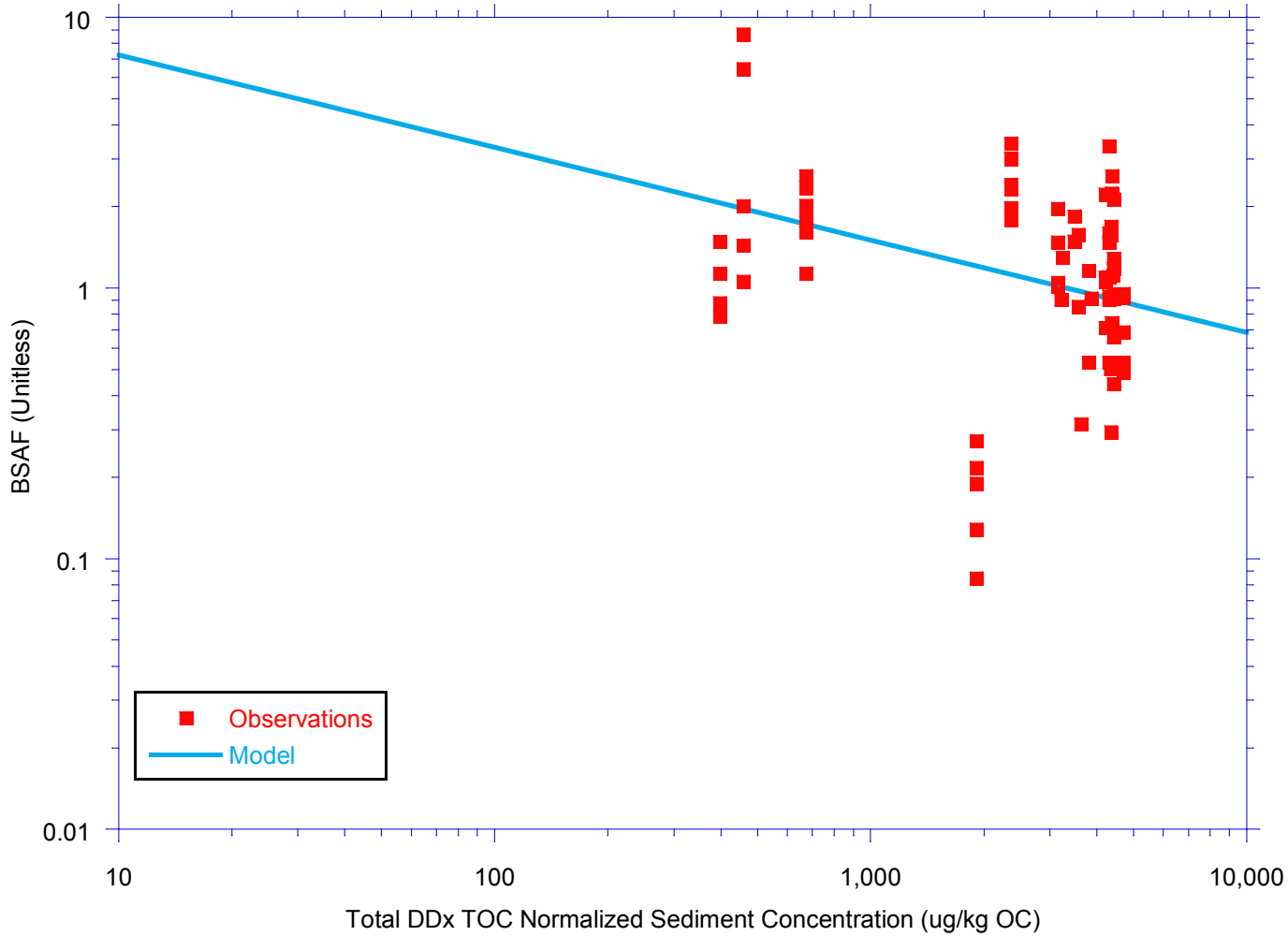
R2-0027692



Regression Model Results

	American Eel **BSAF *vs.* Total DDx TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-25a 2014

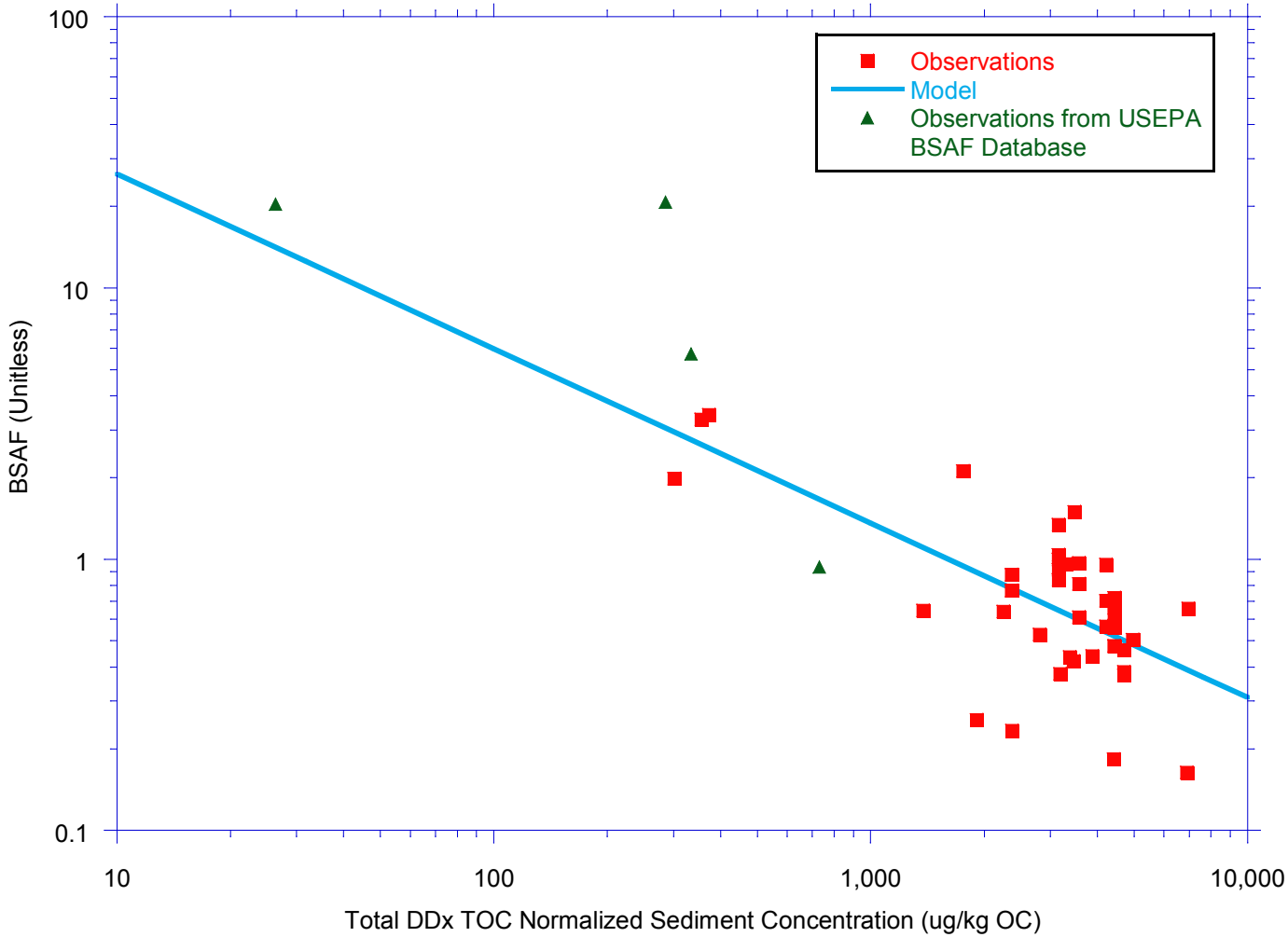
R2-0027693



Regression Model Results

	Blue Crab **BSAF *vs.* Total DDx TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-25b 2014

R2-0027694



Regression Model Results

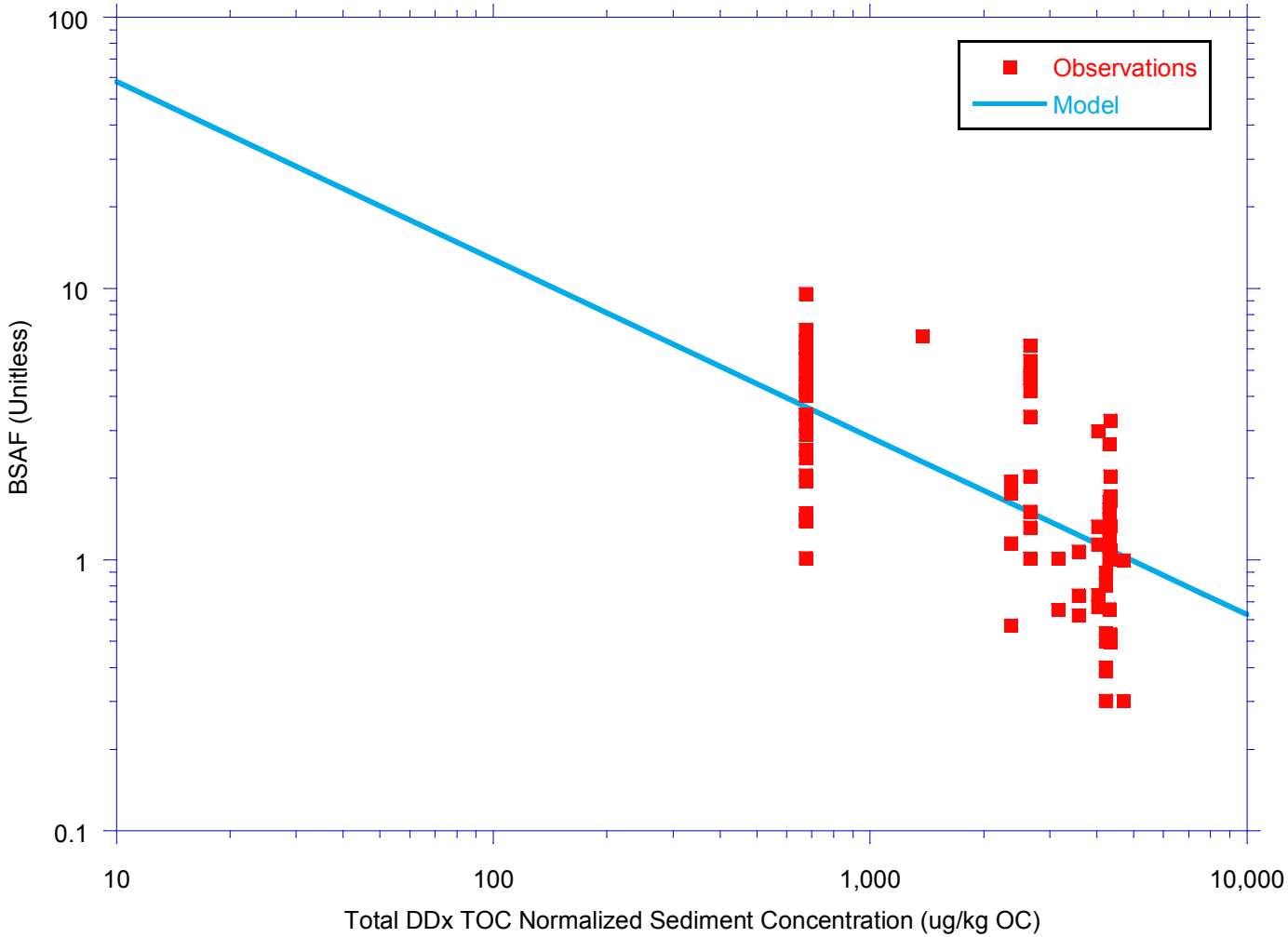
Mummichog
BSAF *vs.* Total DDx TOC Normalized Sediment Concentration

Lower Eight Miles of the Lower Passaic River

Figure 3-25c

2014

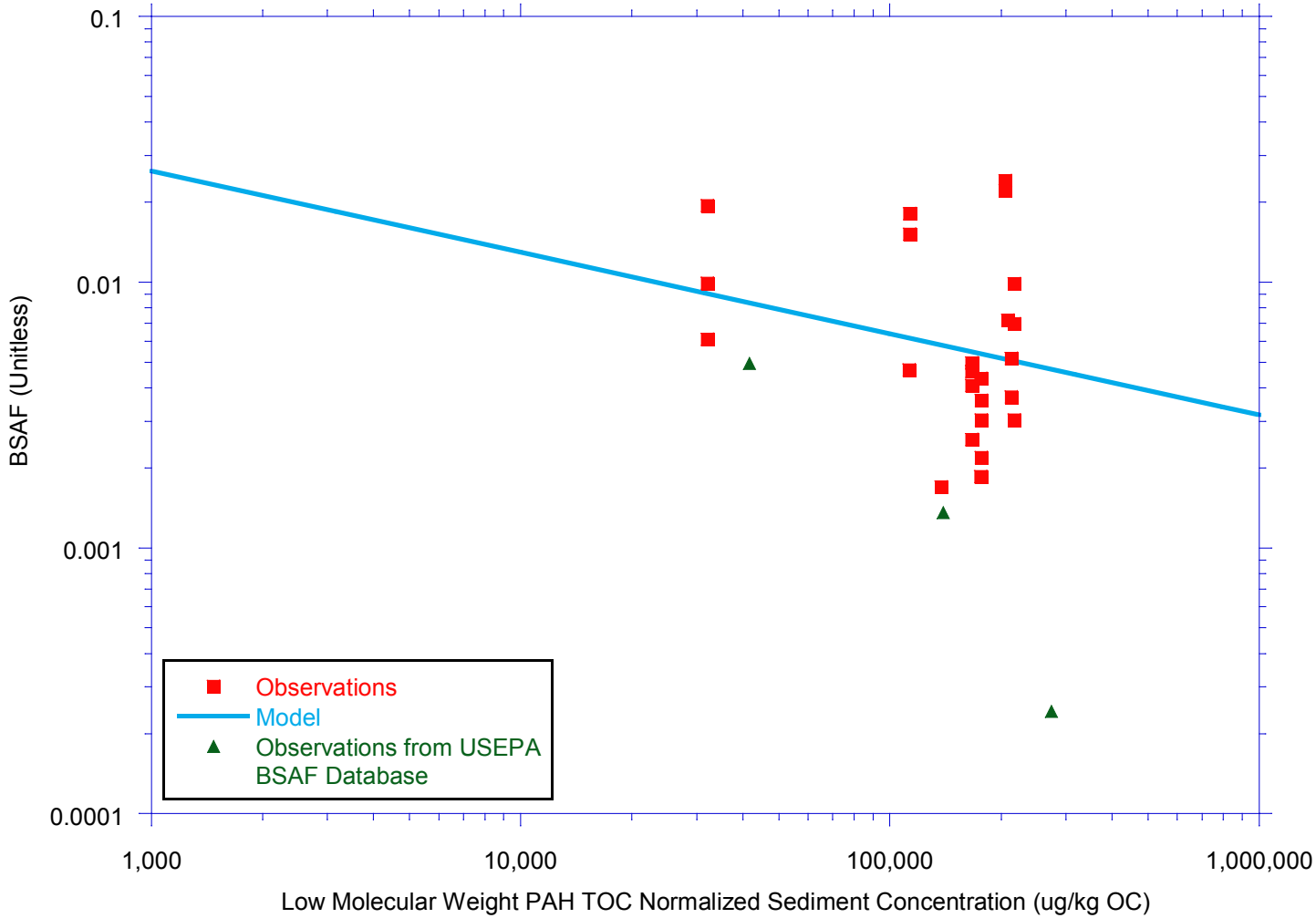
R2-0027695



Regression Model Results

	White Perch **BSAF *vs.* Total DDx TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-25d 2014

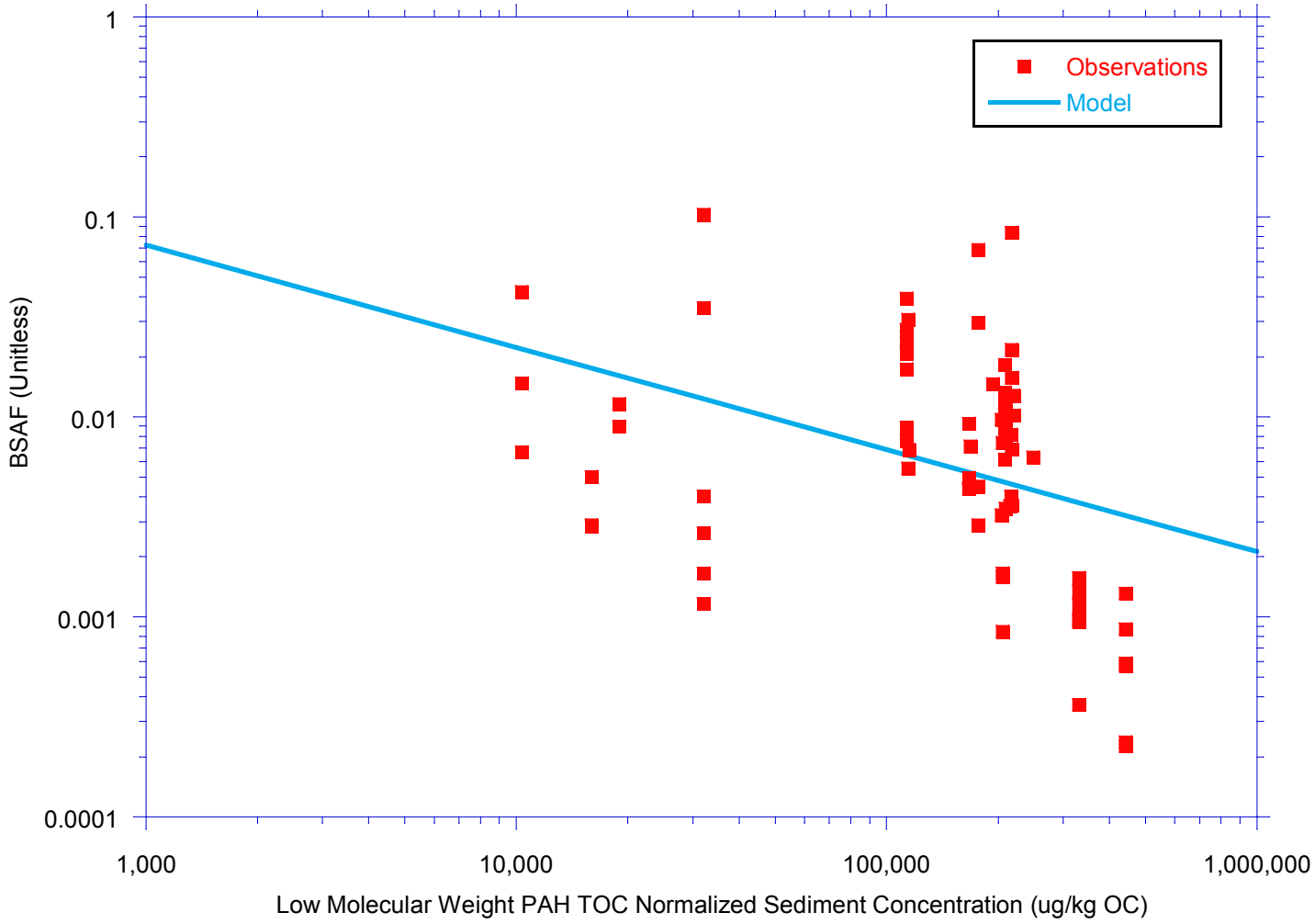
R2-0027696



Regression Model Results

	American Eel **BSAF *vs.* Low Molecular Weight PAH TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-26a 2014

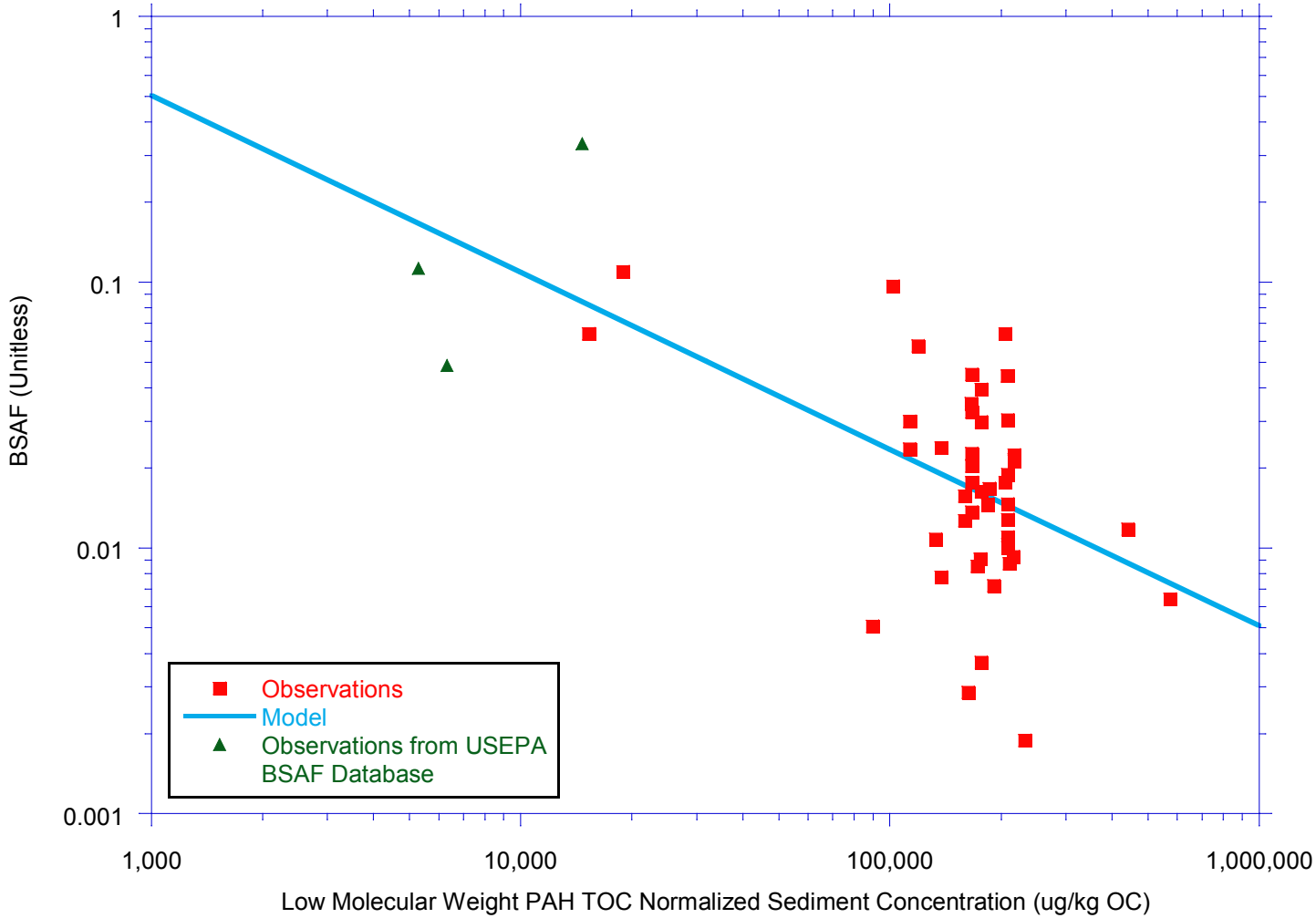
R2-0027697



Regression Model Results

	Blue Crab **BSAF *vs.* Low Molecular Weight PAH TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-26b 2014

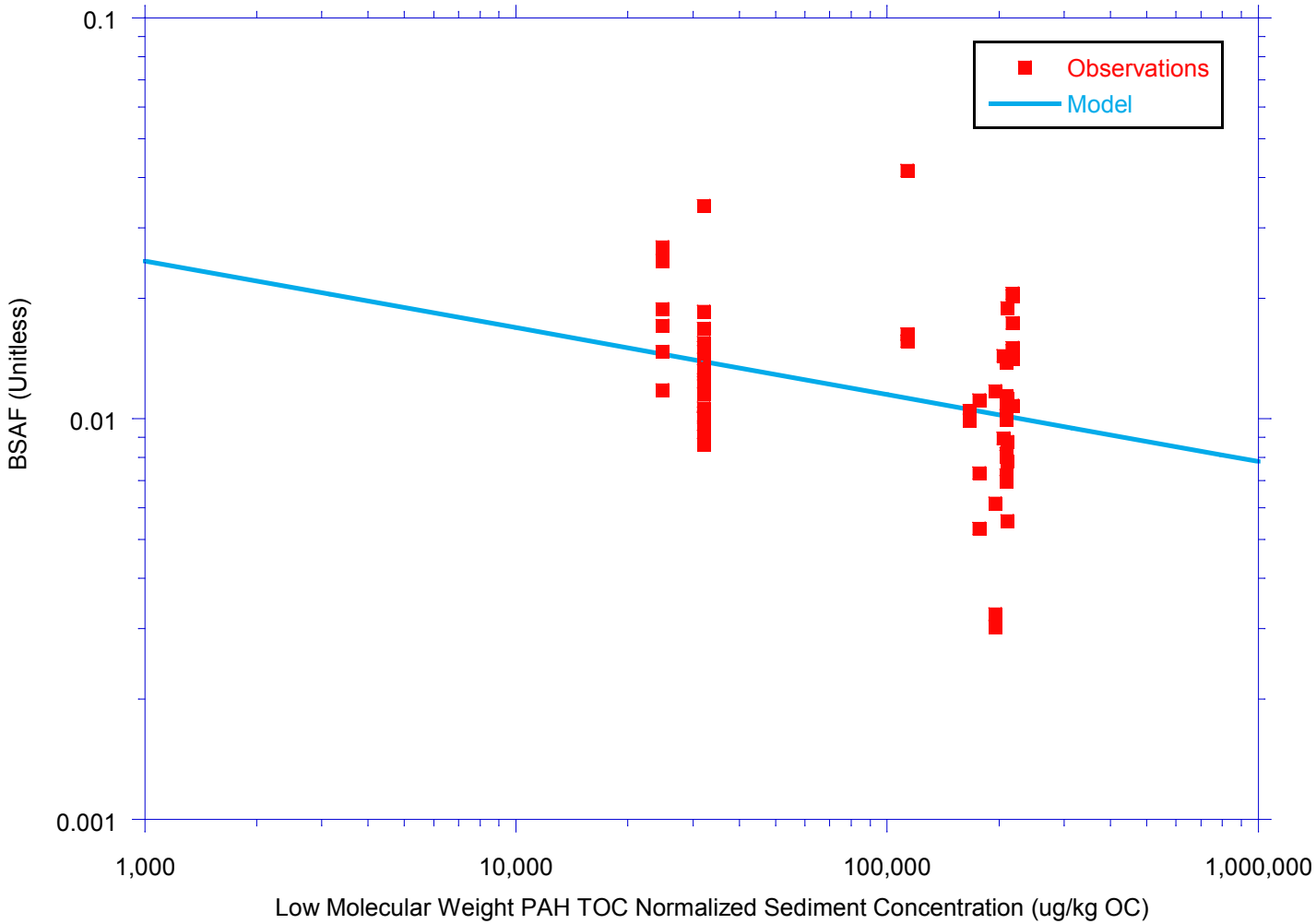
R2-0027698



Regression Model Results

	Mummichog **BSAF *vs.* Low Molecular Weight PAH TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-26c 2014

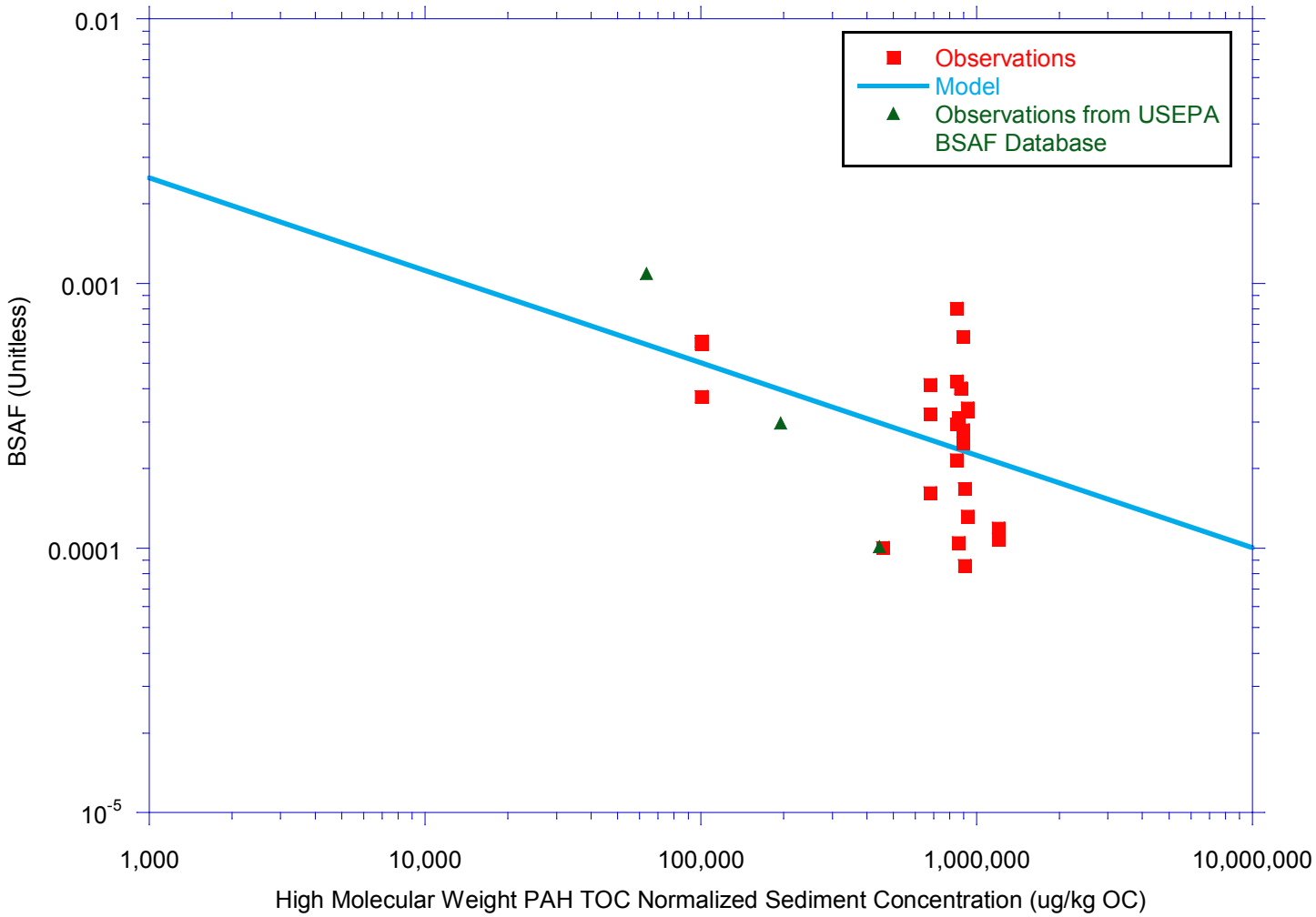
R2-0027699



Regression Model Results

	White Perch **BSAF *vs*. Low Molecular Weight PAH TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-26d 2014

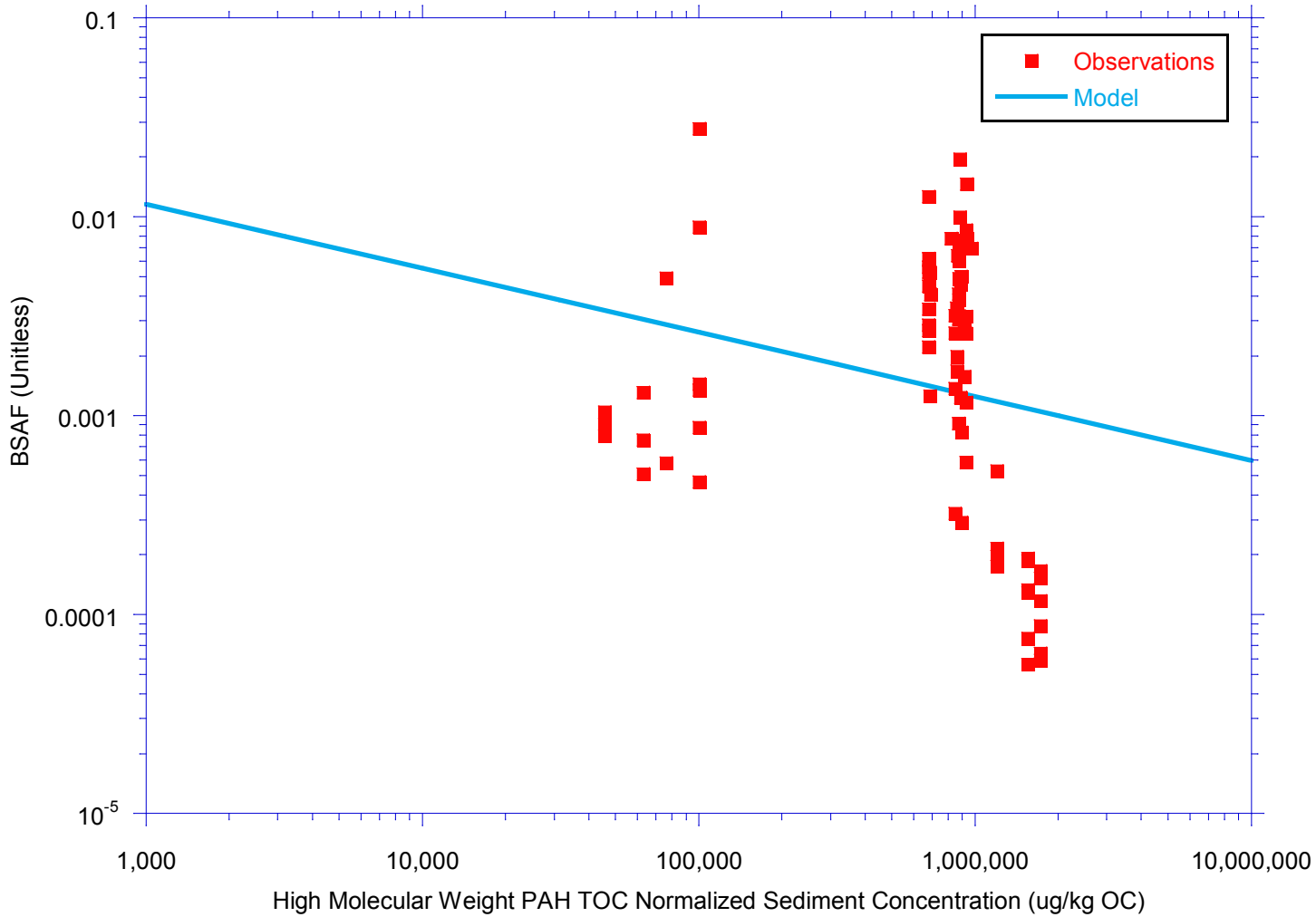
R2-0027700



Regression Model Results

	American Eel **BSAF *vs.* High Molecular Weight PAH TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-27a 2014

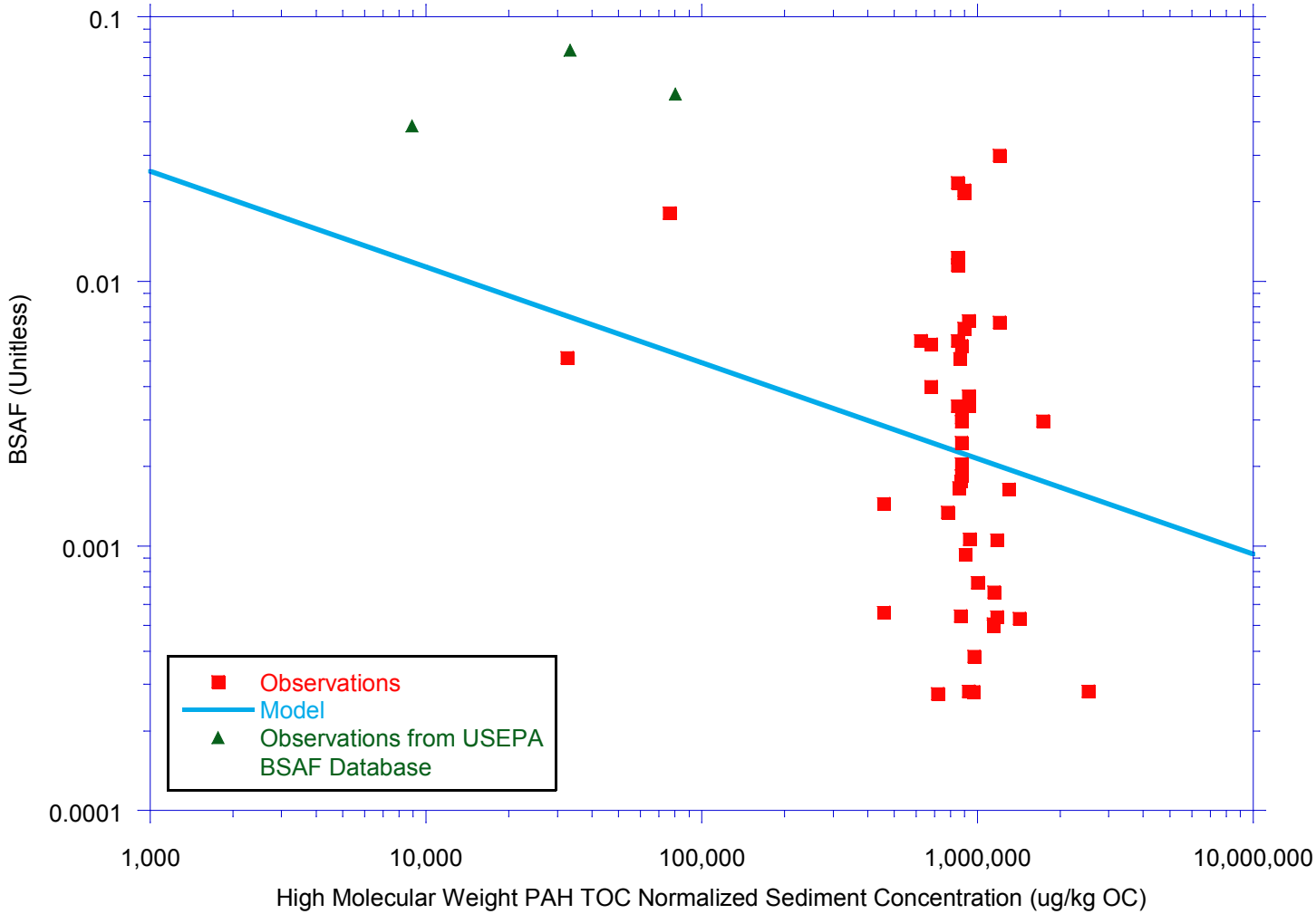
R2-0027701



Regression Model Results

	Blue Crab **BSAF *vs.* High Molecular Weight PAH TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-27b 2014

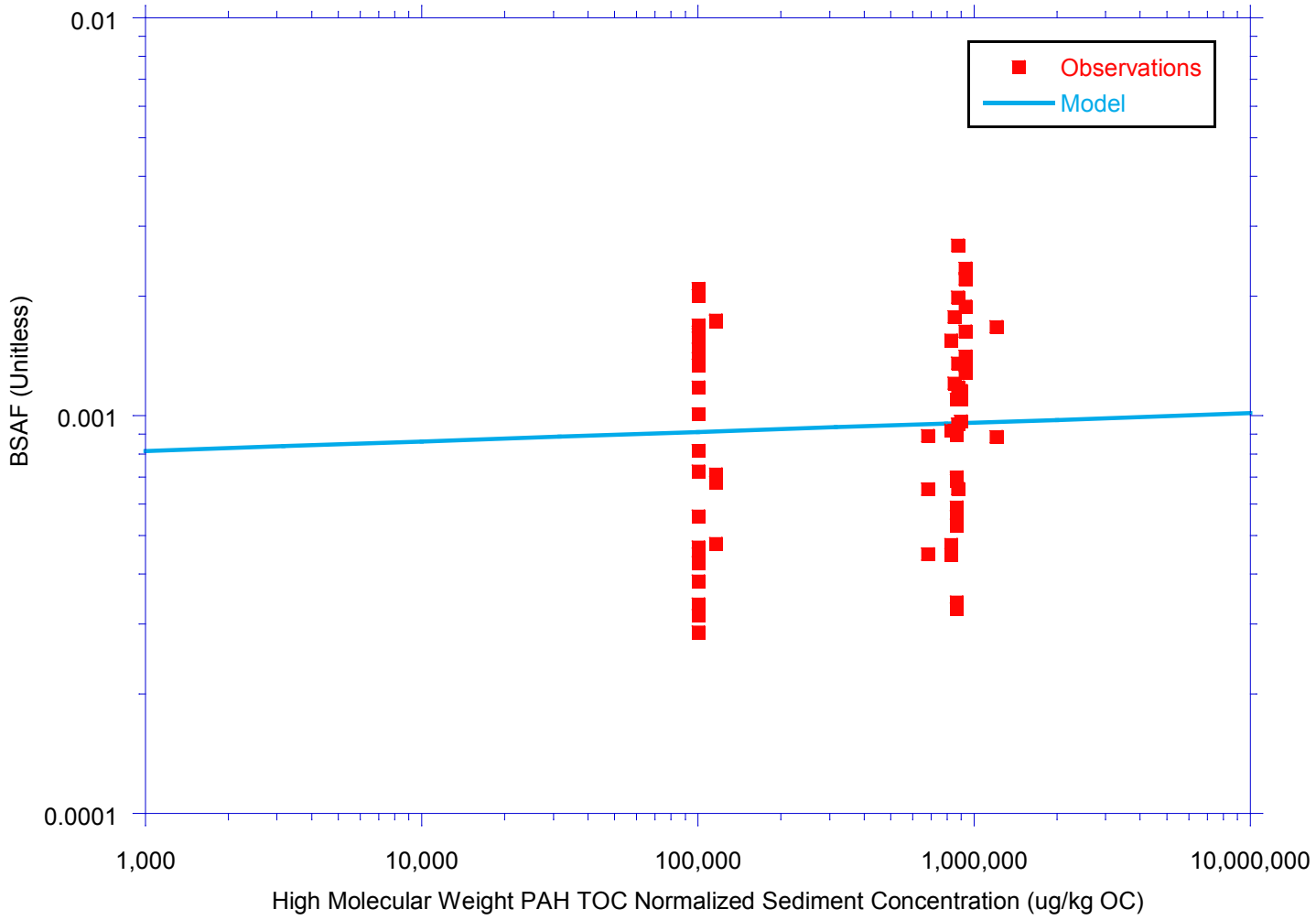
R2-0027702



Regression Model Results

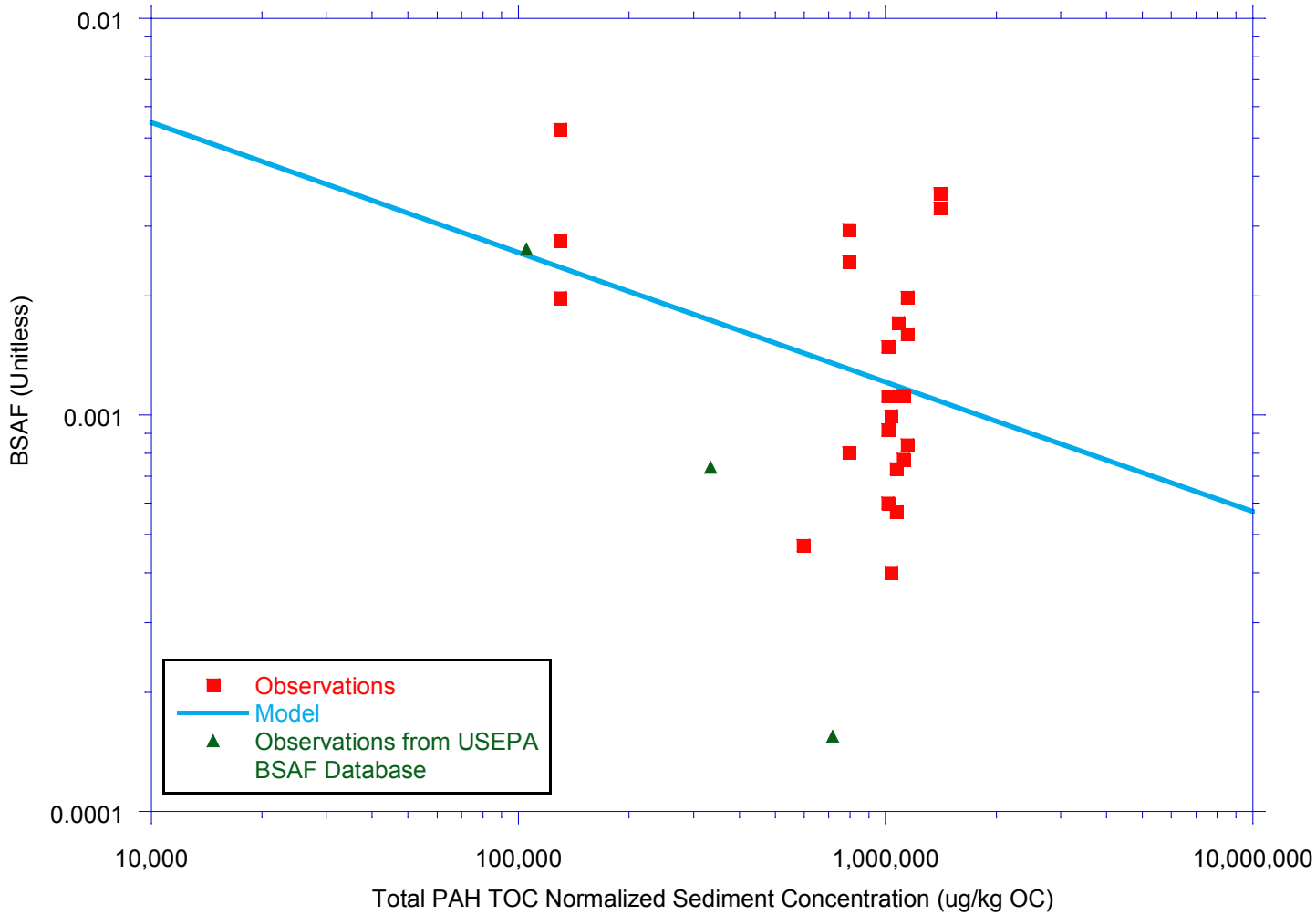
	Mummichog **BSAF *vs.* High Molecular Weight PAH TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-27c 2014

R2-0027703



Regression Model Results

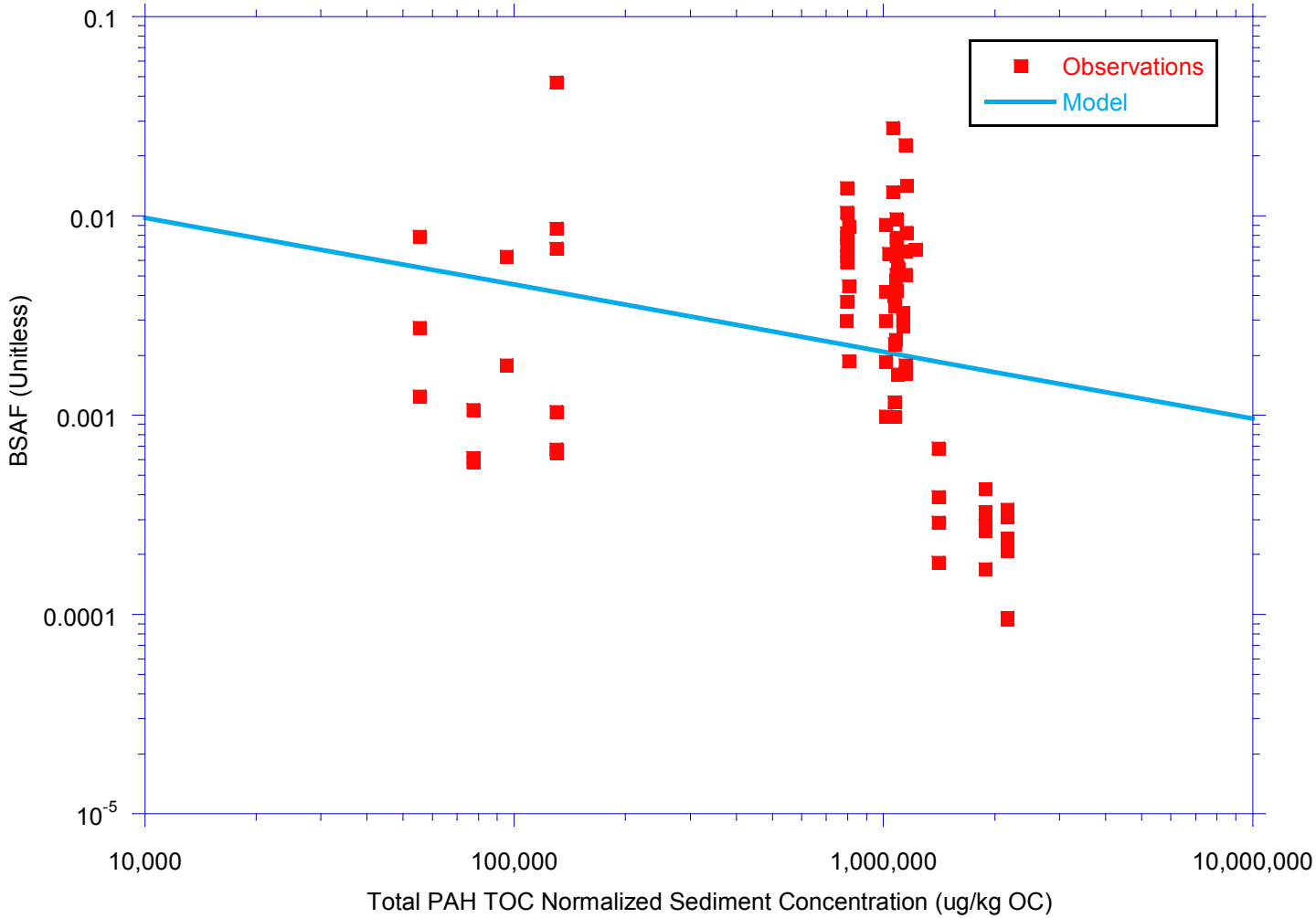
	White Perch **BSAF *vs.* High Molecular Weight PAH TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-27d 2014



Regression Model Results

	American Eel **BSAF *vs.* Total PAH TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-28a 2014

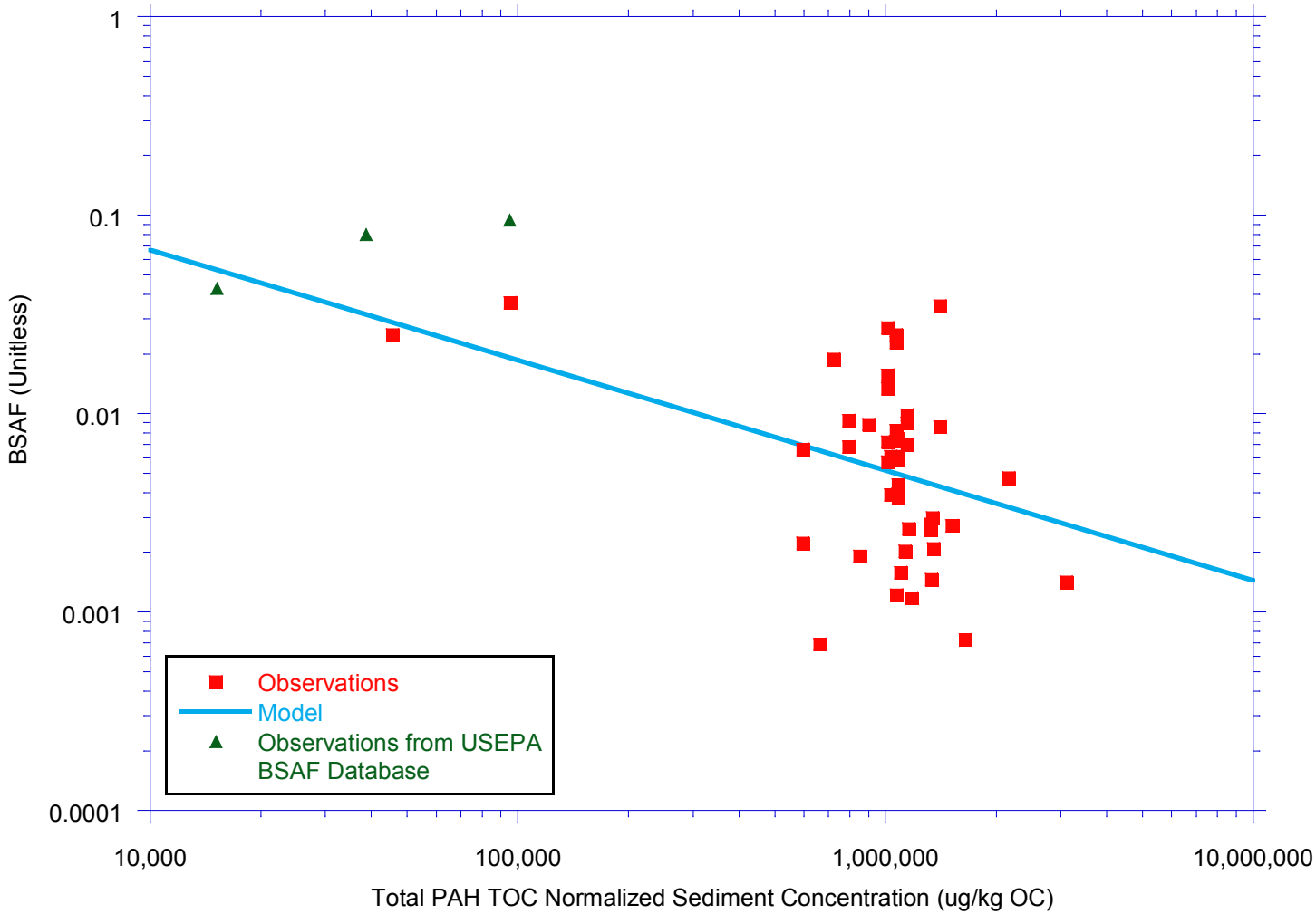
R2-0027705



Regression Model Results

	Blue Crab **BSAF *vs.* Total PAH TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-28b 2014

R2-0027706



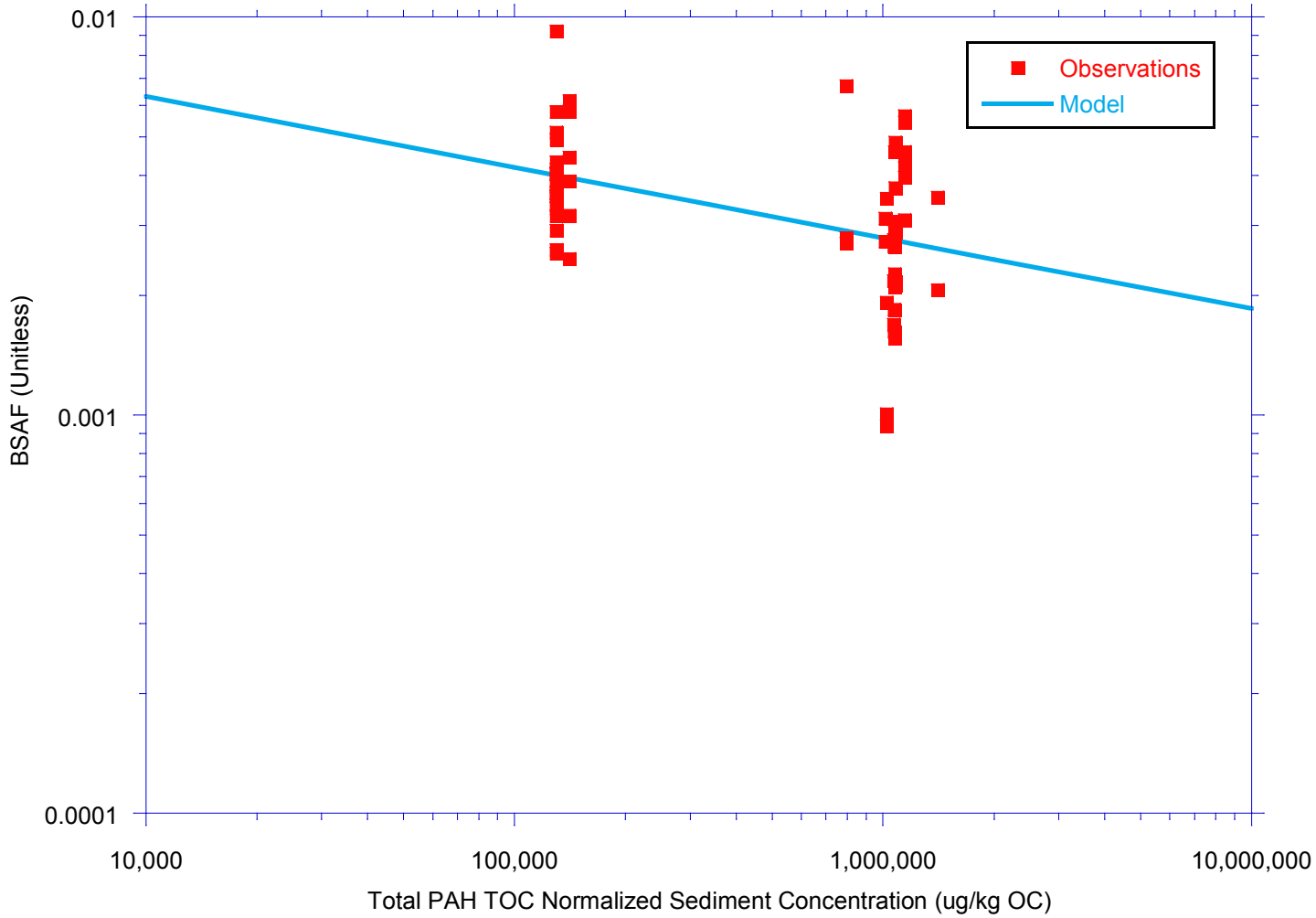
Regression Model Results

Mummichog
BSAF *vs.* Total PAH TOC Normalized Sediment Concentration
Lower Eight Miles of the Lower Passaic River

Figure 3-28c

2014

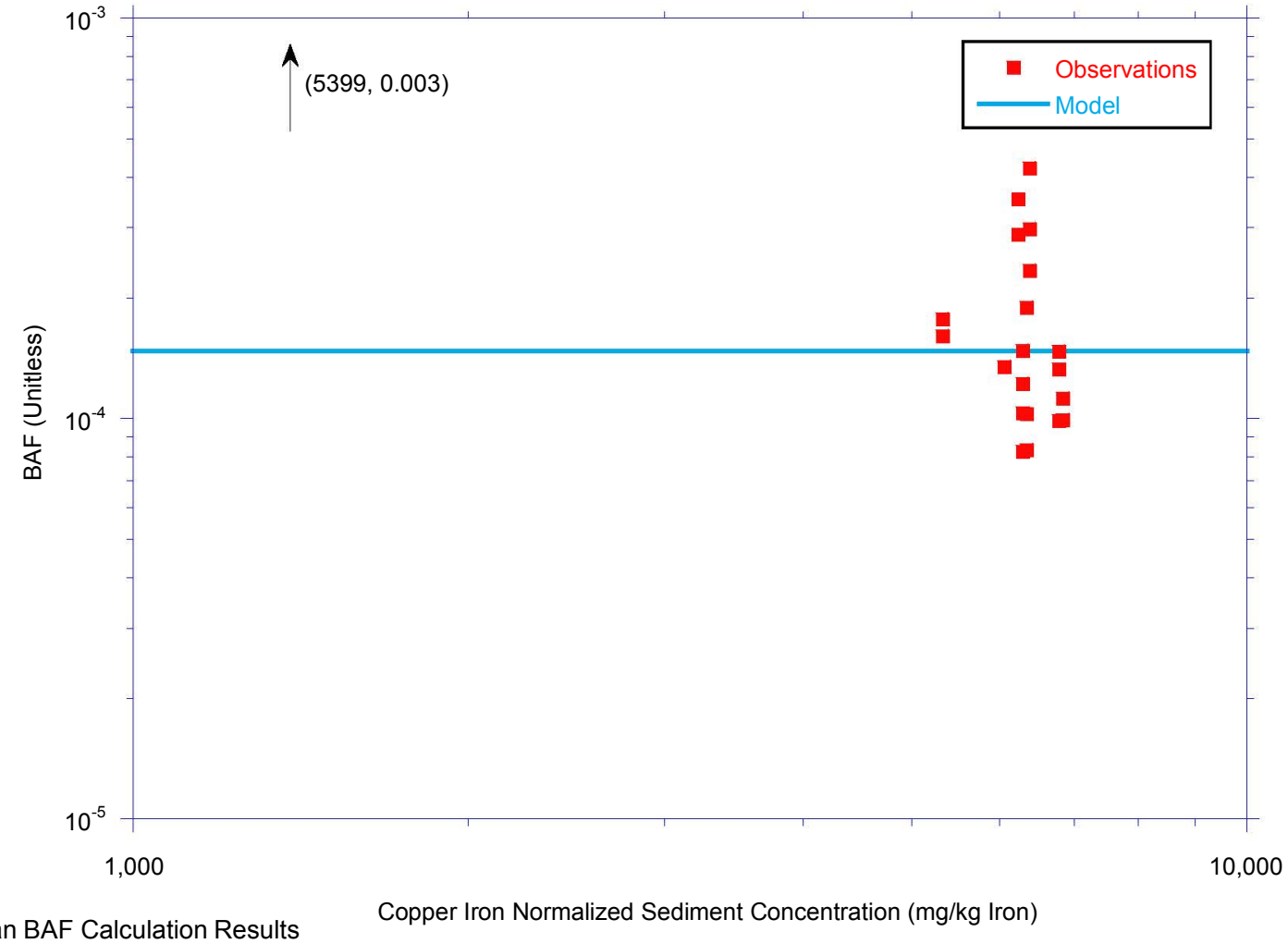
R2-0027707



Regression Model Results

	White Perch **BSAF *vs.* Total PAH TOC Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-28d 2014

R2-0027708

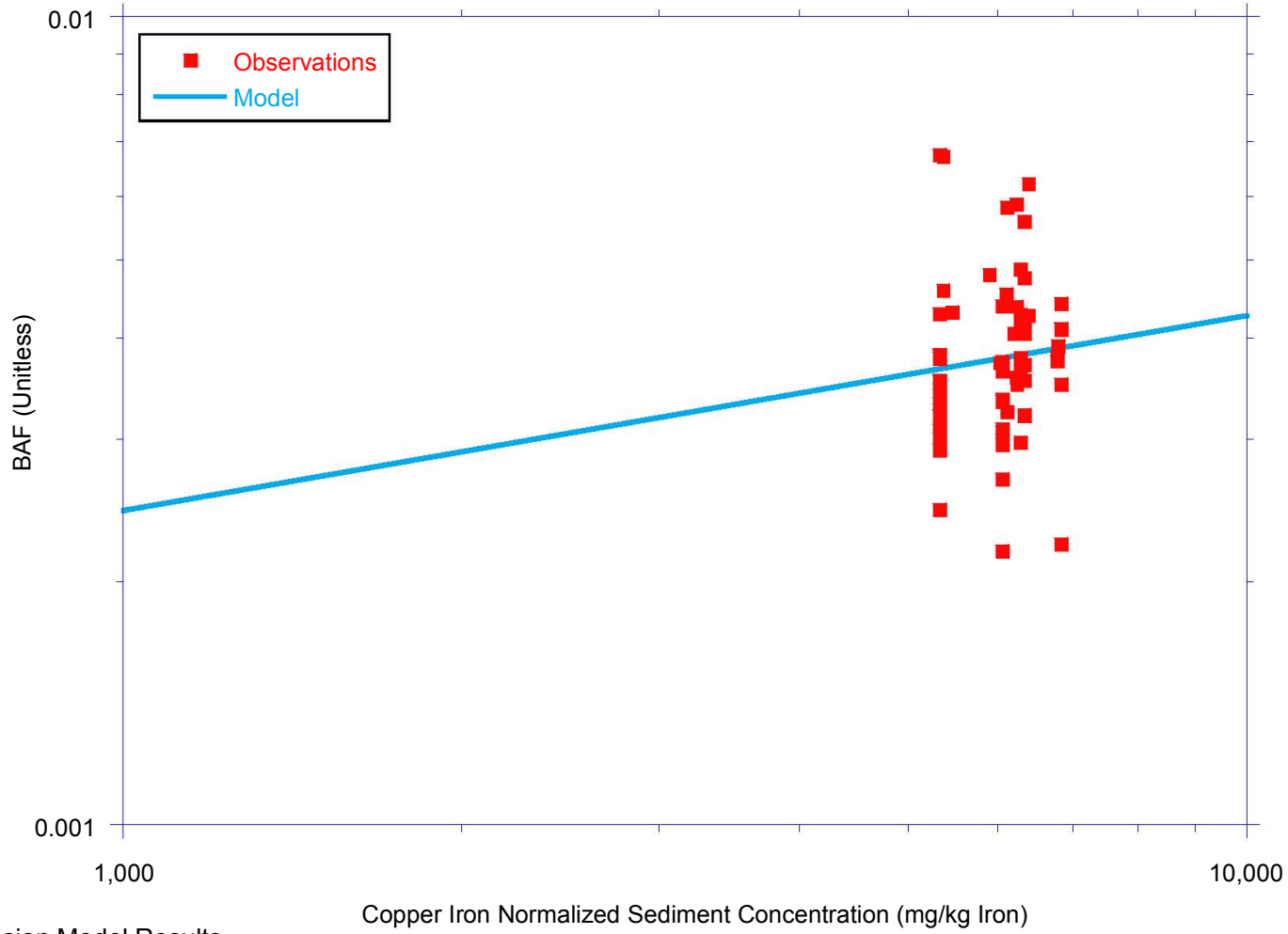


American Eel
BSF *vs.* Copper Iron Normalized Sediment Concentration
Lower Eight Miles of the Lower Passaic River

Figure 3-29a

2014

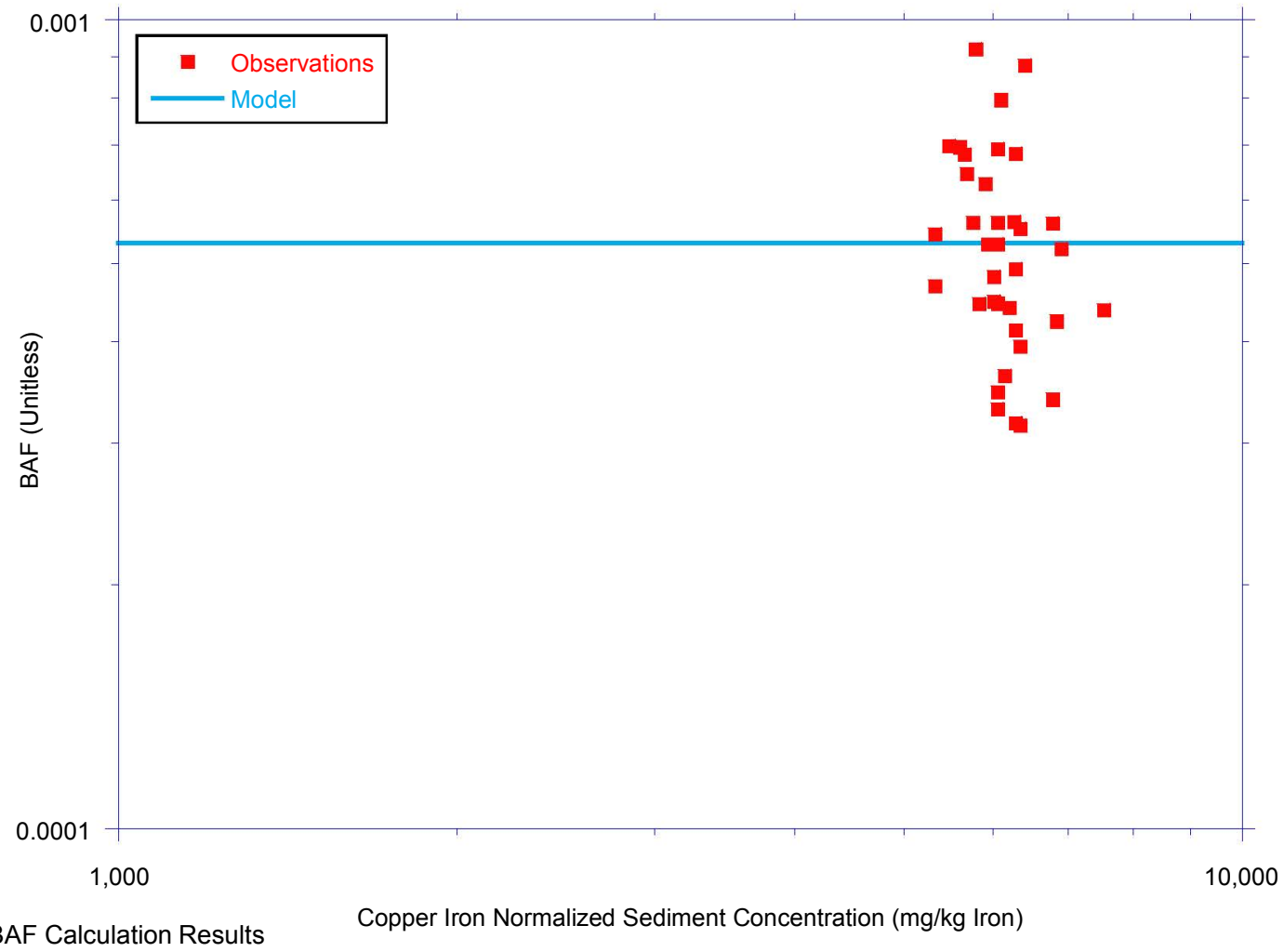
R2-0027709



Regression Model Results

	Blue Crab **BAF *vs.* Copper Iron Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-29b 2014

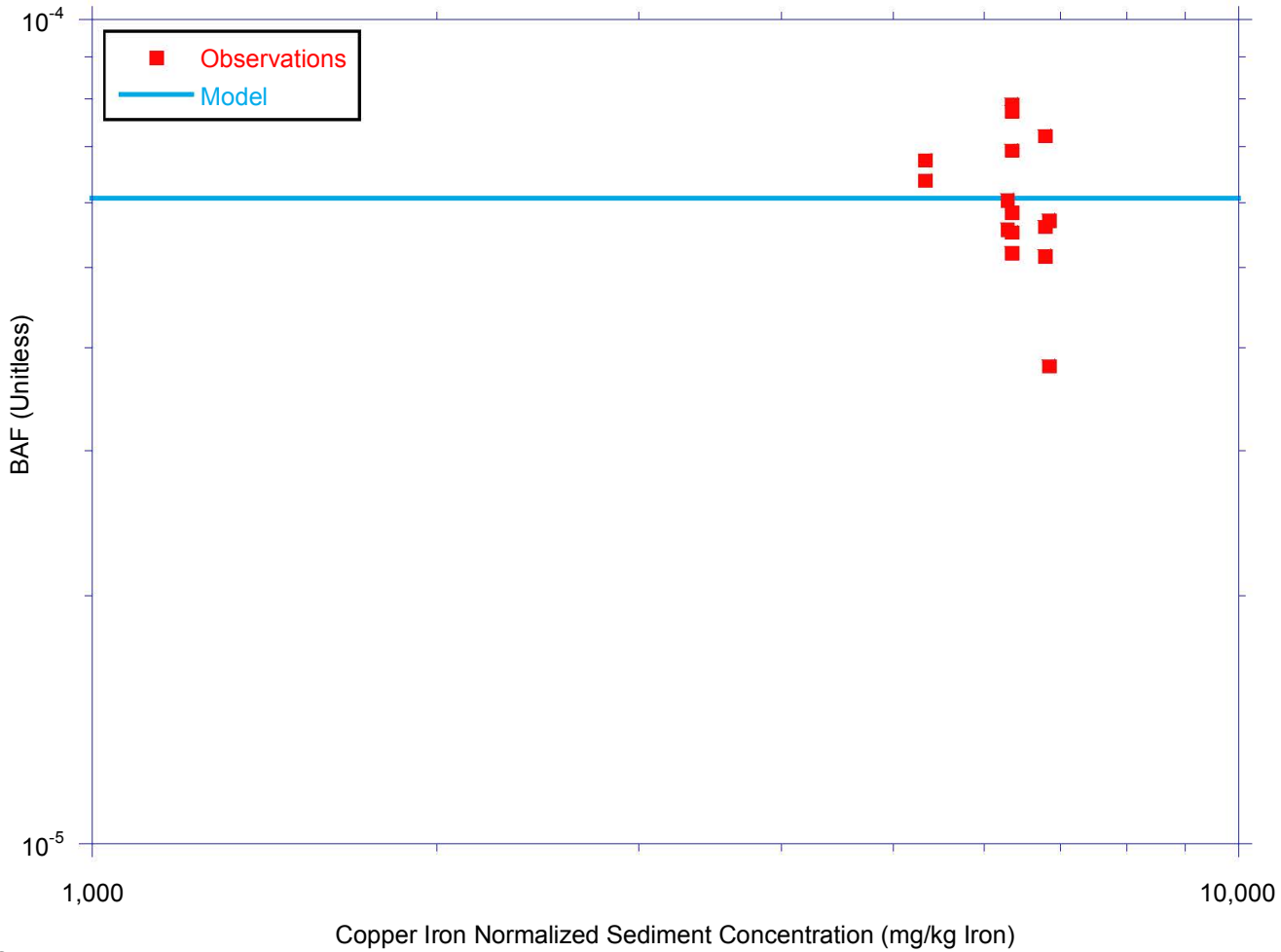
R2-0027710



Mean BAF Calculation Results

	Mummichog **BAF *vs.* Copper Iron Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-29c 2014

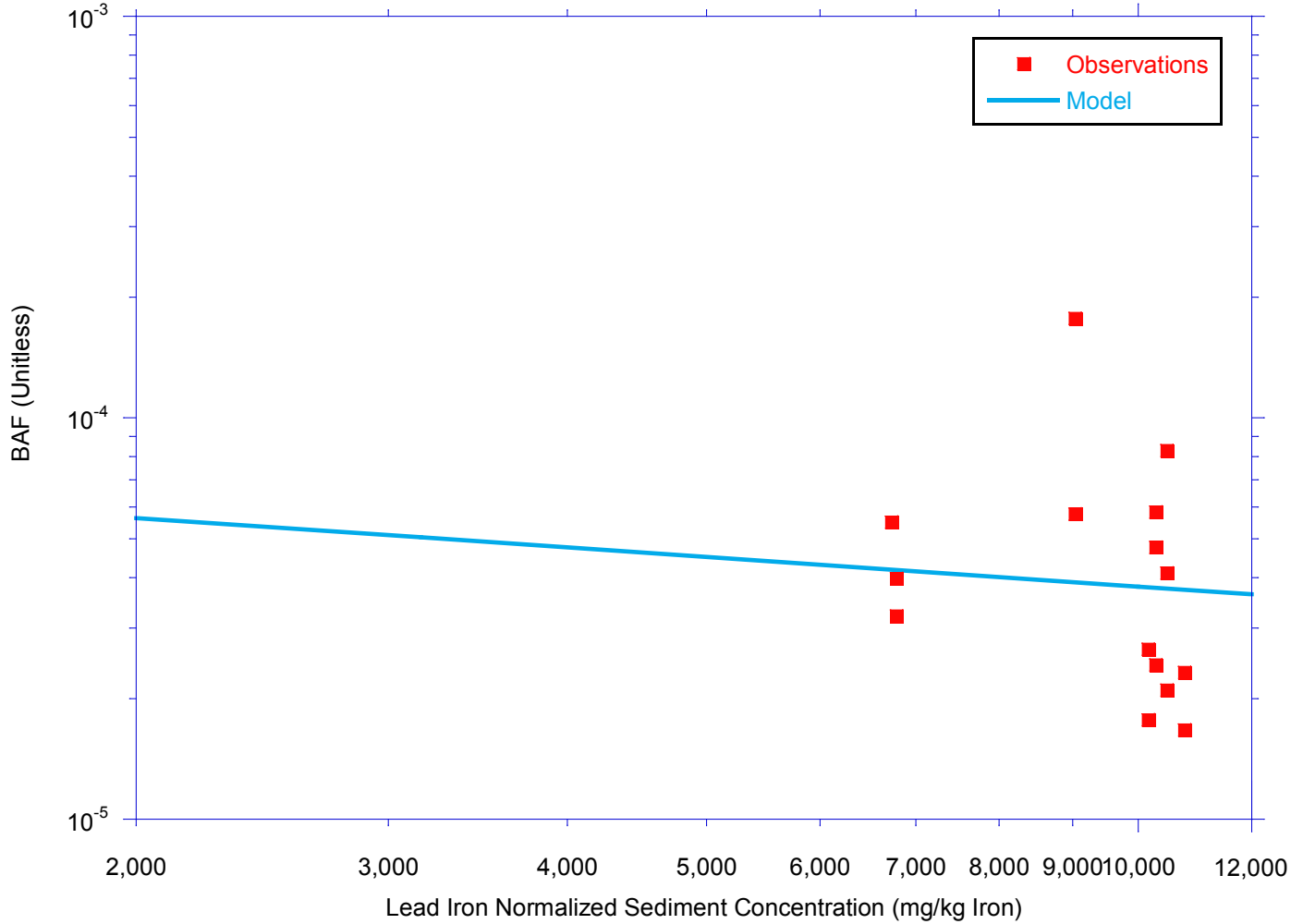
R2-0027711



Mean BAF Calculation Results

	White Perch **BAF *vs.* Copper Iron Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-29d 2014

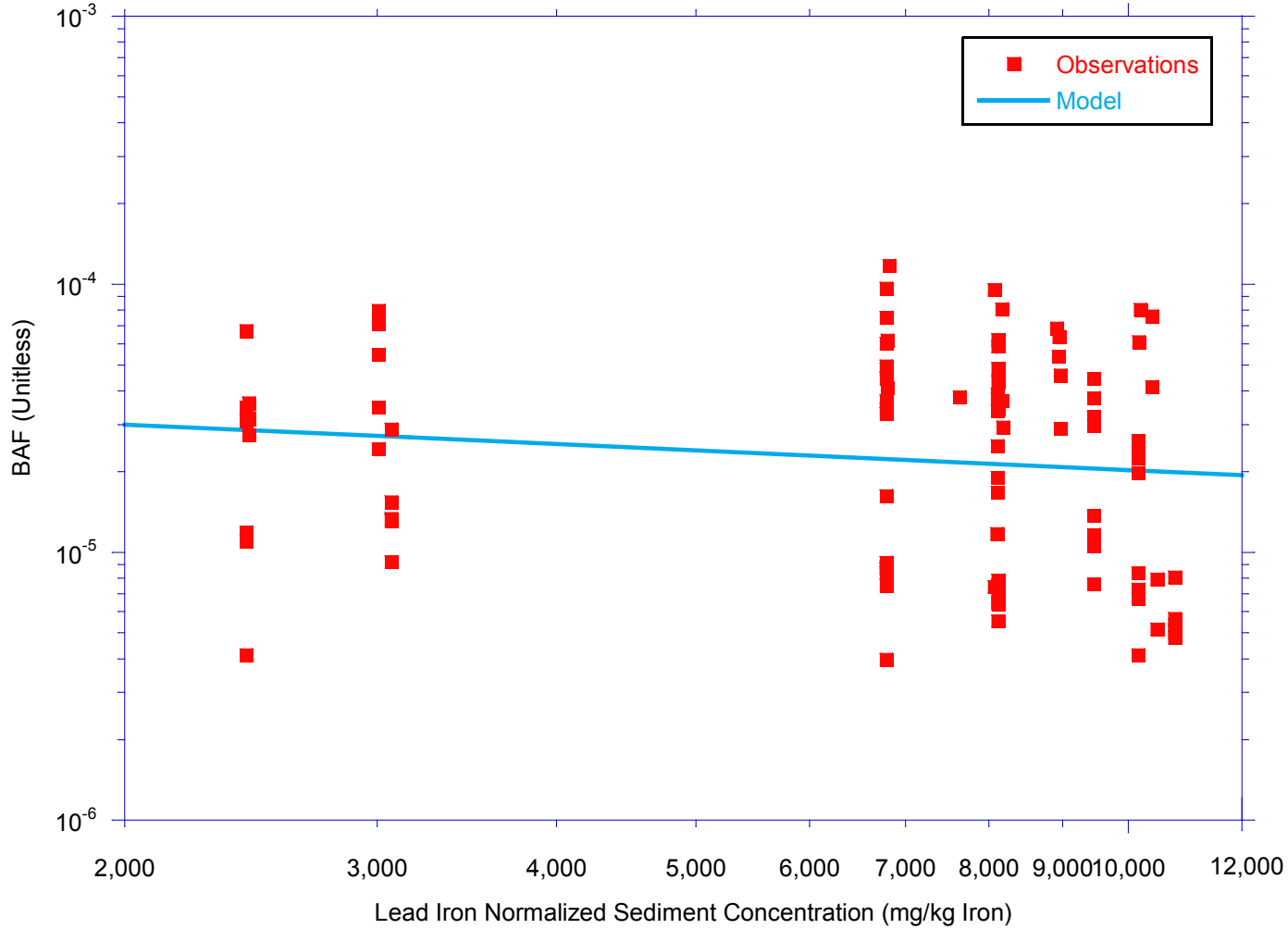
R2-0027712



Regression Model Results

	American Eel **BAF *vs.* Lead Iron Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-30a 2014

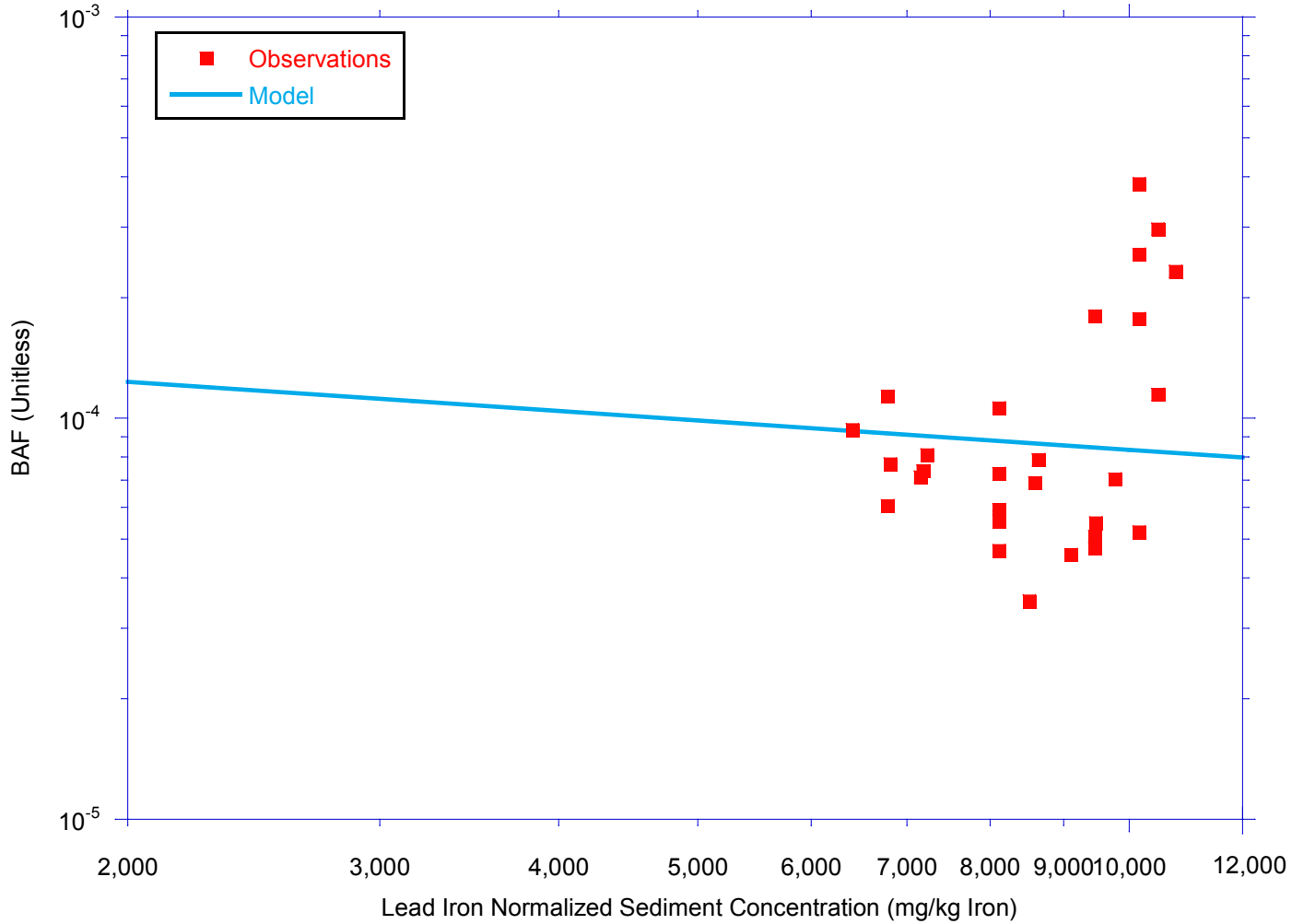
R2-0027713



Regression Model Results

	Blue Crab **BAF *vs.* Lead Iron Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-30b 2014

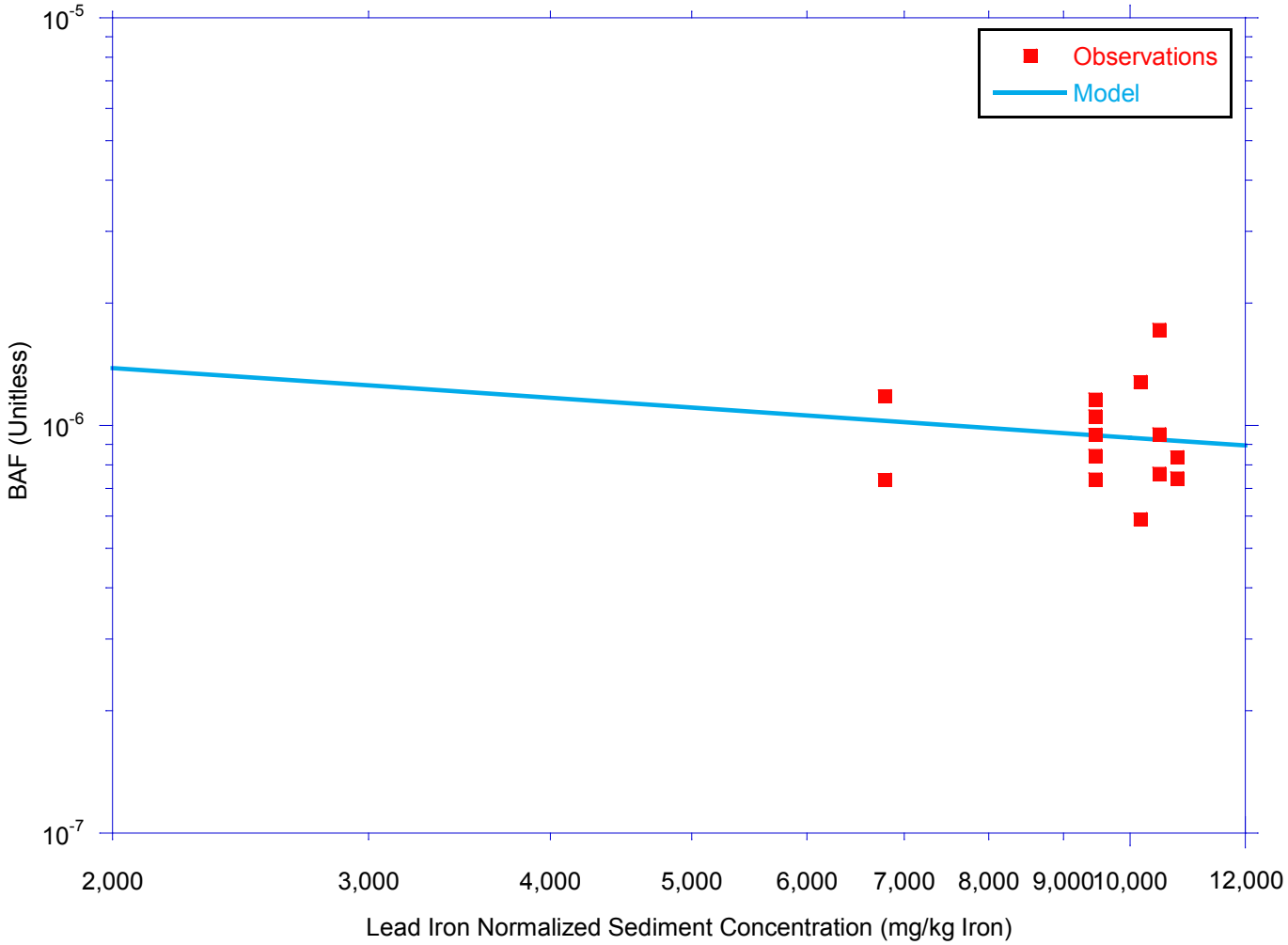
R2-0027714



Regression Model Results

	Mummichog **BAF *vs.* Lead Iron Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-30c 2014

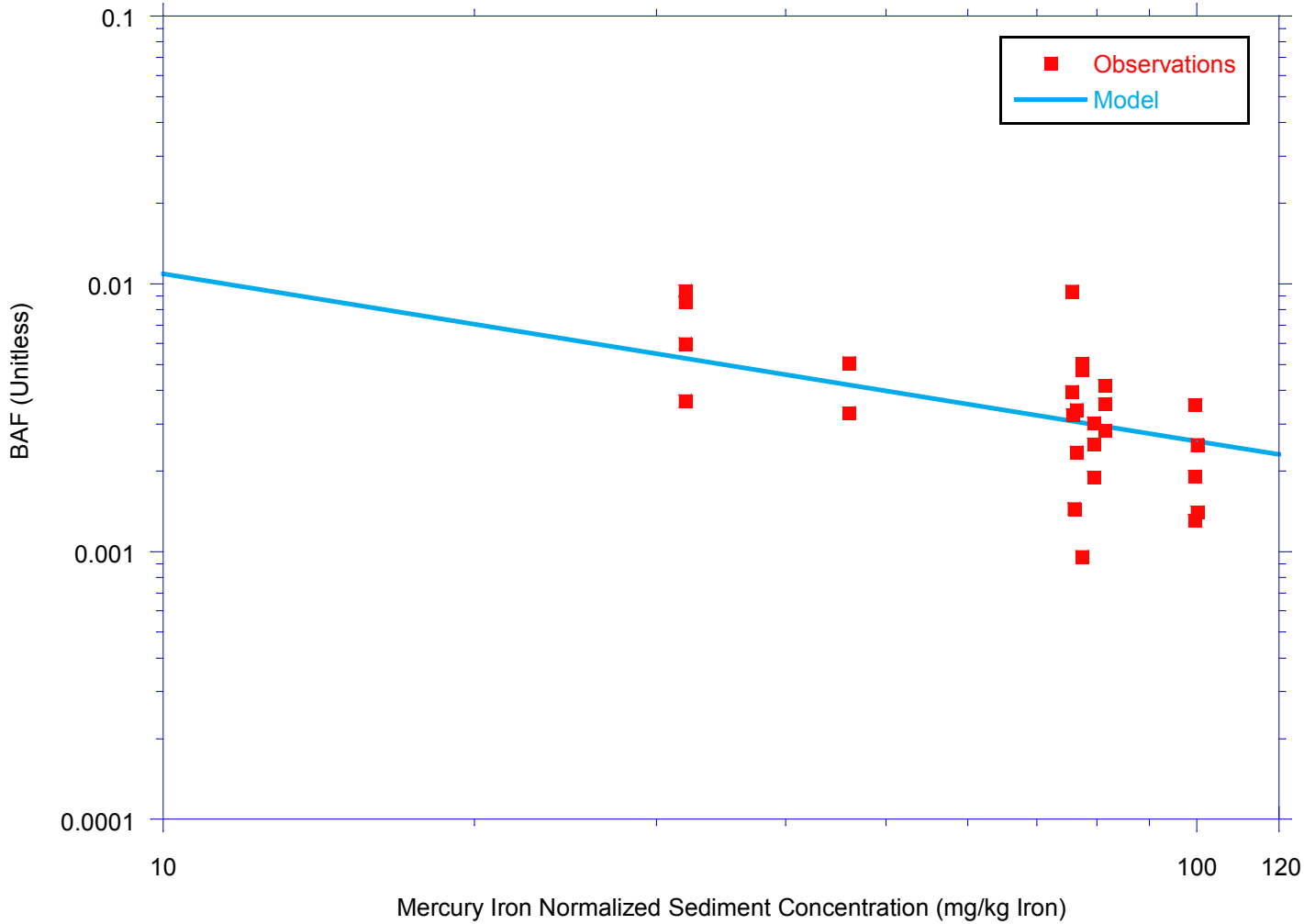
R2-0027715



Regression Model Results

	White Perch **BAF *vs.* Lead Iron Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-30d 2014

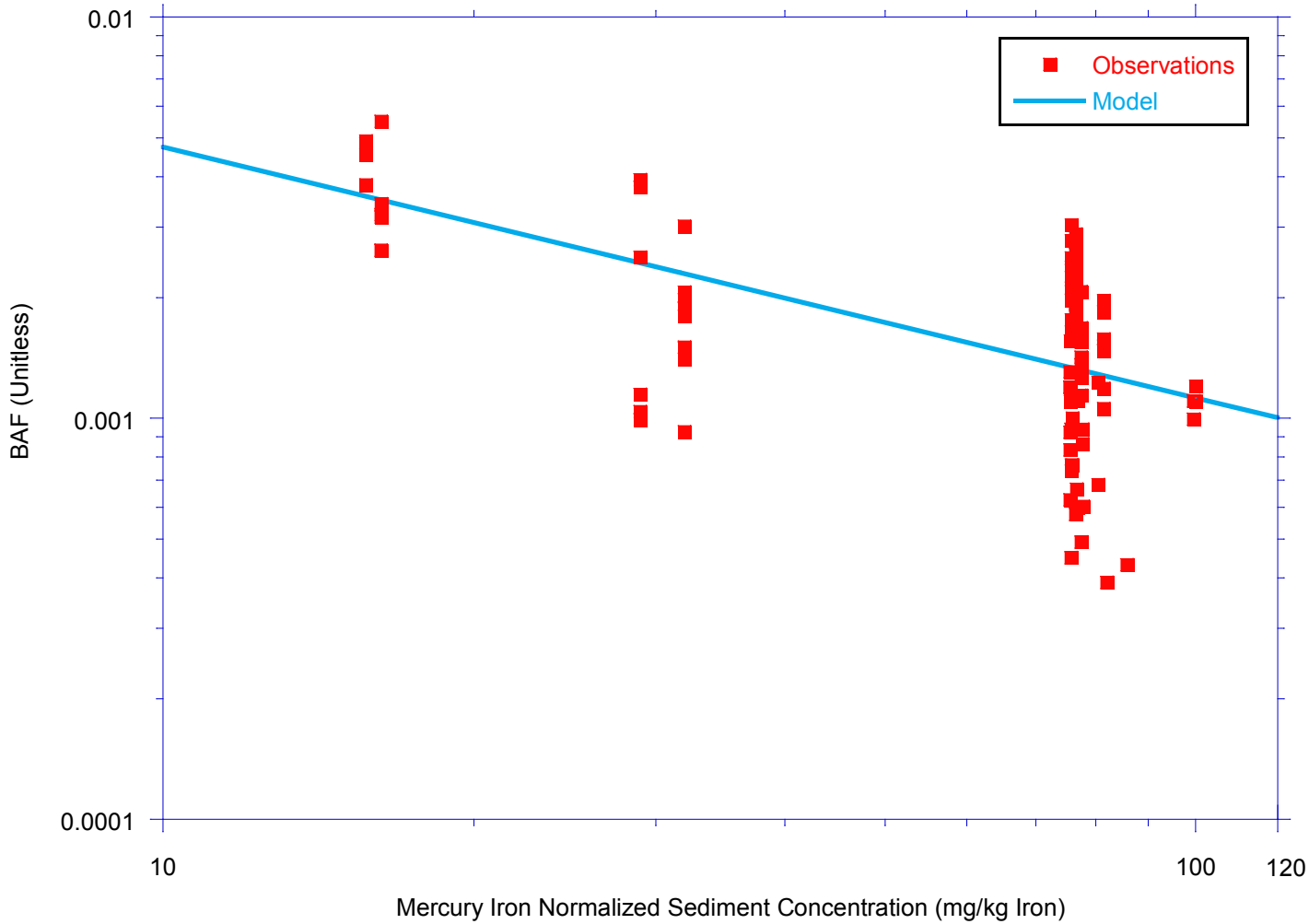
R2-0027716



Regression Model Results

	American Eel **BAF *vs.* Mercury Iron Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-31a 2014

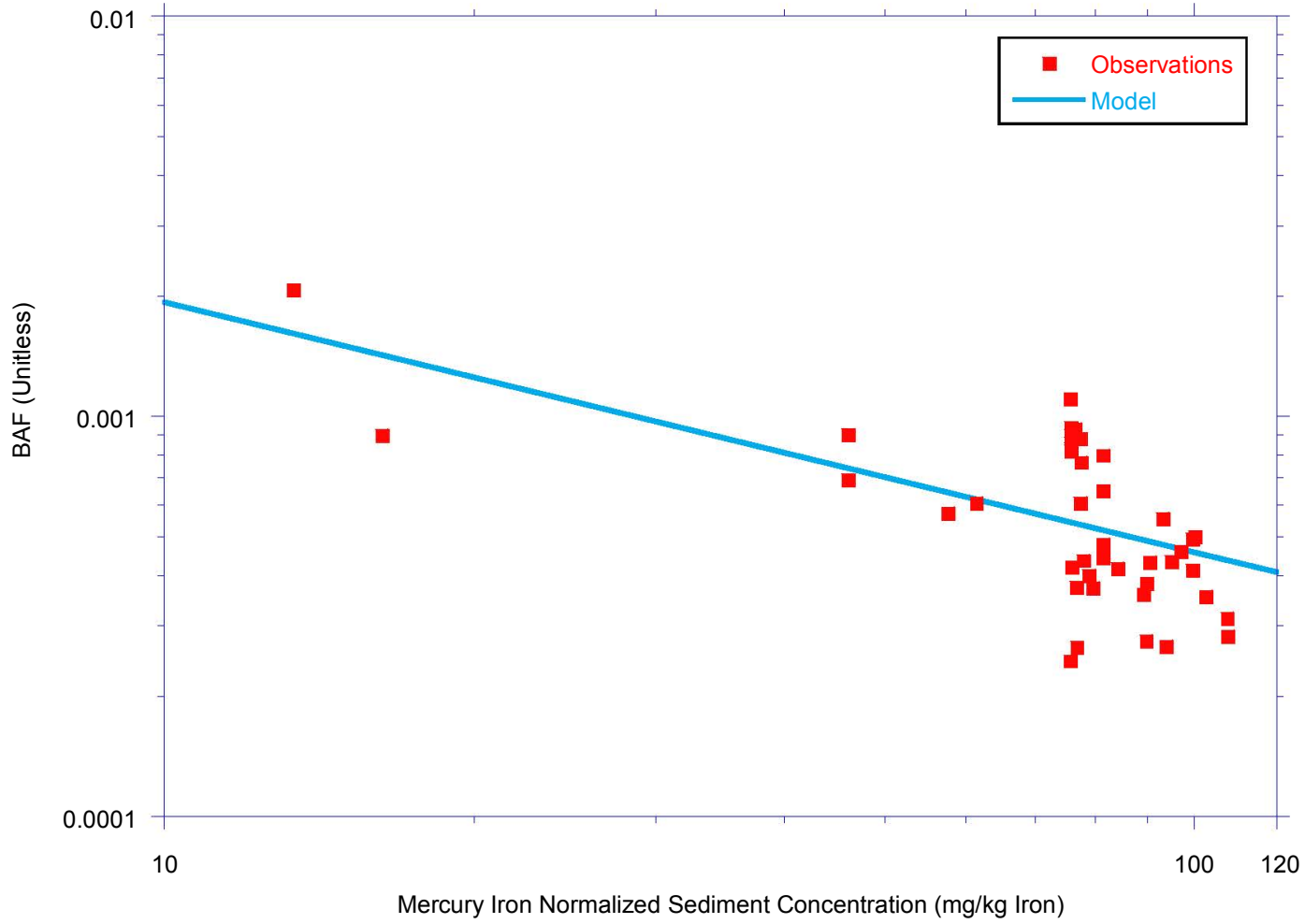
R2-0027717



Regression Model Results

	Blue Crab **BAF *vs.* Mercury Iron Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-31b 2014

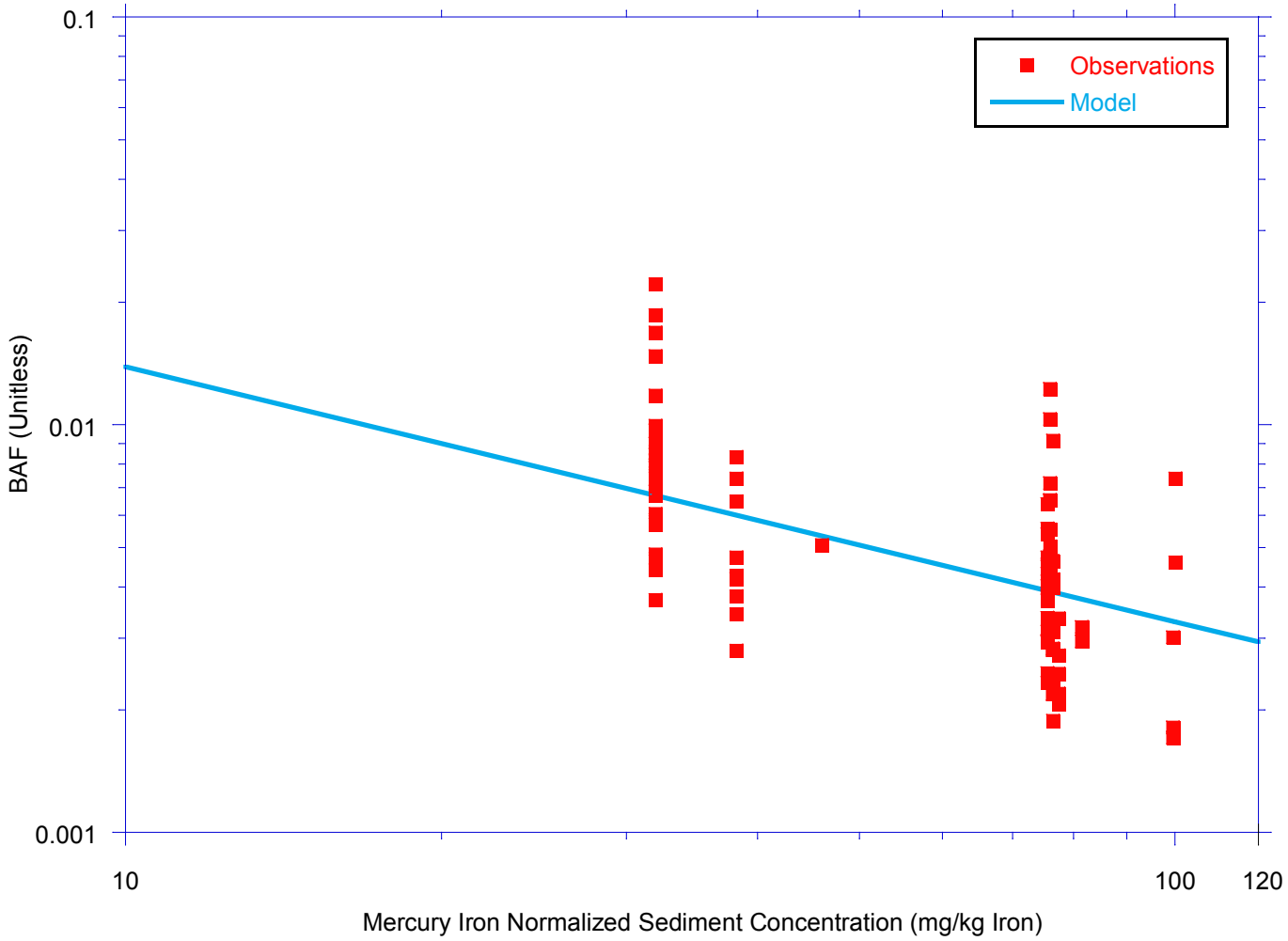
R2-0027718



Regression Model Results

	Mummichog **BAF *vs.* Mercury Iron Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-31c 2014

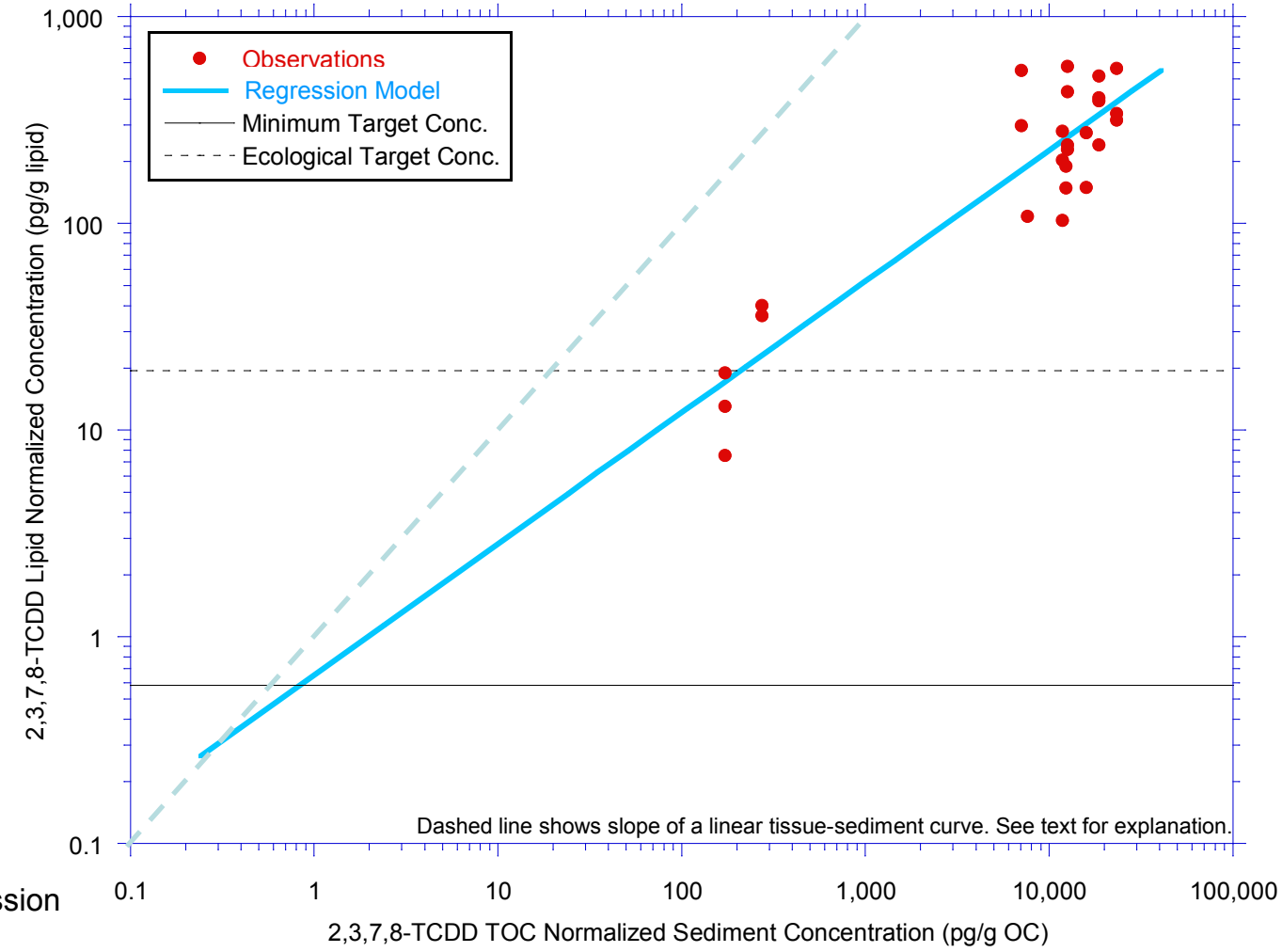
R2-0027719



Regression Model Results

	White Perch **BAF *vs.* Mercury Iron Normalized Sediment Concentration** *Lower Eight Miles of the Lower Passaic River*	Figure 3-31d 2014

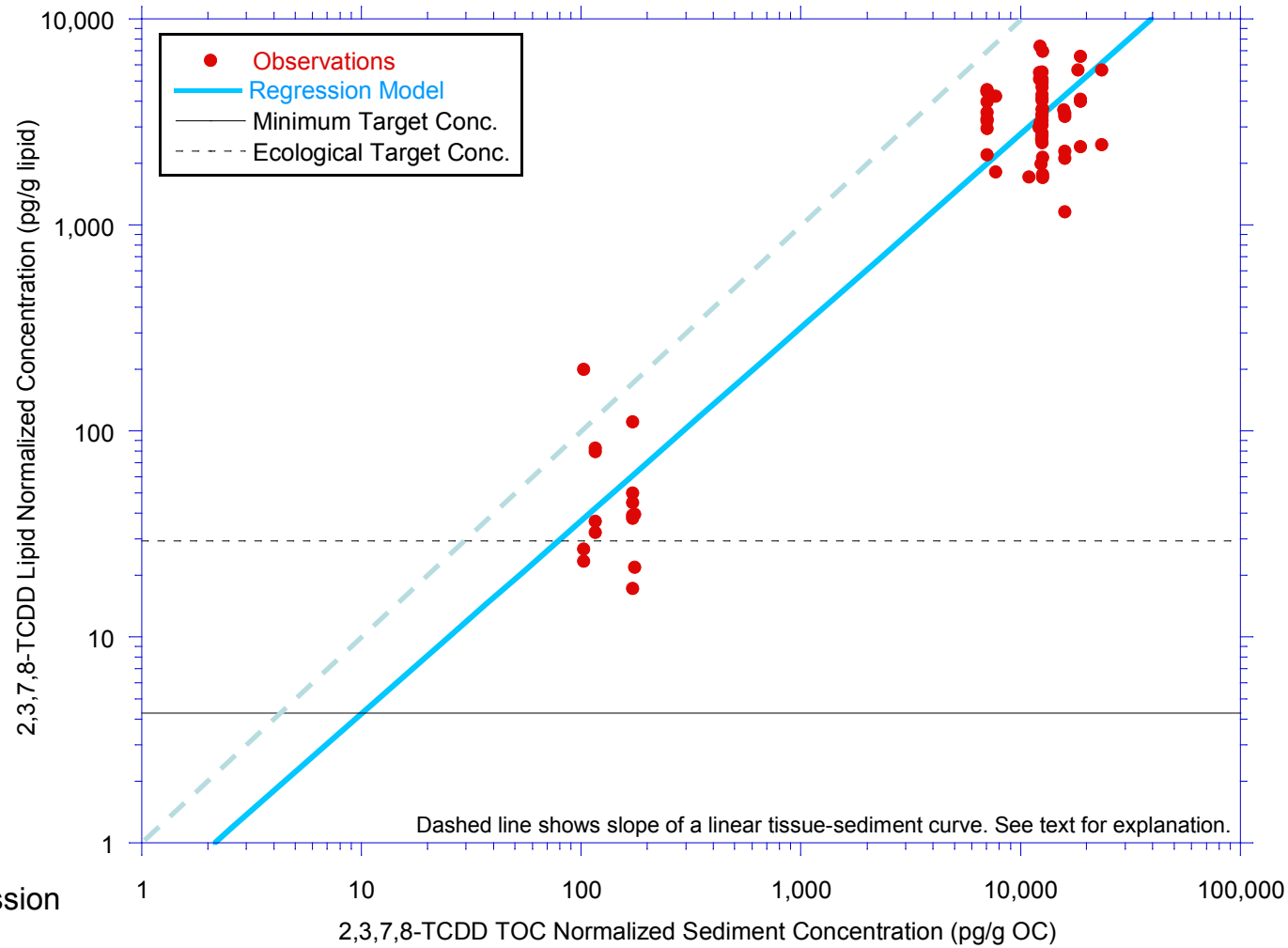
R2-0027720



Regression Model

	American Eel **2,3,7,8-TCDD Lipid Normalized Concentration in Tissue vs. 2,3,7,8-TCDD TOC Normalized Concentration in Sediment** *Lower Eight Miles of the Lower Passaic River*	Figure 3-32a 2014

R2-0027721



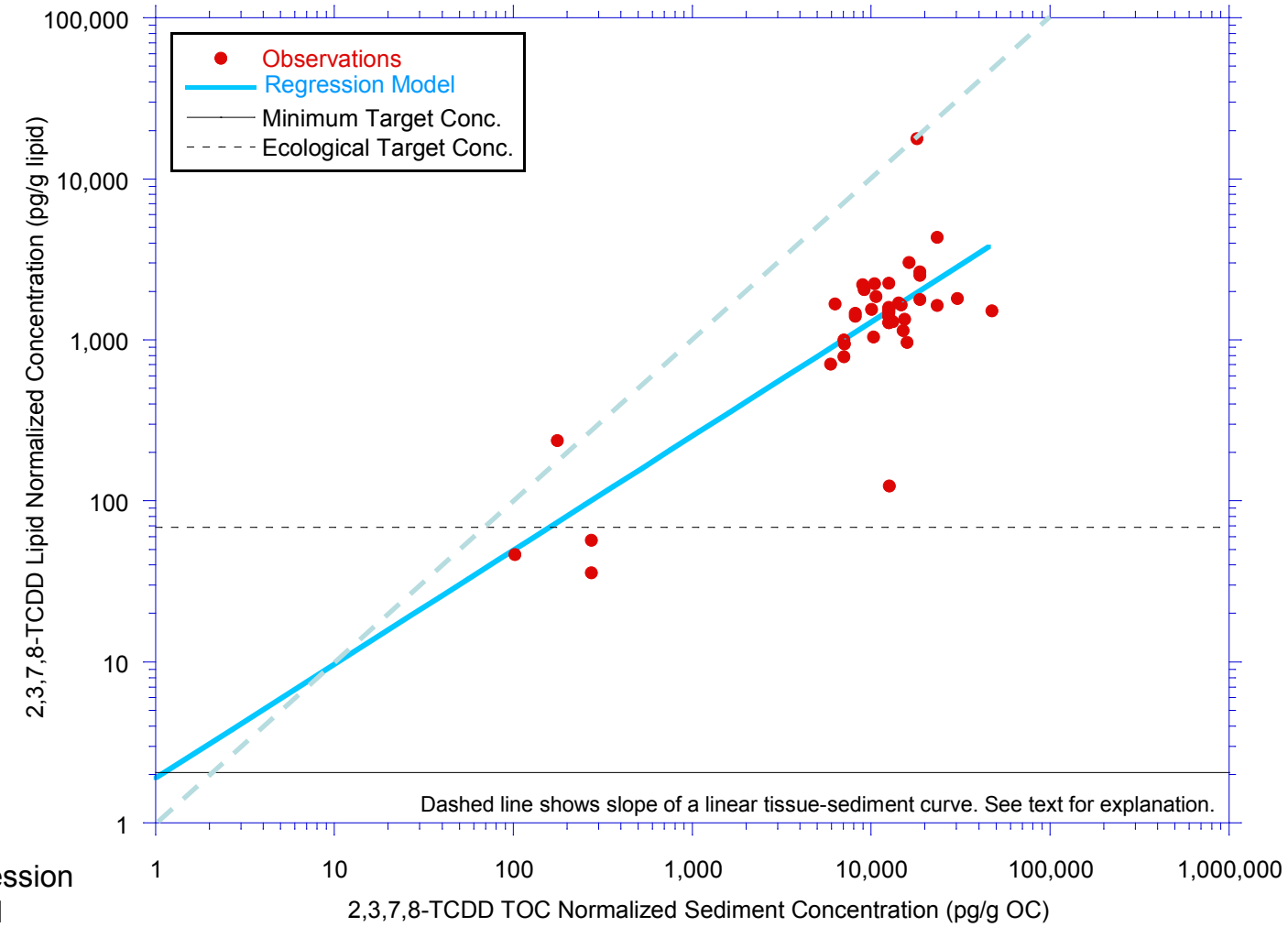
Regression Model

Blue Crab
2,3,7,8-TCDD Lipid Normalized Concentration in Tissue vs. 2,3,7,8-TCDD TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-32b

2014

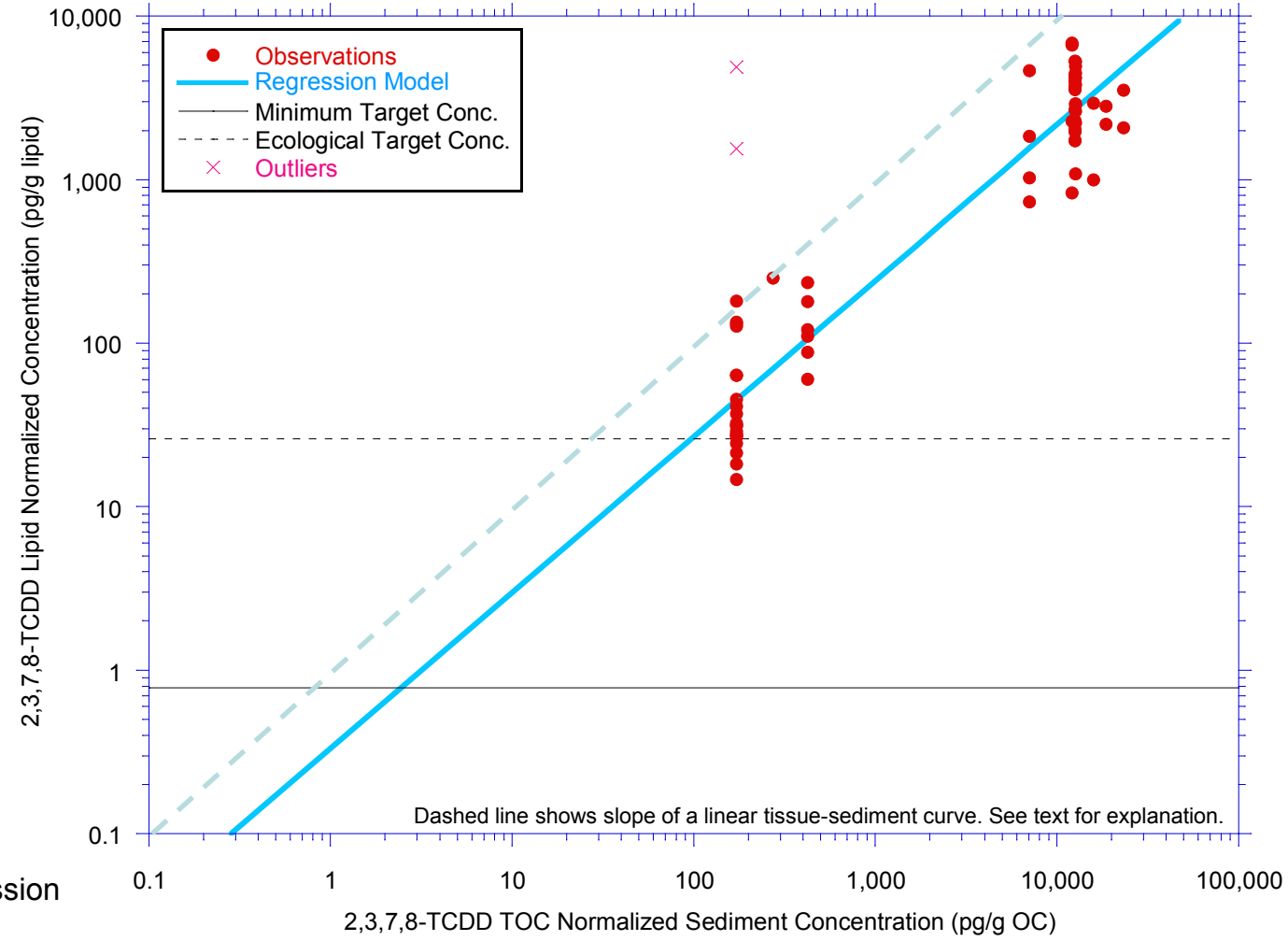
R2-0027722



Regression Model

	Mummichog **2,3,7,8-TCDD Lipid Normalized Concentration in Tissue vs. 2,3,7,8-TCDD TOC Normalized Concentration in Sediment** *Lower Eight Miles of the Lower Passaic River*	Figure 3-32c 2014

R2-0027723



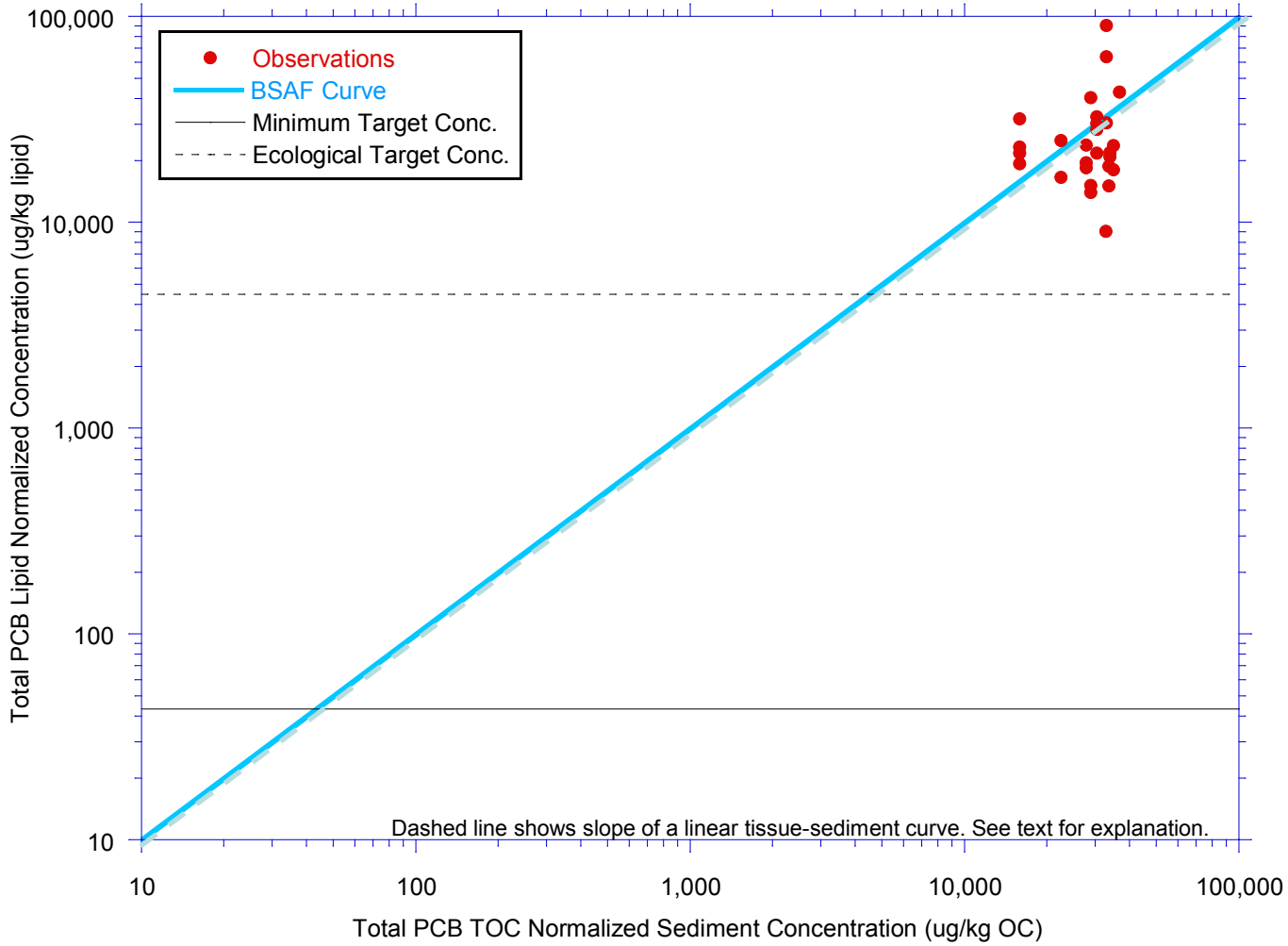
Regression Model

White Perch
2,3,7,8-TCDD Lipid Normalized Concentration in Tissue vs. 2,3,7,8-TCDD TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-32d

2014

R2-0027724



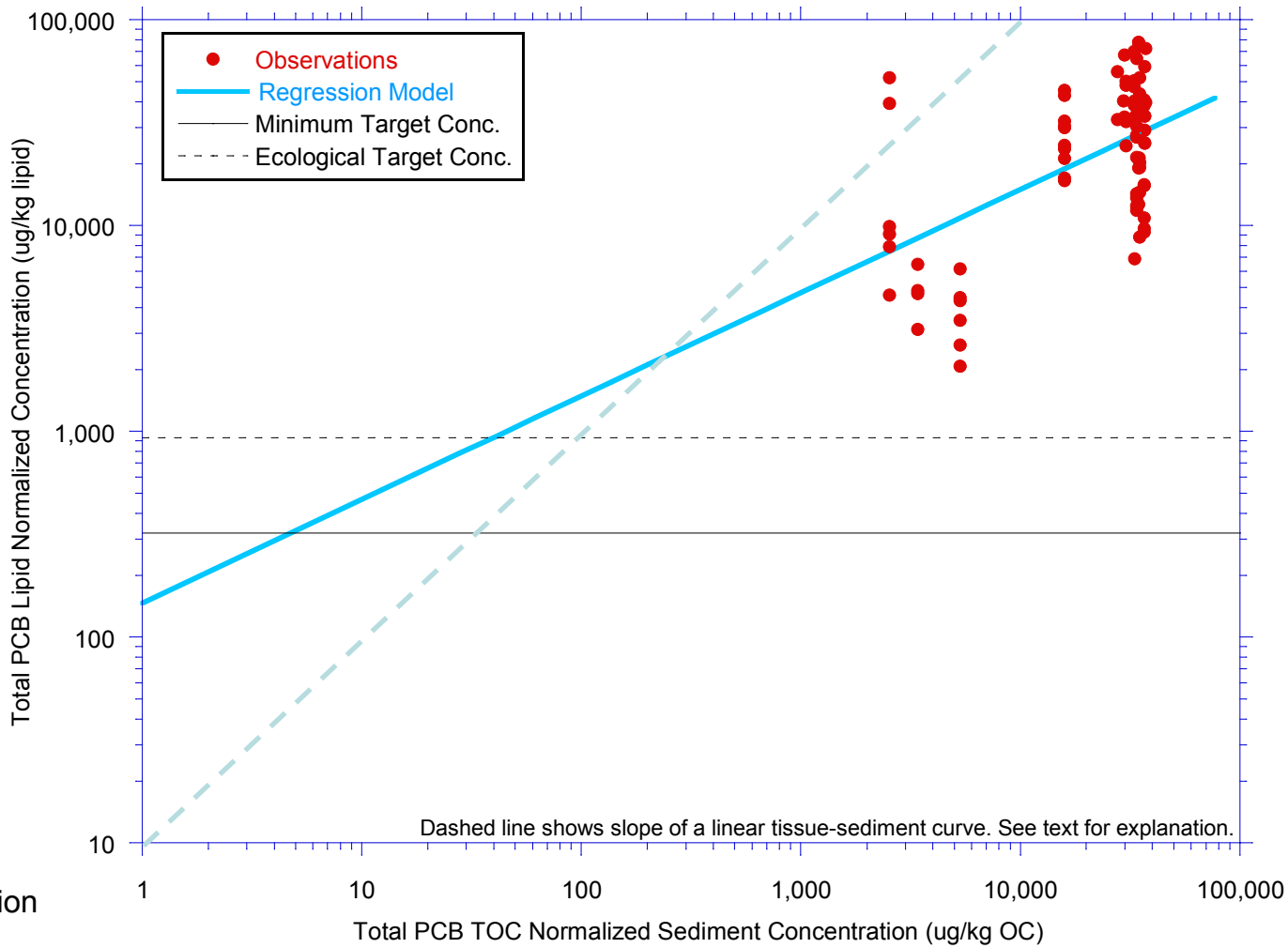
BSAF Curve

American Eel
Total PCB Lipid Normalized Concentration in Tissue vs. Total PCB TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-33a

2014

R2-0027725



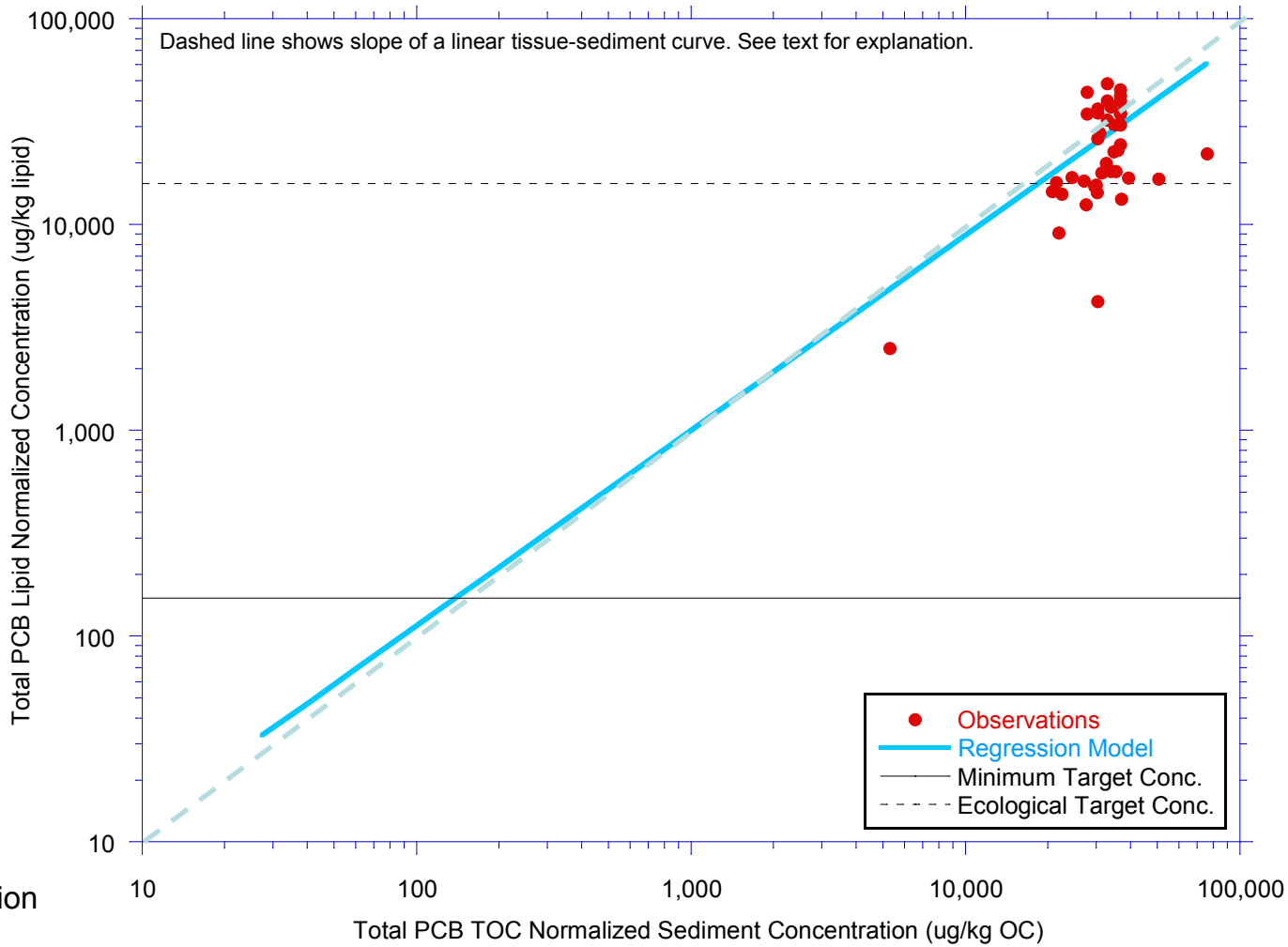
Regression Model

Blue Crab
Total PCB Lipid Normalized Concentration in Tissue vs. Total PCB TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-33b

2014

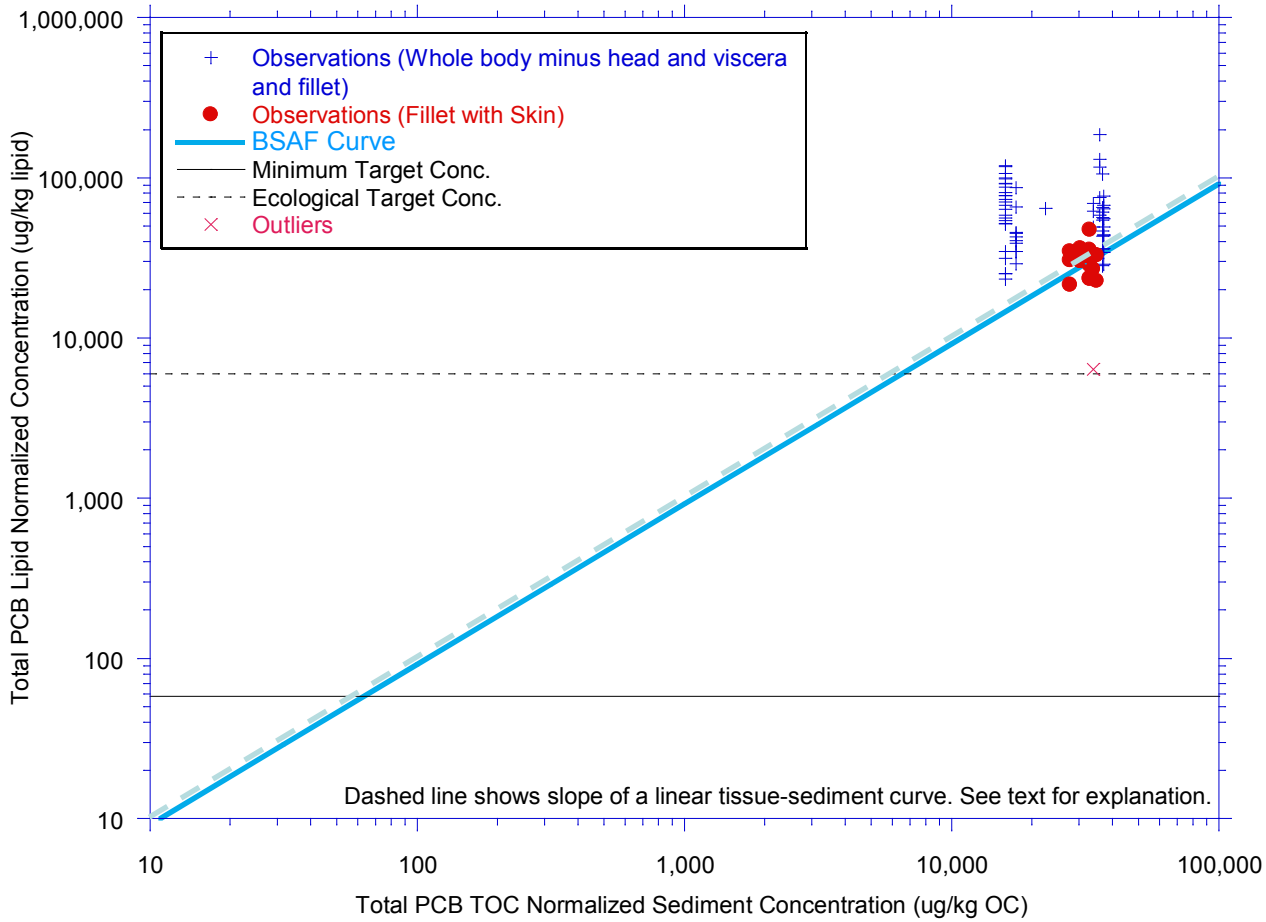
R2-0027726



Regression Model

	Mummichog **Total PCB Lipid Normalized Concentration in Tissue vs. Total PCB TOC Normalized Concentration in Sediment** *Lower Eight Miles of the Lower Passaic River*	Figure 3-33c 2014

R2-0027727

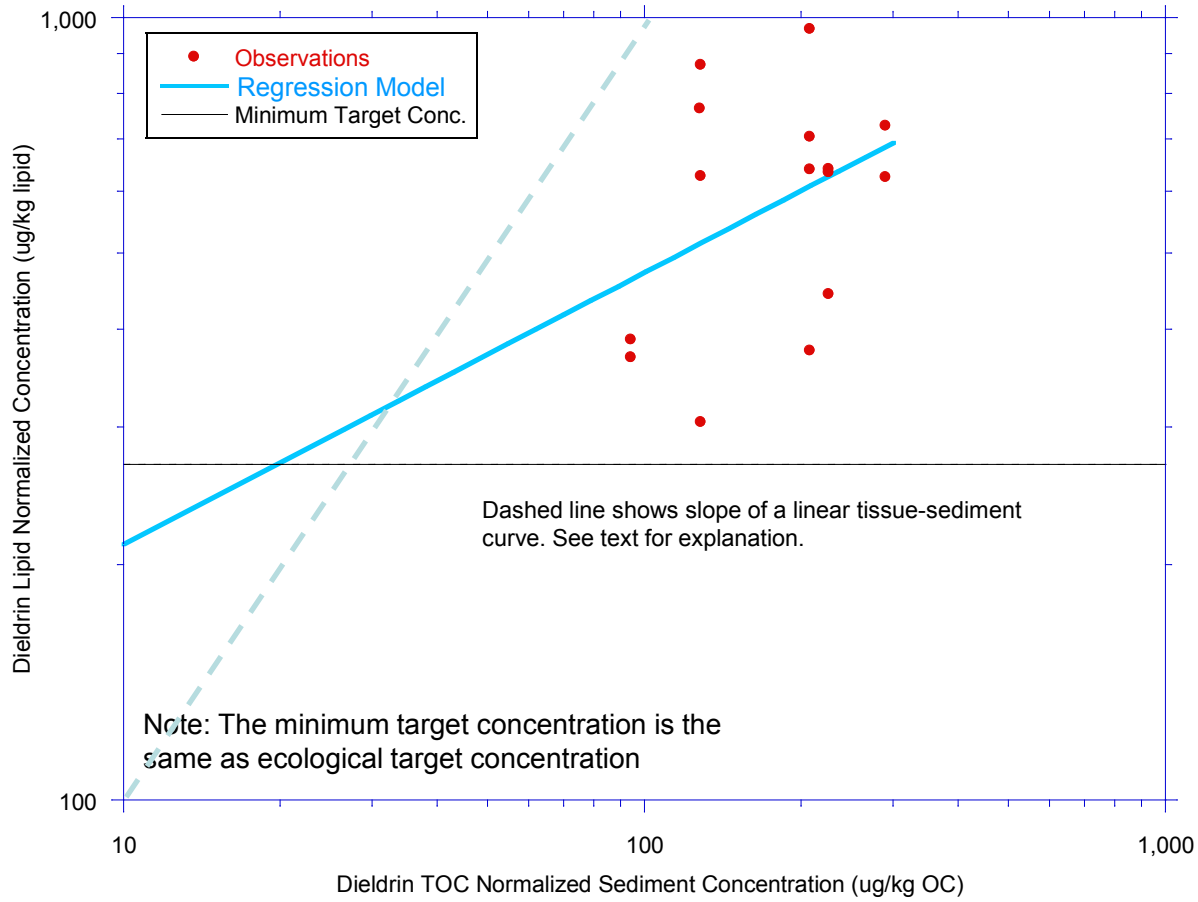


BSAF Curve

Notes:

1. Observations (Whole body minus head and viscera and fillet) from year 1999 and 2000 datasets are not included in the model curve development.
2. The model curve is developed by using mean BSAF of fillet with skin samples from year 2009 dataset.

	White Perch **Total PCB Lipid Normalized Concentration in Tissue vs. Total PCB TOC Normalized Concentration in Sediment** *Lower Eight Miles of the Lower Passaic River*	Figure 3-33d 2014



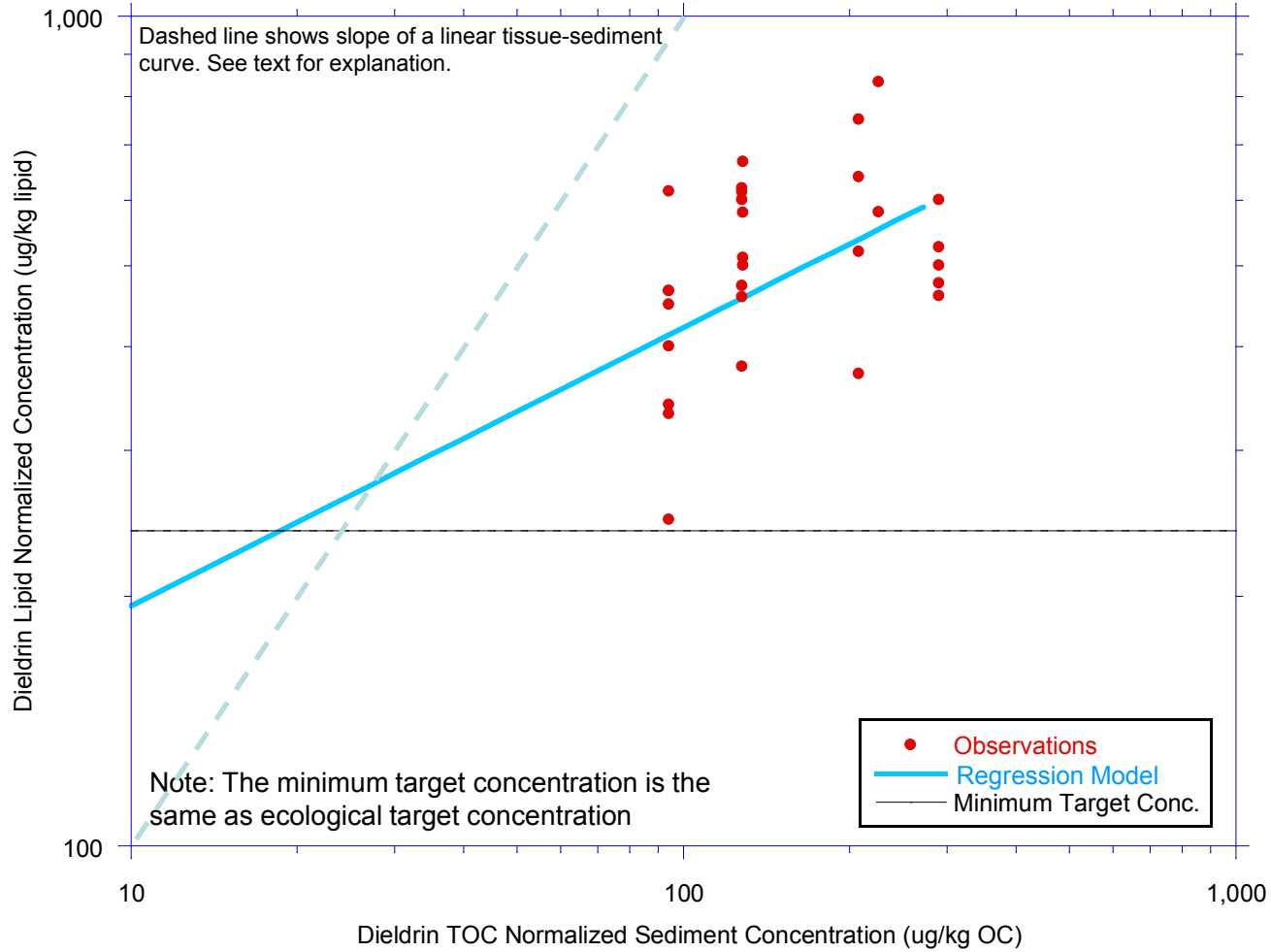
Regression Model

American Eel
Dieldrin Lipid Normalized Concentration in Tissue vs. Dieldrin TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-34a

2014

R2-0027729



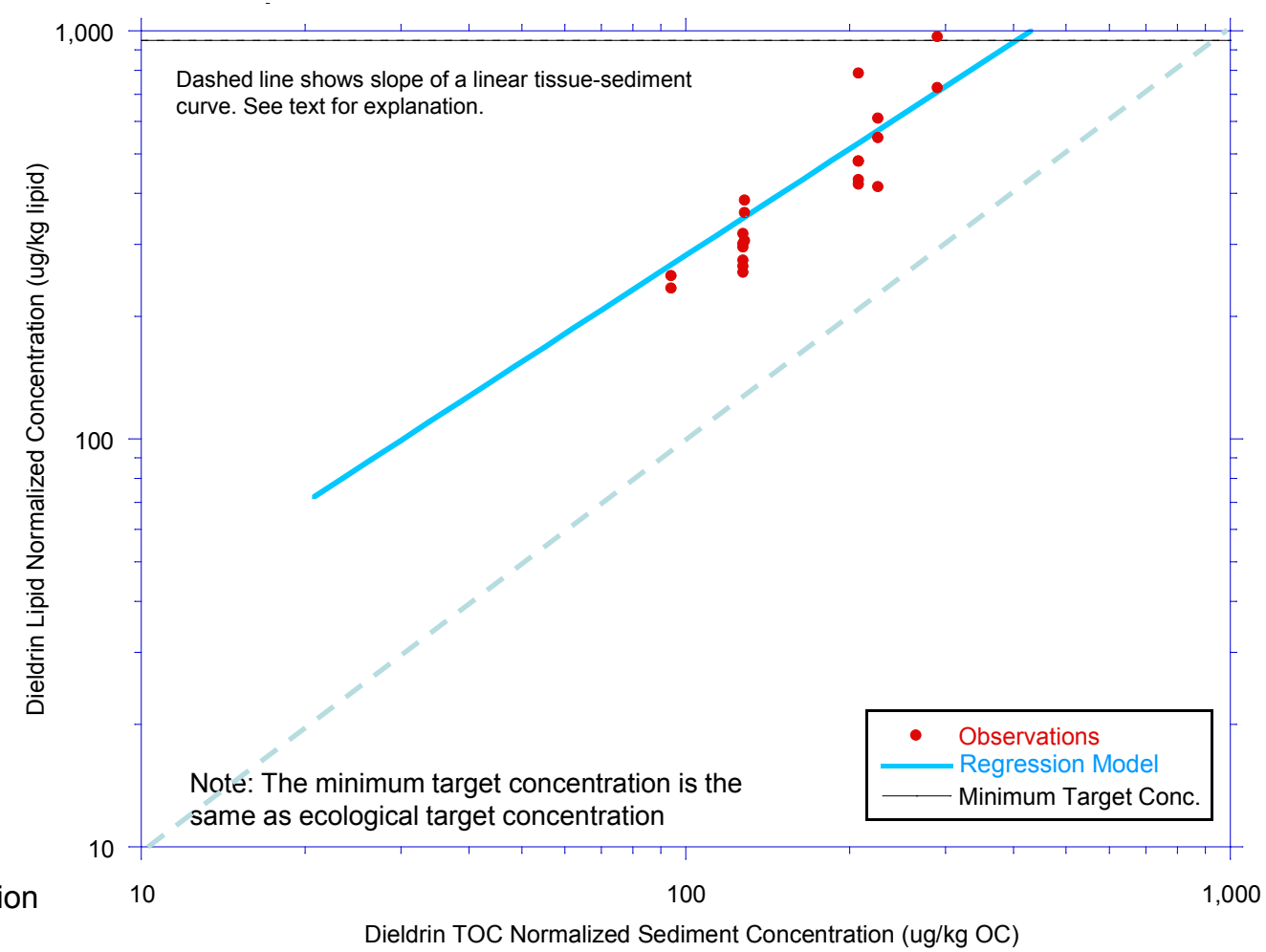
Regression Model

Blue Crab
Dieldrin Lipid Normalized Concentration in Tissue vs. Dieldrin TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-34b

2014

R2-0027730



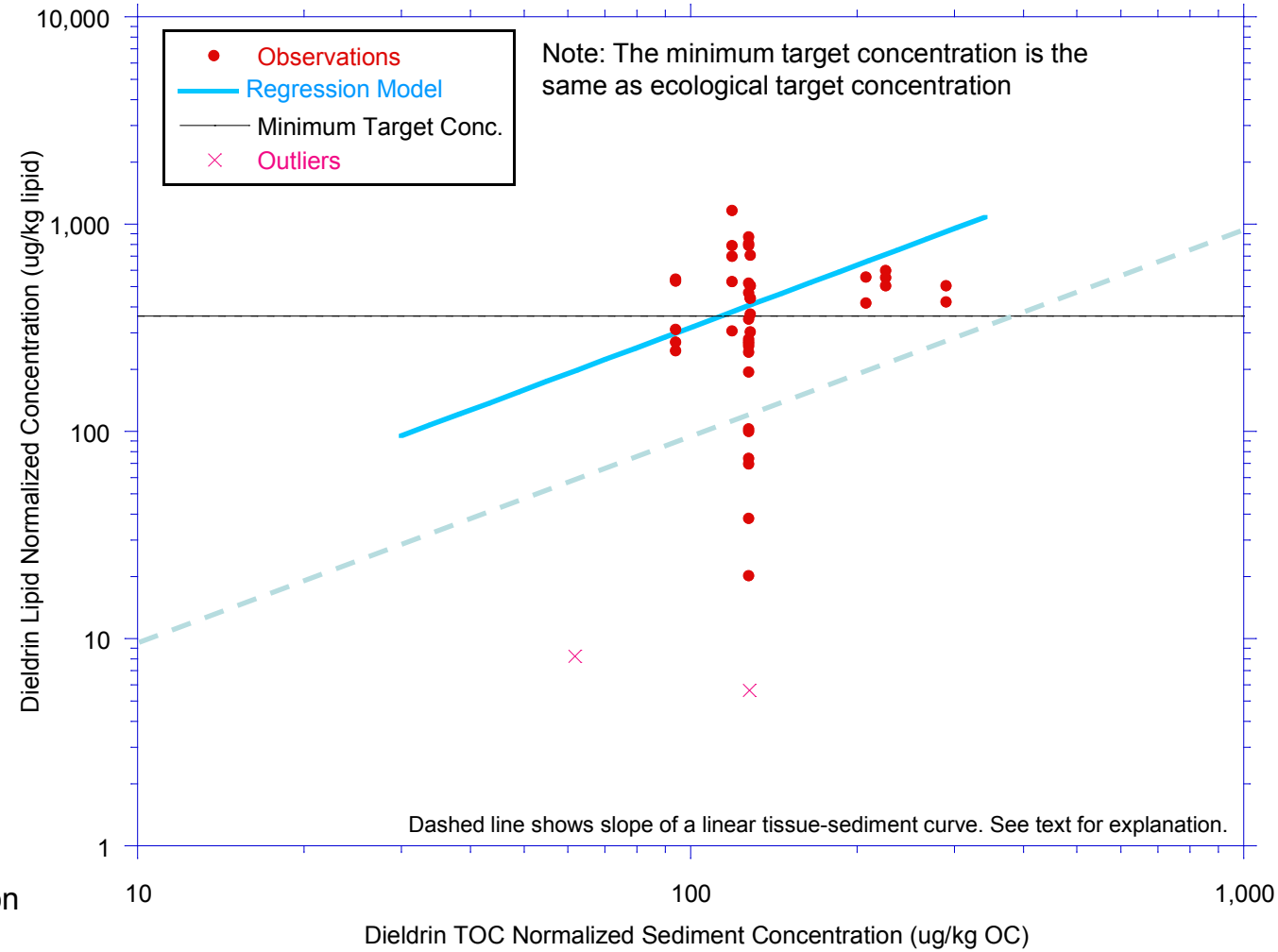
Regression Model

Mummichog
Dieldrin Lipid Normalized Concentration in Tissue vs. Dieldrin TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-34c

2014

R2-0027731



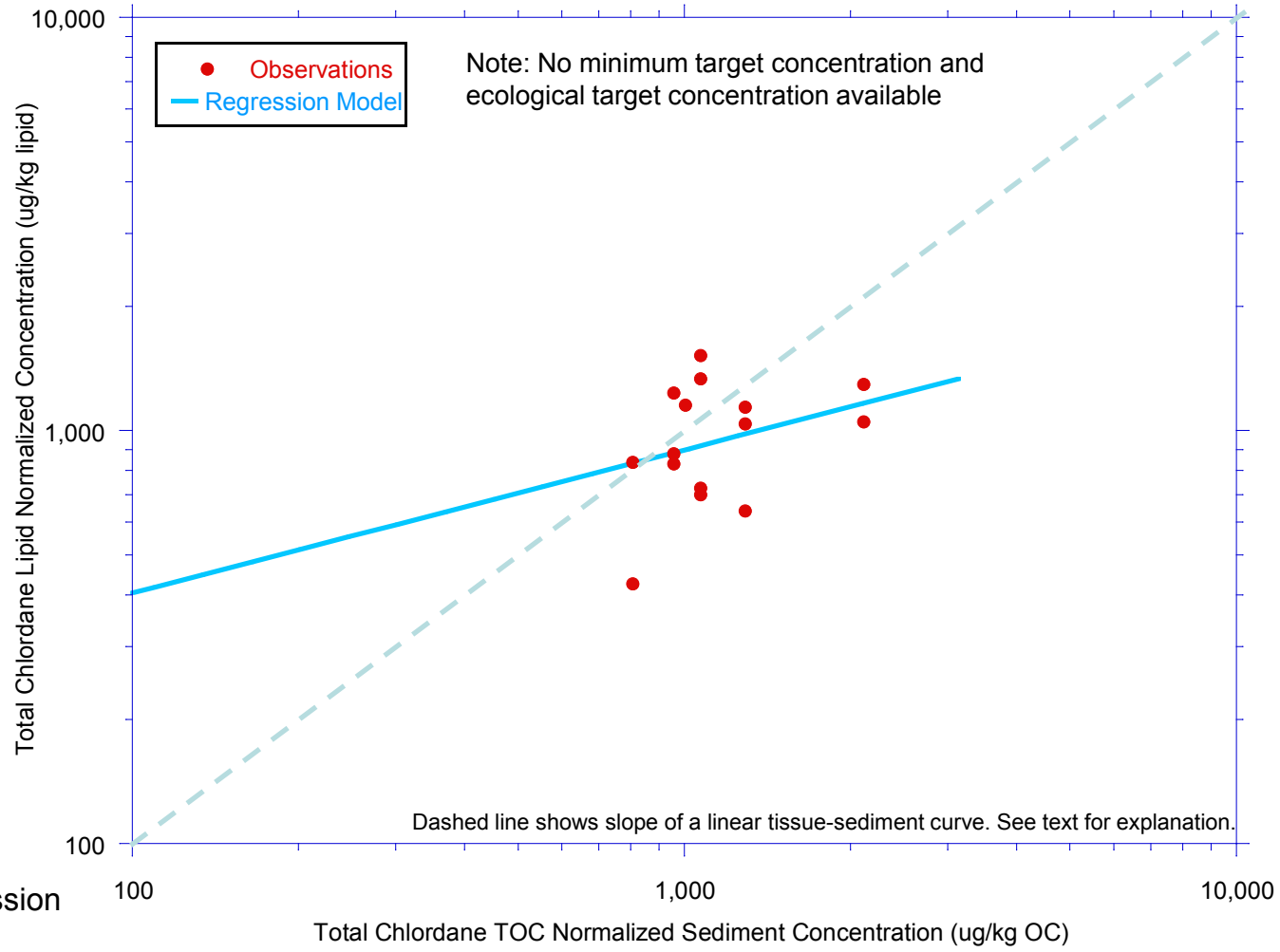
Regression Model

White Perch
Dieldrin Lipid Normalized Concentration in Tissue vs. Dieldrin TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-34d

2014

R2-0027732



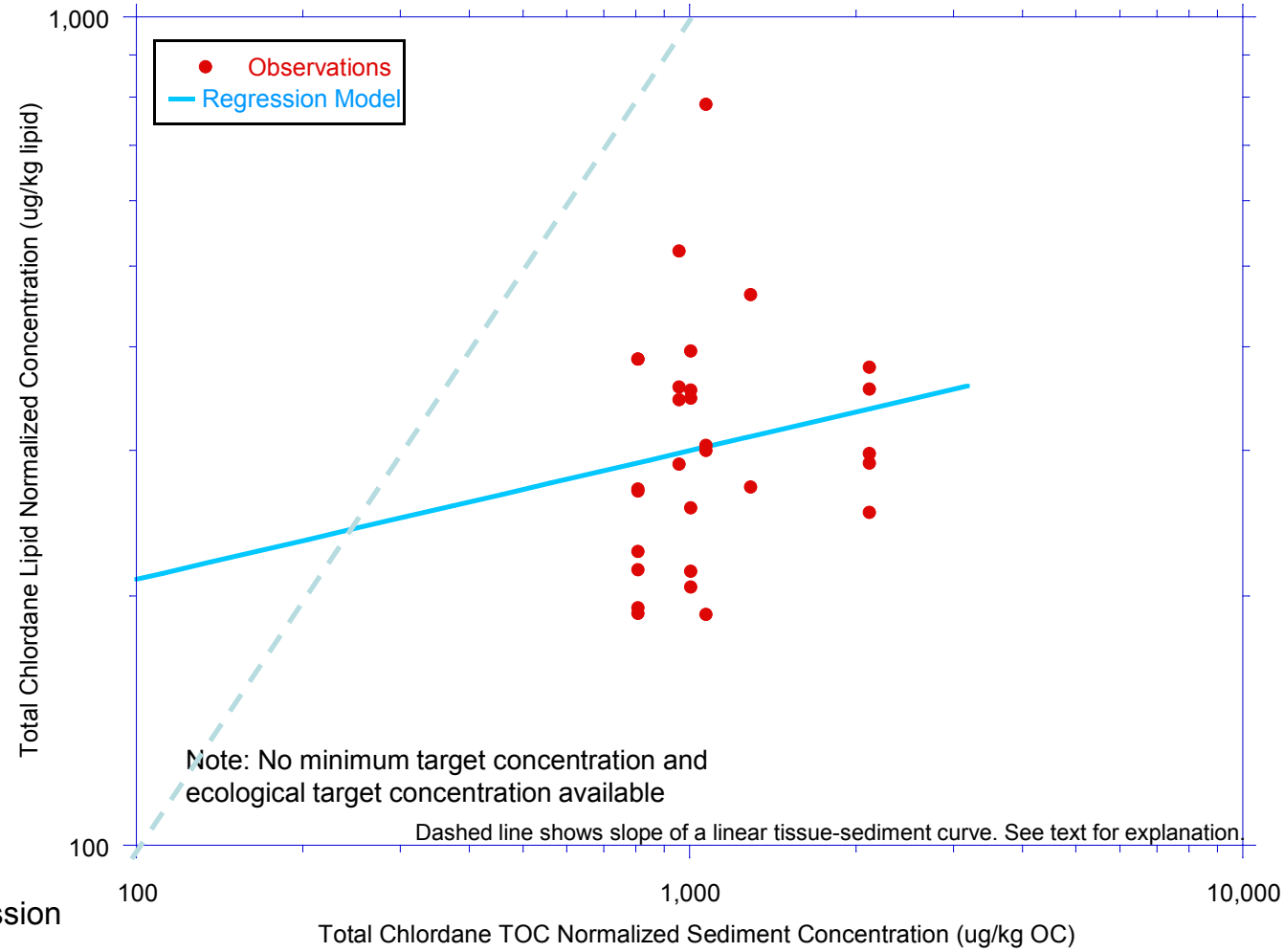
Regression Model

American Eel
Total Chlordane Lipid Normalized Concentration in Tissue vs. Total Chlordane TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-35a

2014

R2-0027733



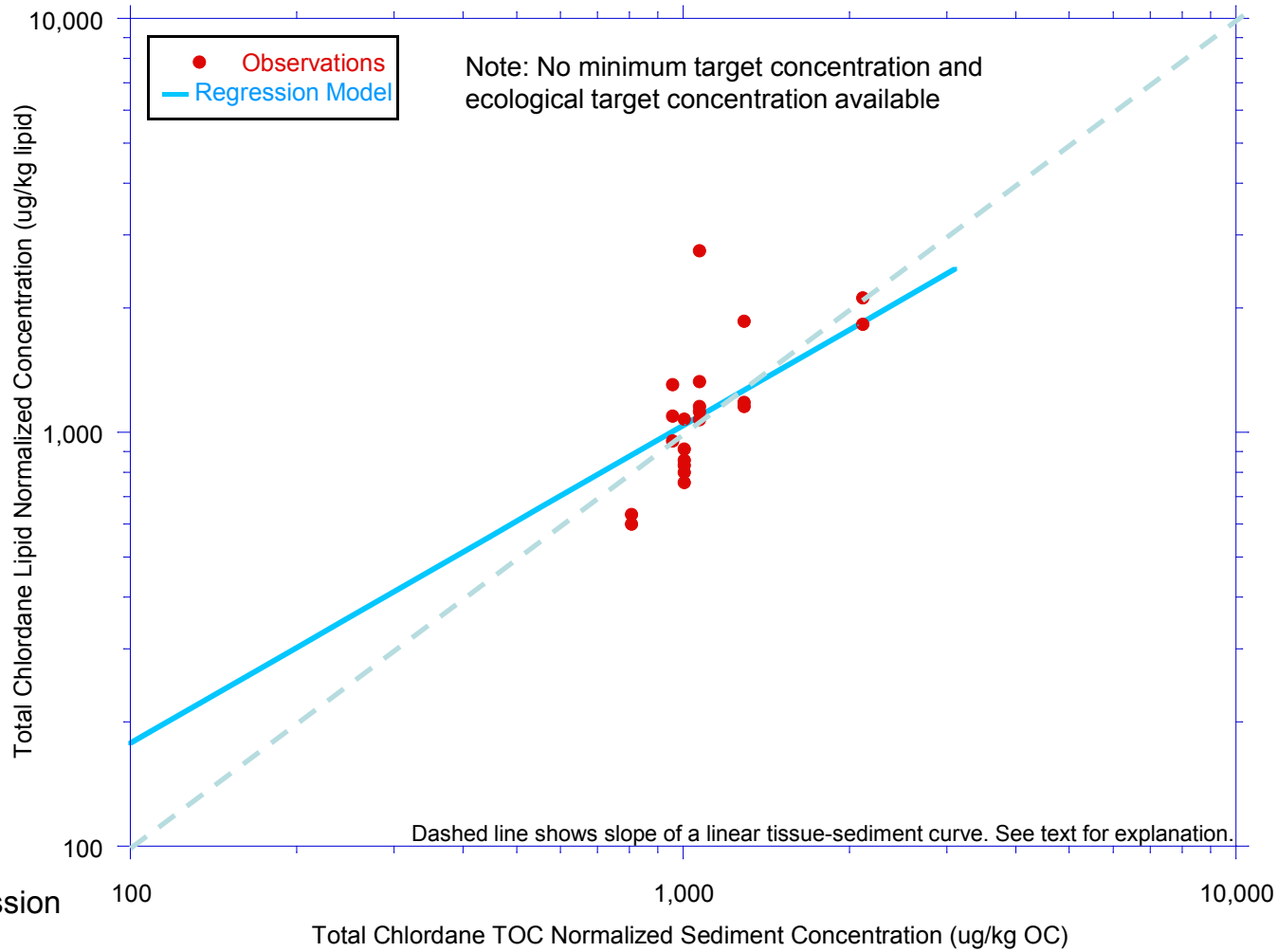
Regression Model

Blue Crab
Total Chlordane Lipid Normalized Concentration in Tissue vs. Total Chlordane TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-35b

2014

R2-0027734



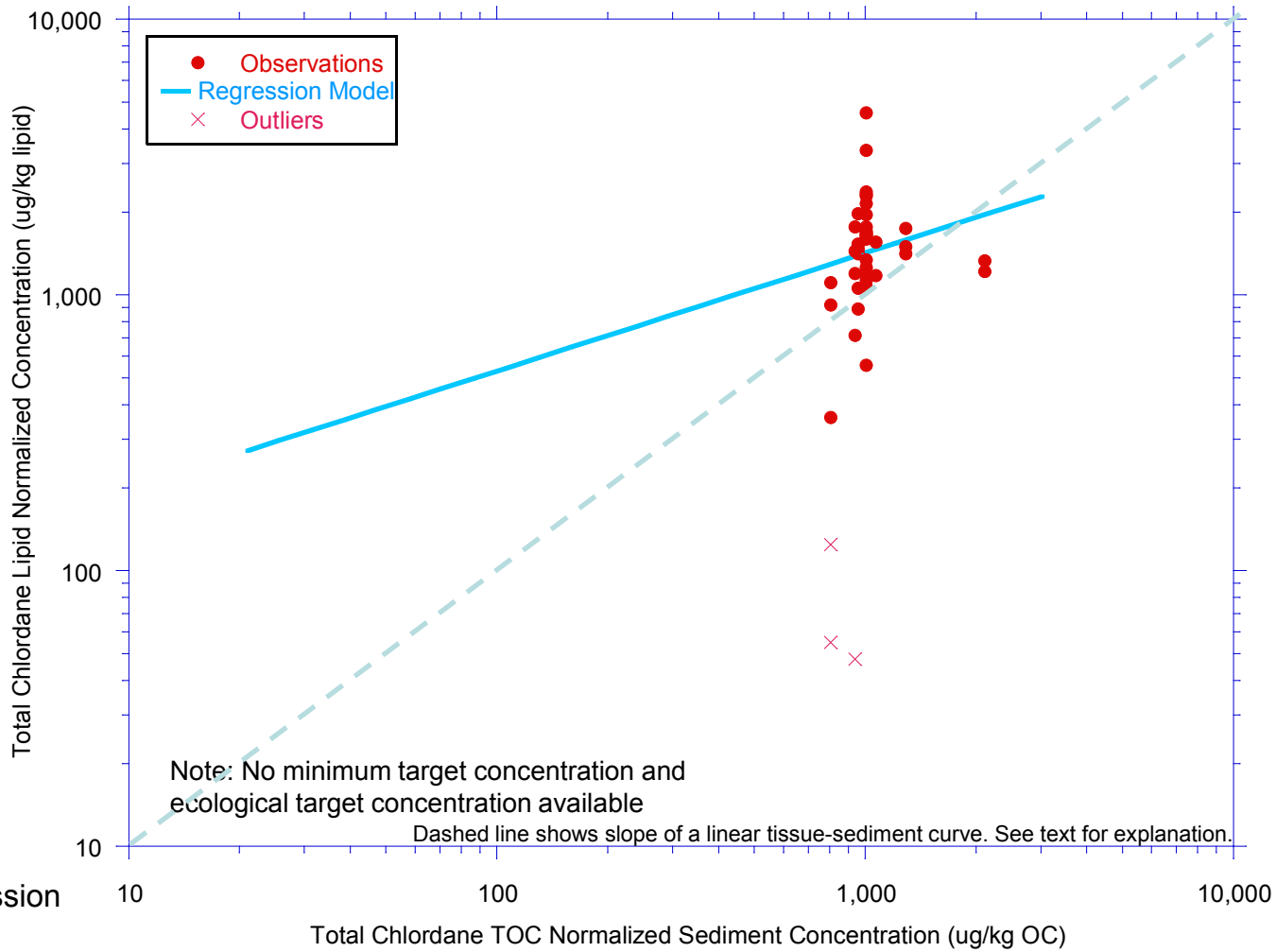
Regression Model

Mummichog
Total Chlordane Lipid Normalized Concentration in Tissue vs. Total Chlordane TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-35c

2014

R2-0027735



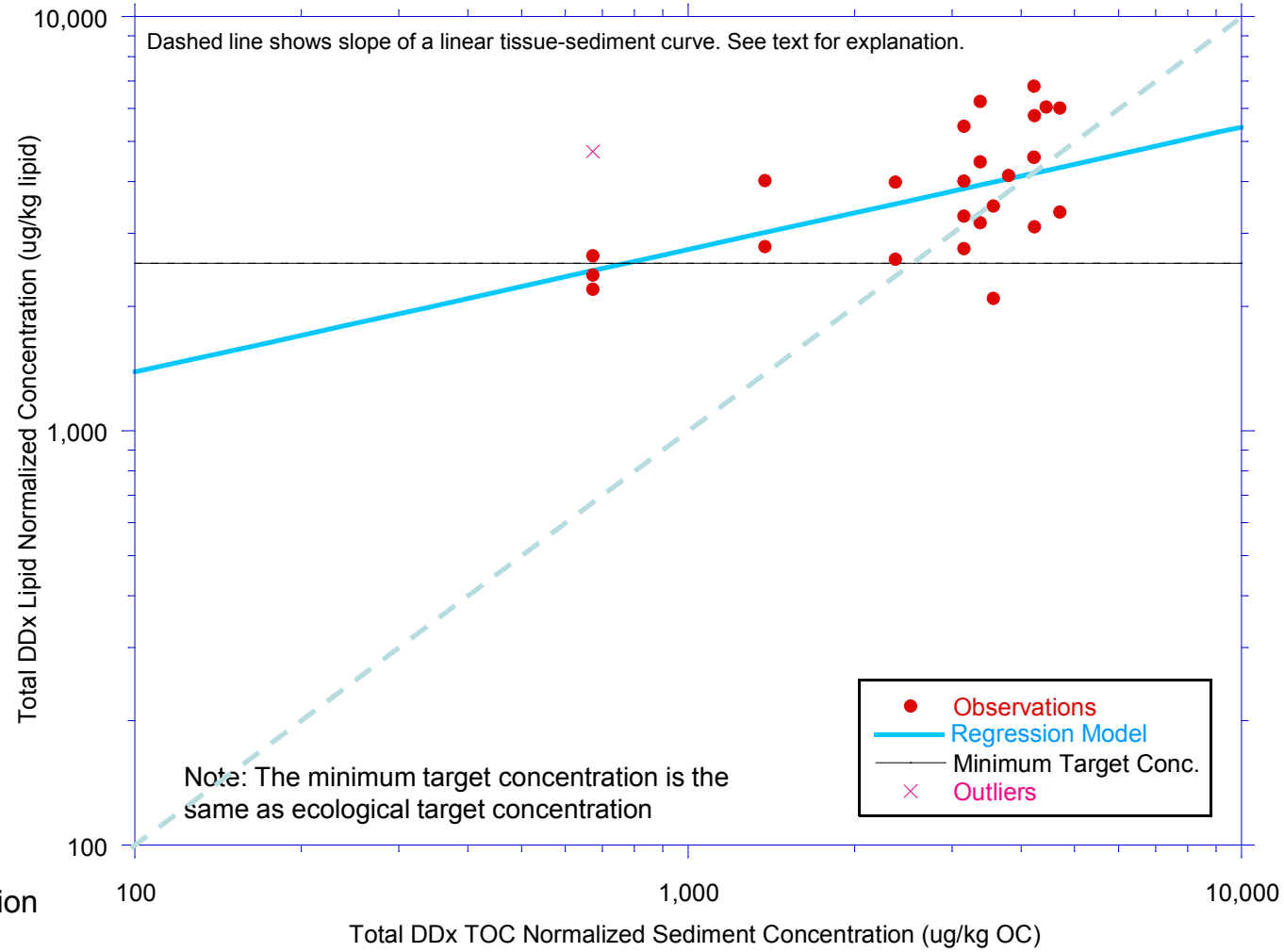
Regression Model

White Perch
Total Chlordane Lipid Normalized Concentration in Tissue vs. Total Chlordane TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-35d

2014

R2-0027736



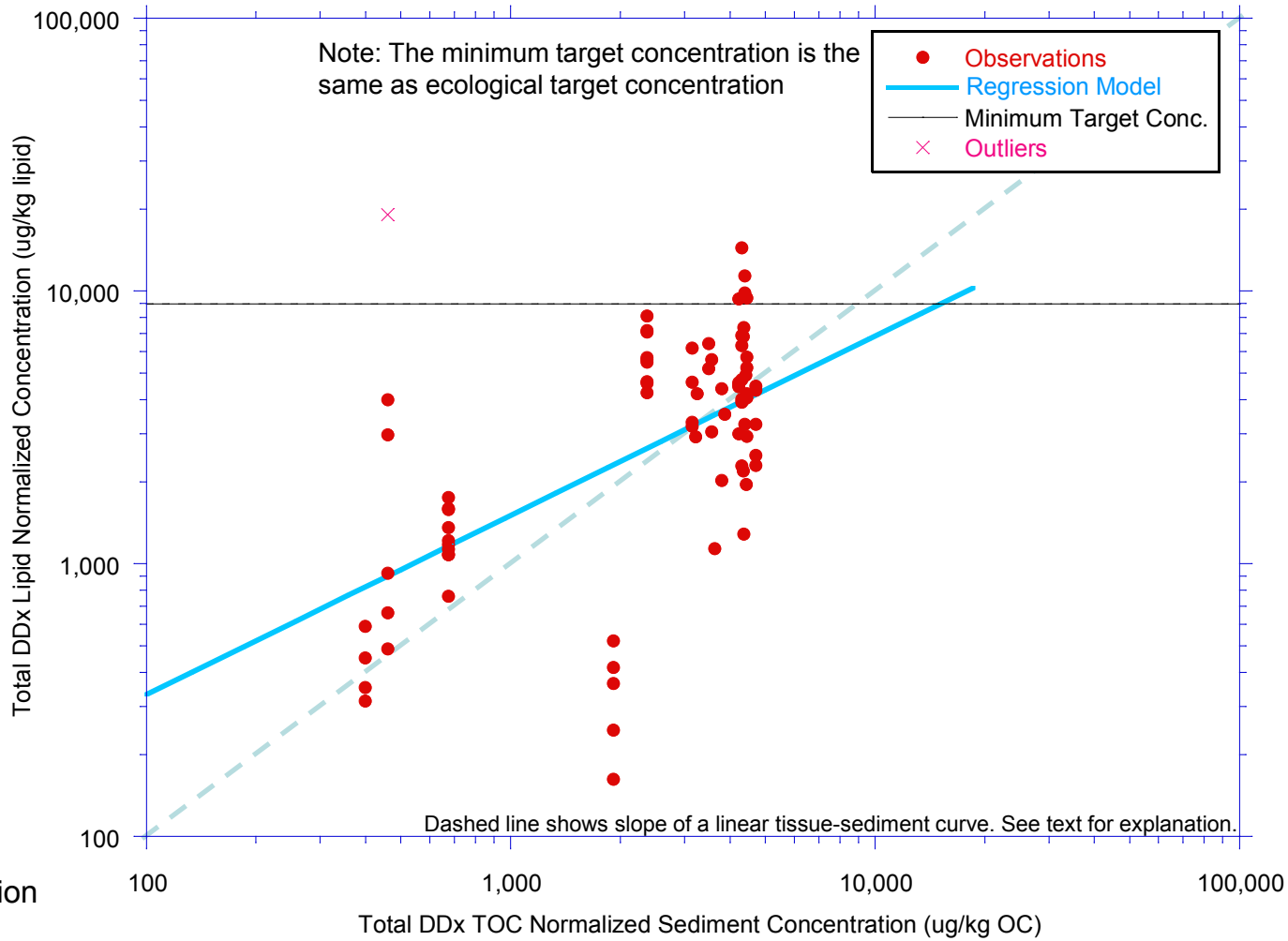
Regression Model

American Eel
Total DDx Lipid Normalized Concentration in Tissue vs. Total DDx TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-36a

2014

R2-0027737



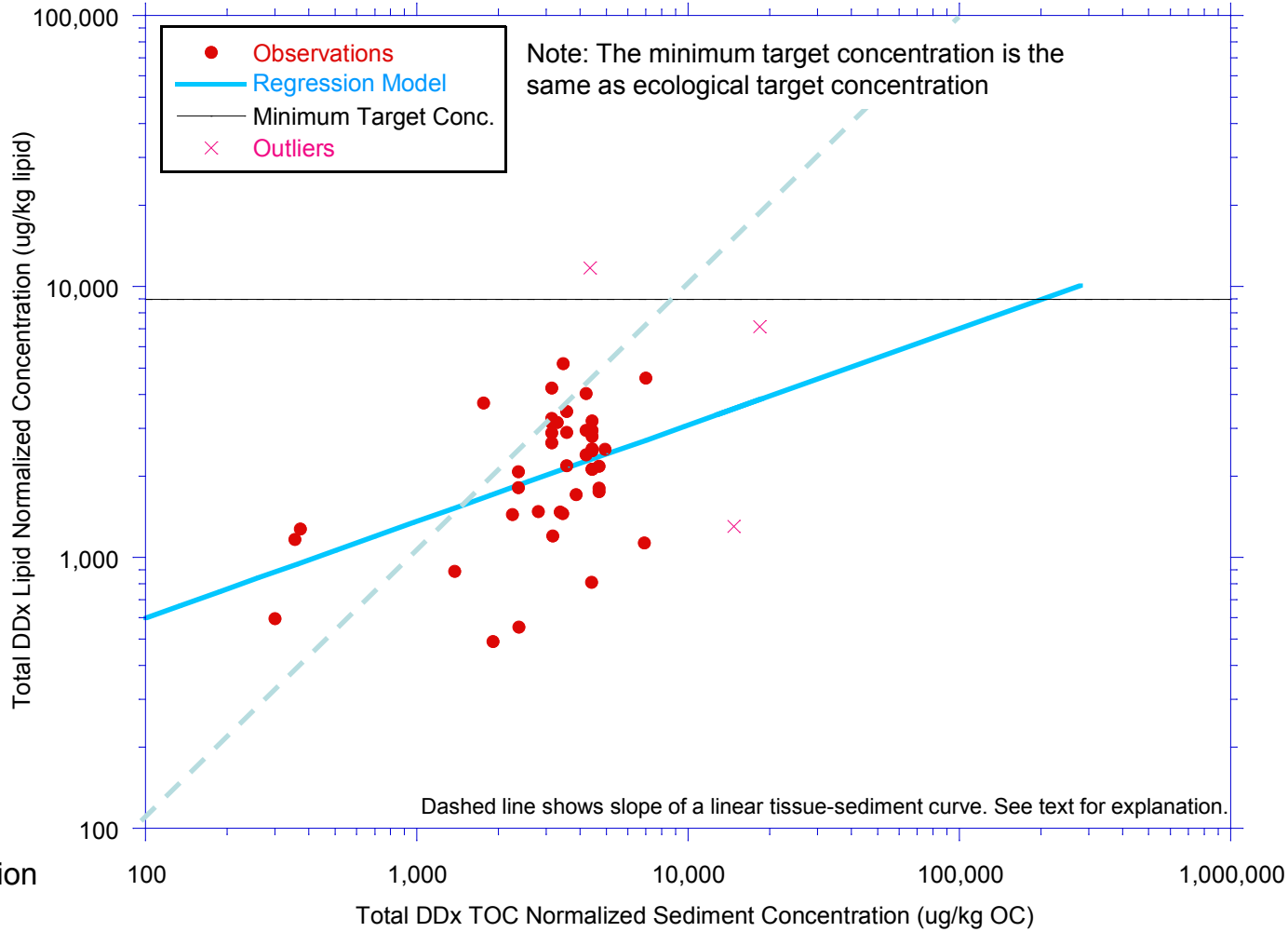
Regression Model

Blue Crab
Total DDx Lipid Normalized Concentration in Tissue vs. Total DDx TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-36b

2014

R2-0027738



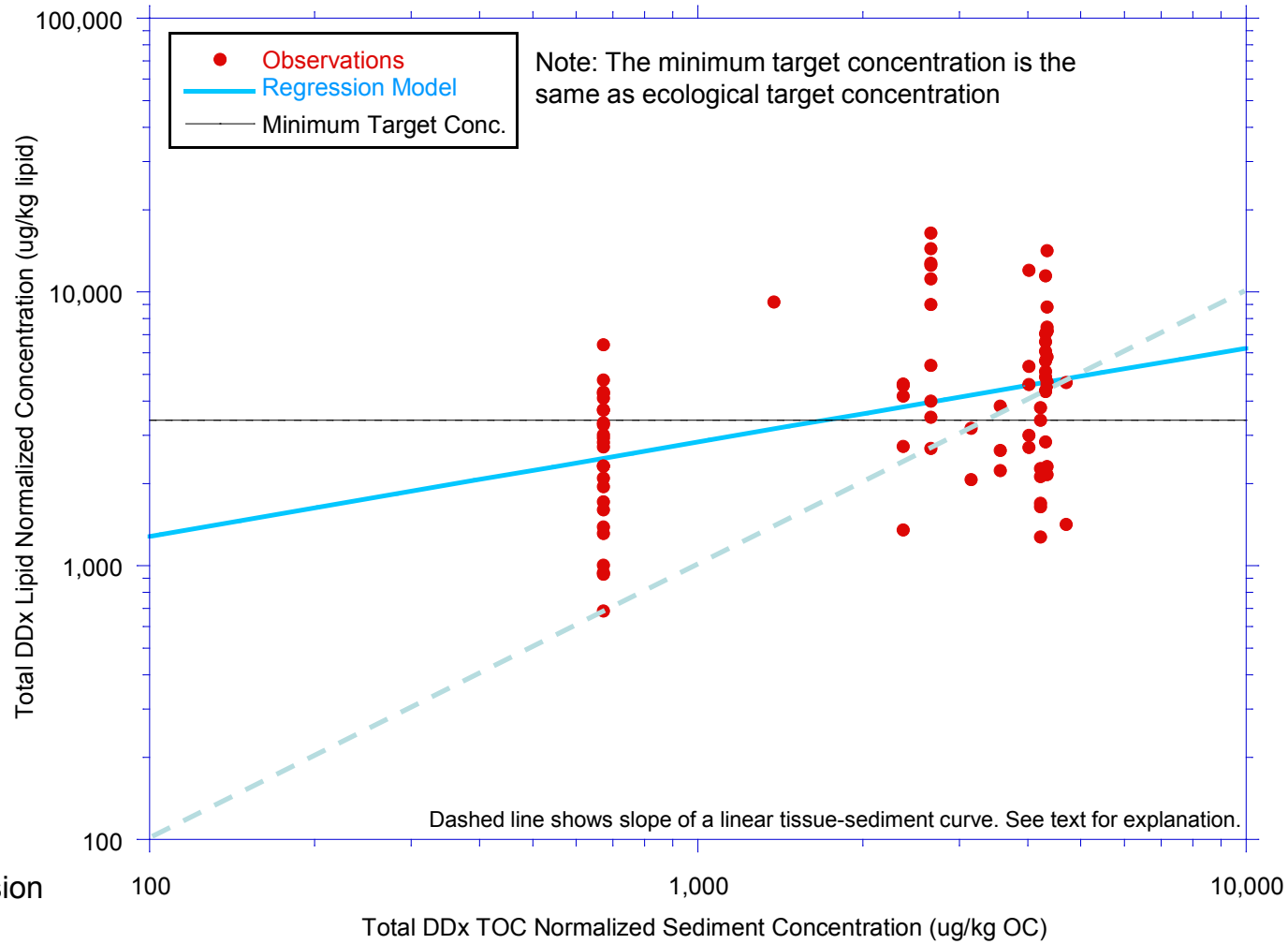
Regression Model

Mummichog
Total DDx Lipid Normalized Concentration in Tissue vs. Total DDx TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-36c

2014

R2-0027739



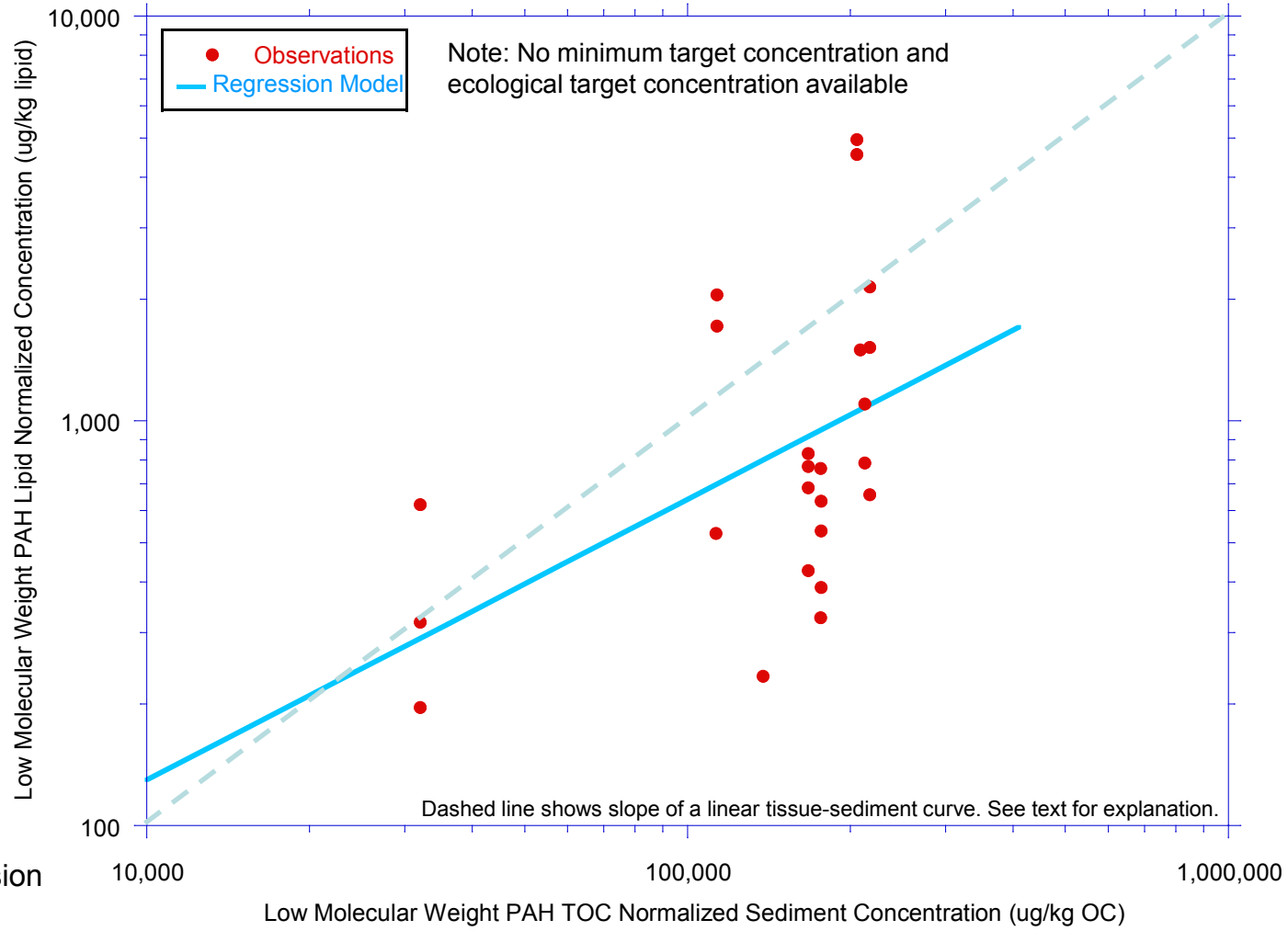
Regression Model

White Perch
Total DDx Lipid Normalized Concentration in Tissue vs. Total DDx TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-36d

2014

R2-0027740



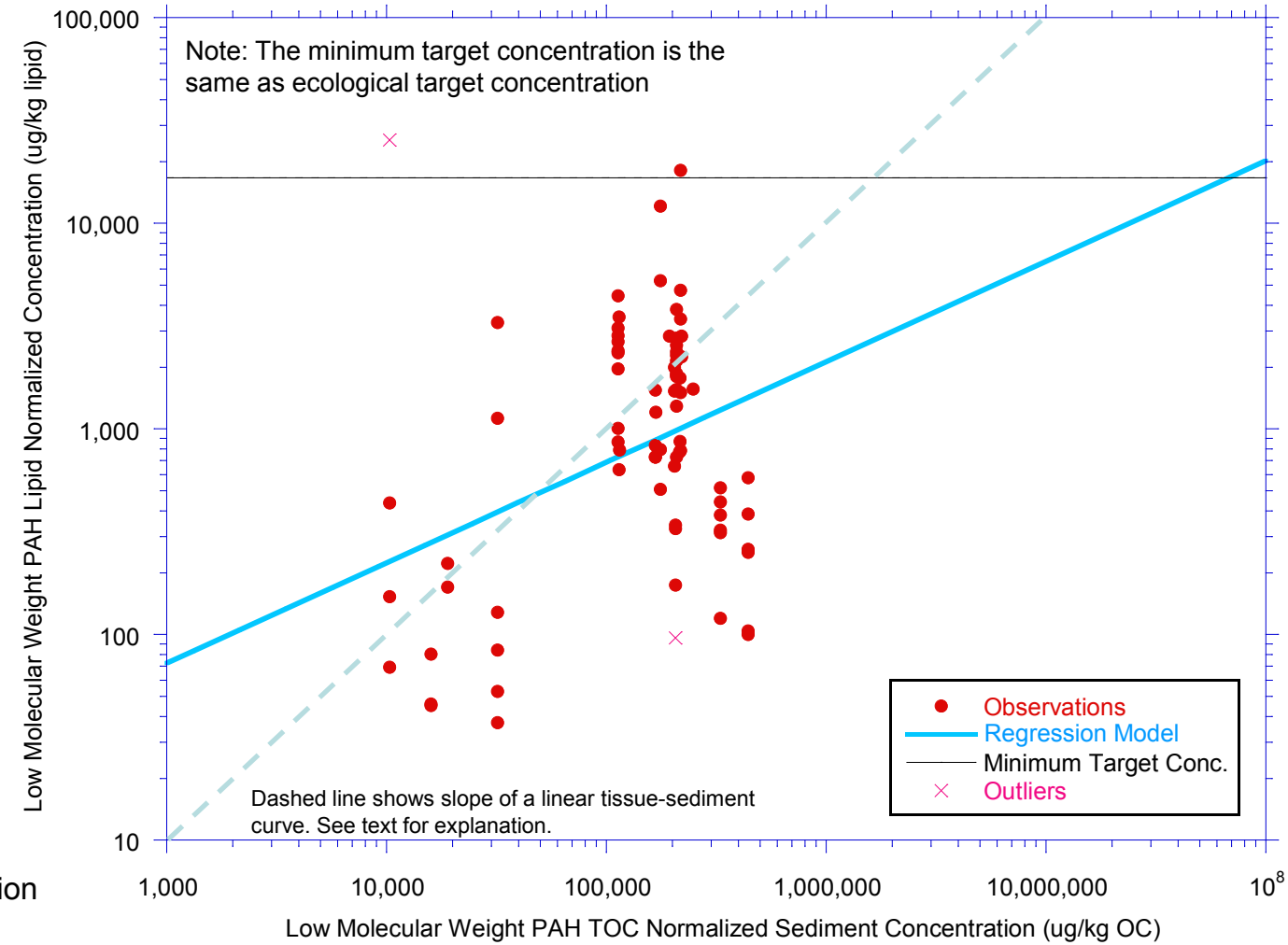
Regression Model

American Eel
Low Molecular Weight PAH Lipid Normalized Concentration in Tissue vs. Low Molecular Weight PAH TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-37a

2014

R2-0027741



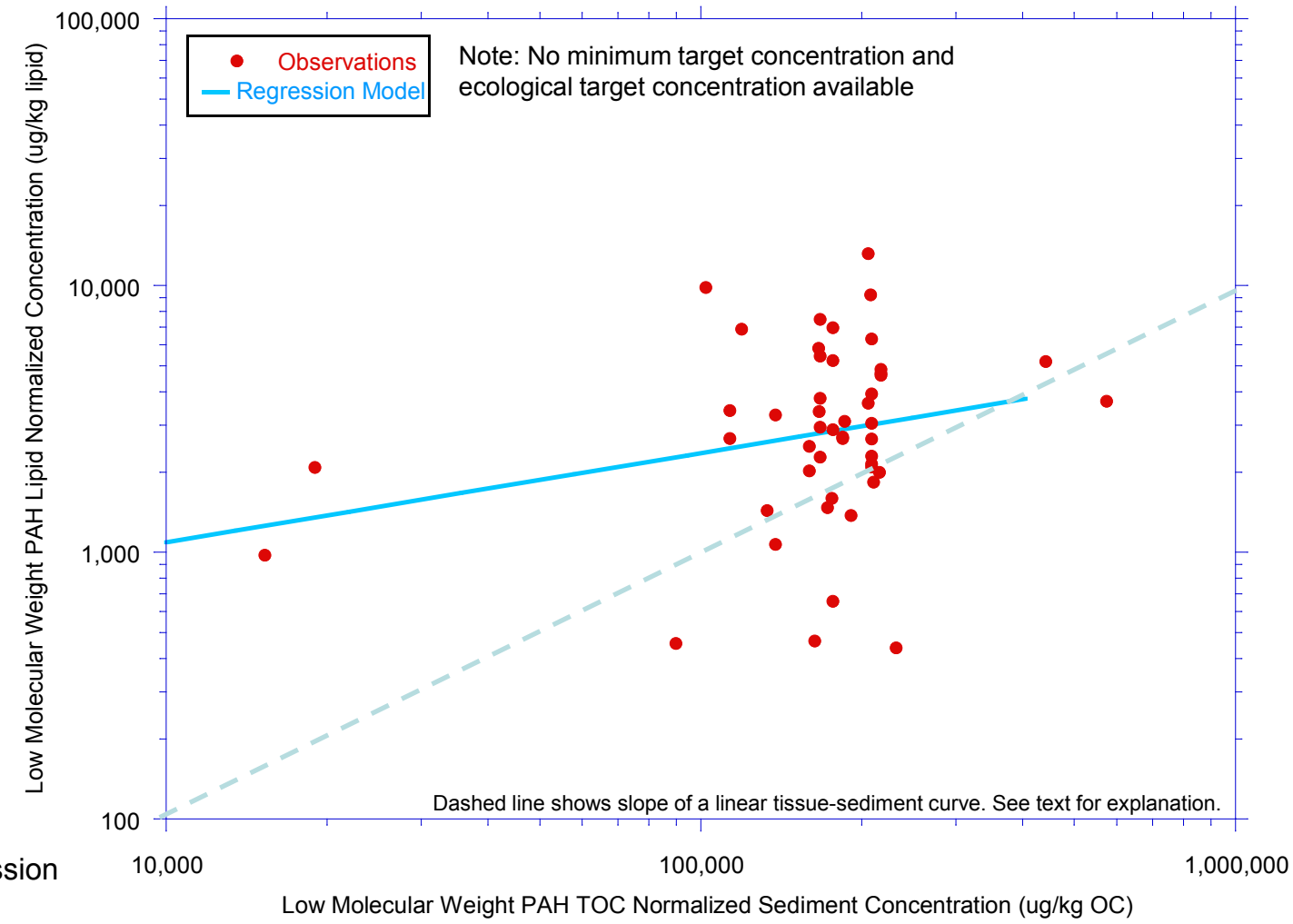
Regression Model

Blue Crab
Low Molecular Weight PAH Lipid Normalized Concentration in Tissue vs. Low Molecular Weight PAH TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-37b

2014

R2-0027742



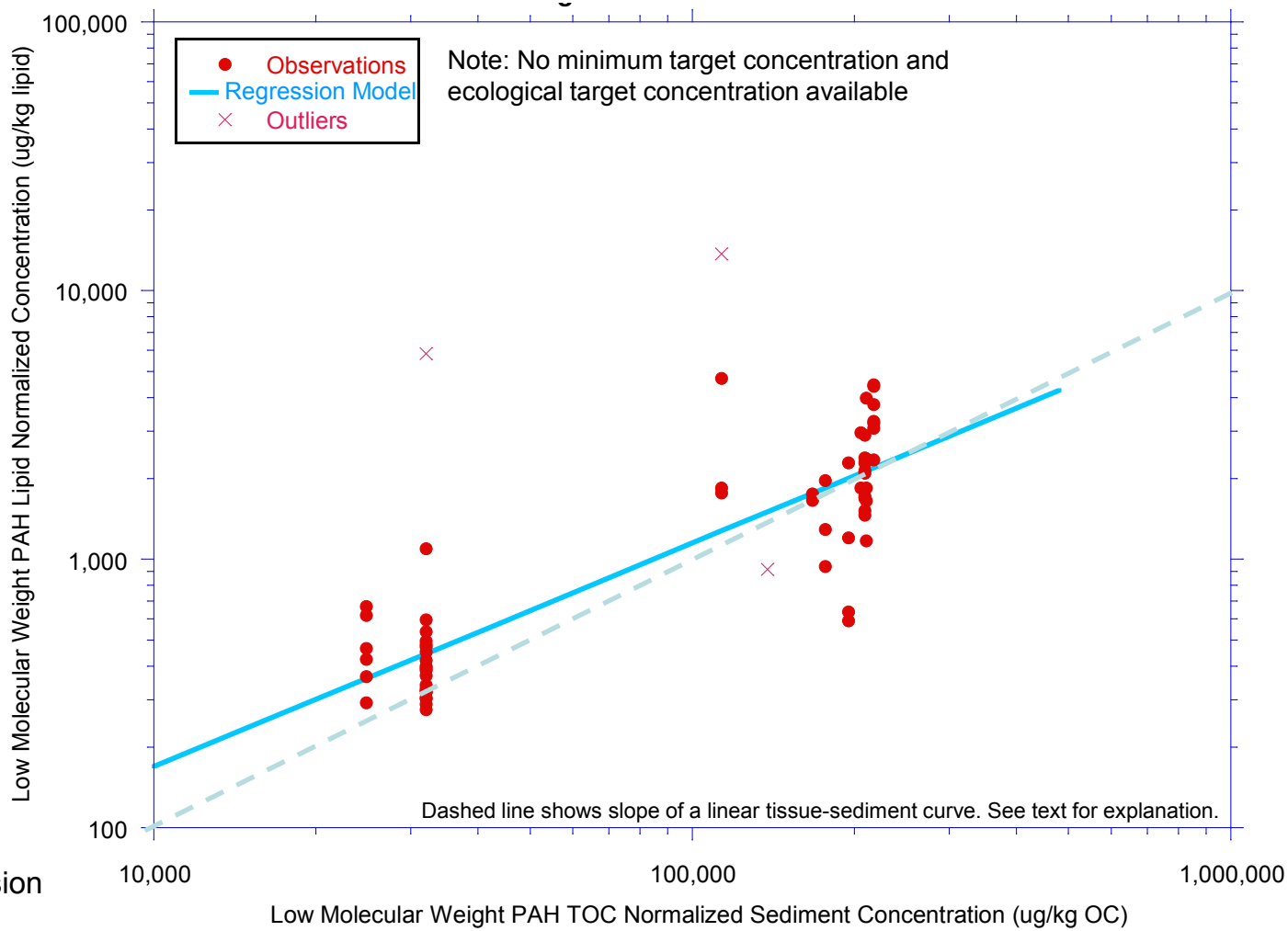
Regression Model

Mummichog
Low Molecular Weight PAH Lipid Normalized Concentration in Tissue vs. Low Molecular Weight PAH TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-37c

2014

R2-0027743



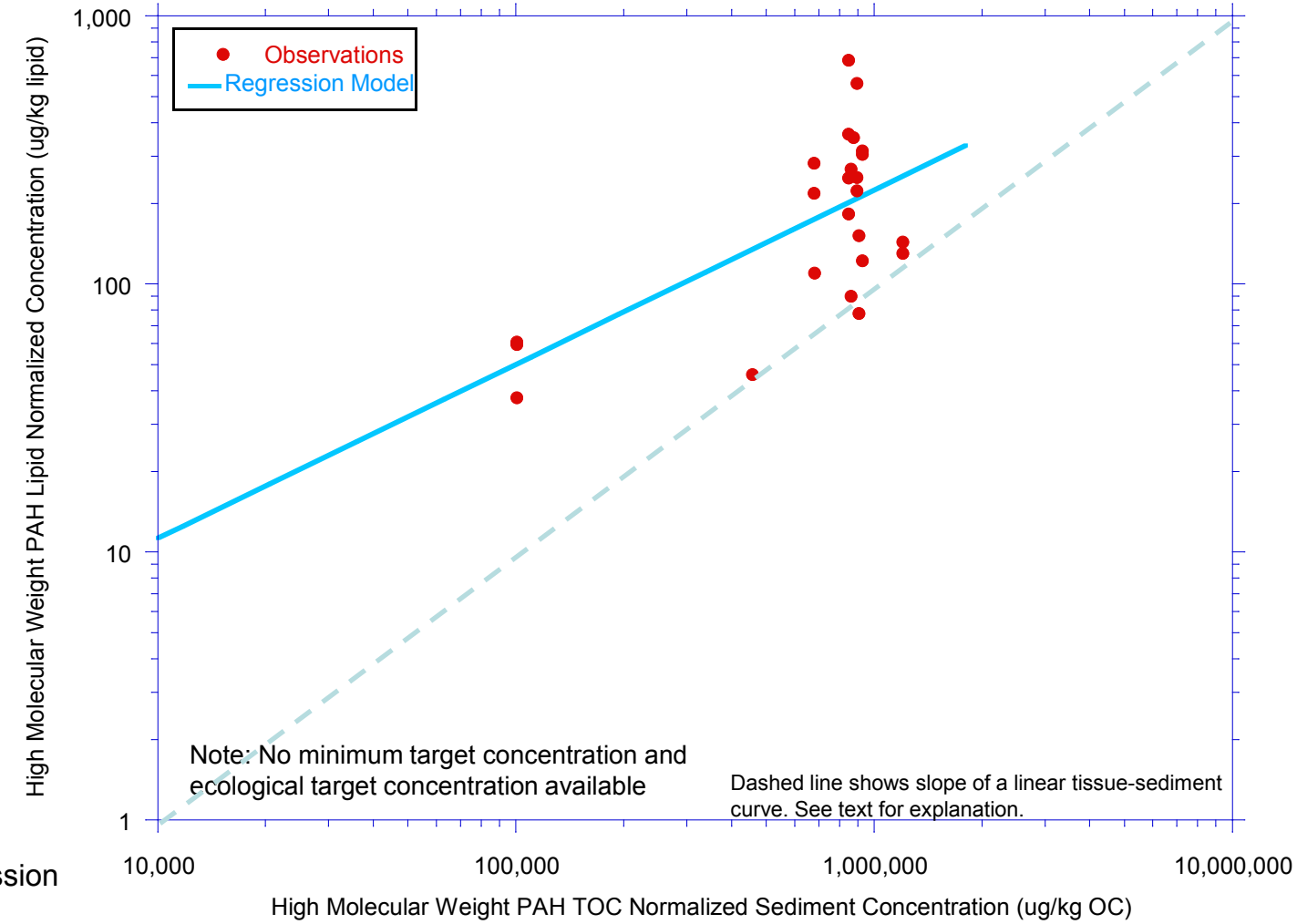
Regression Model

White Perch
Low Molecular Weight PAH Lipid Normalized Concentration in Tissue vs. Low Molecular Weight PAH TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-37d

2014

R2-0027744



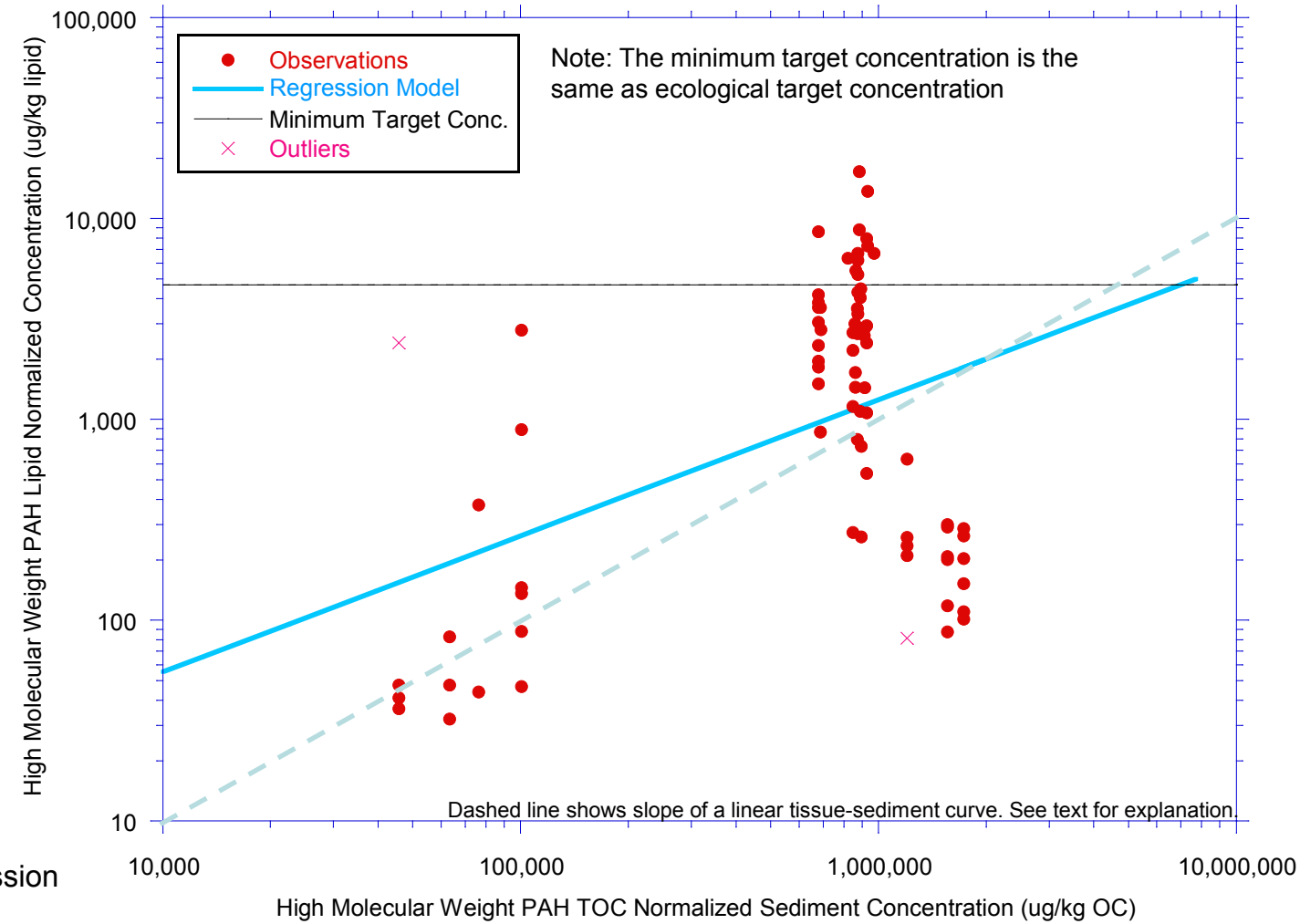
Regression Model

American Eel
High Molecular Weight PAH Lipid Normalized Concentration in Tissue vs. High Molecular Weight PAH TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-38a

2014

R2-0027745



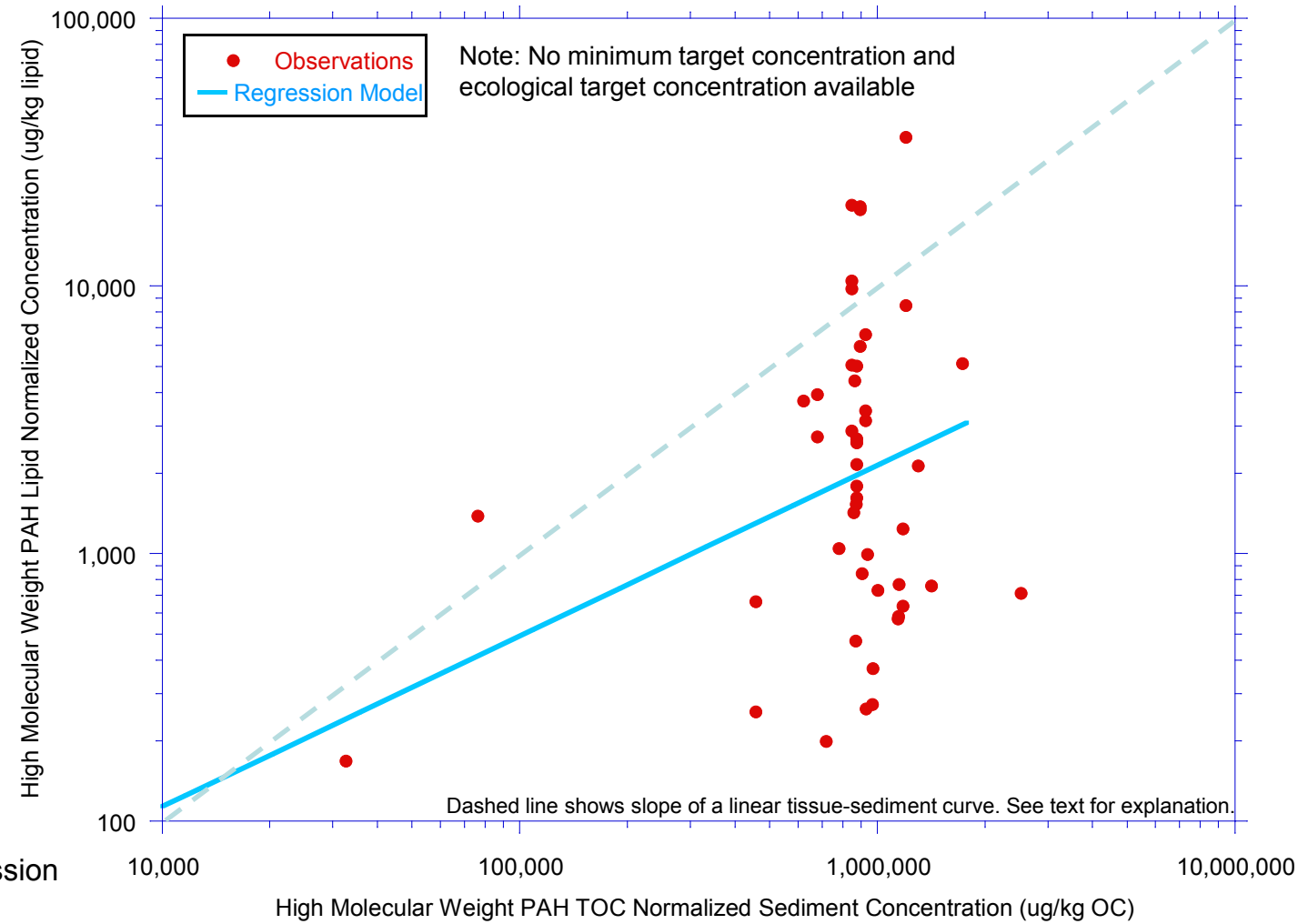
Regression Model

Blue Crab
High Molecular Weight PAH Lipid Normalized Concentration in Tissue vs. High Molecular Weight PAH TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-38b

2014

R2-0027746



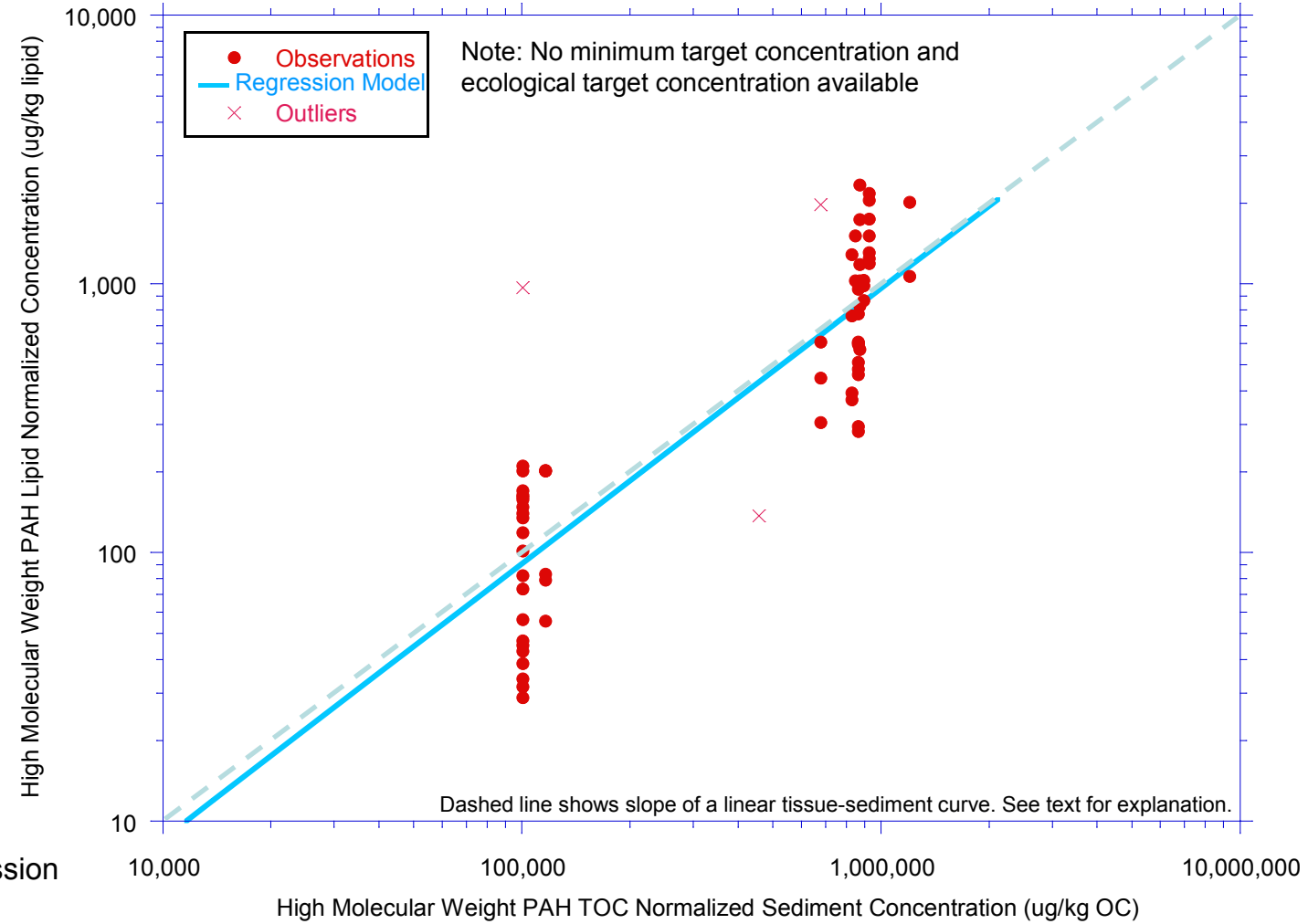
Regression Model

Mummichog
High Molecular Weight PAH Lipid Normalized Concentration in Tissue vs. High Molecular Weight PAH TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-38c

2014

R2-0027747



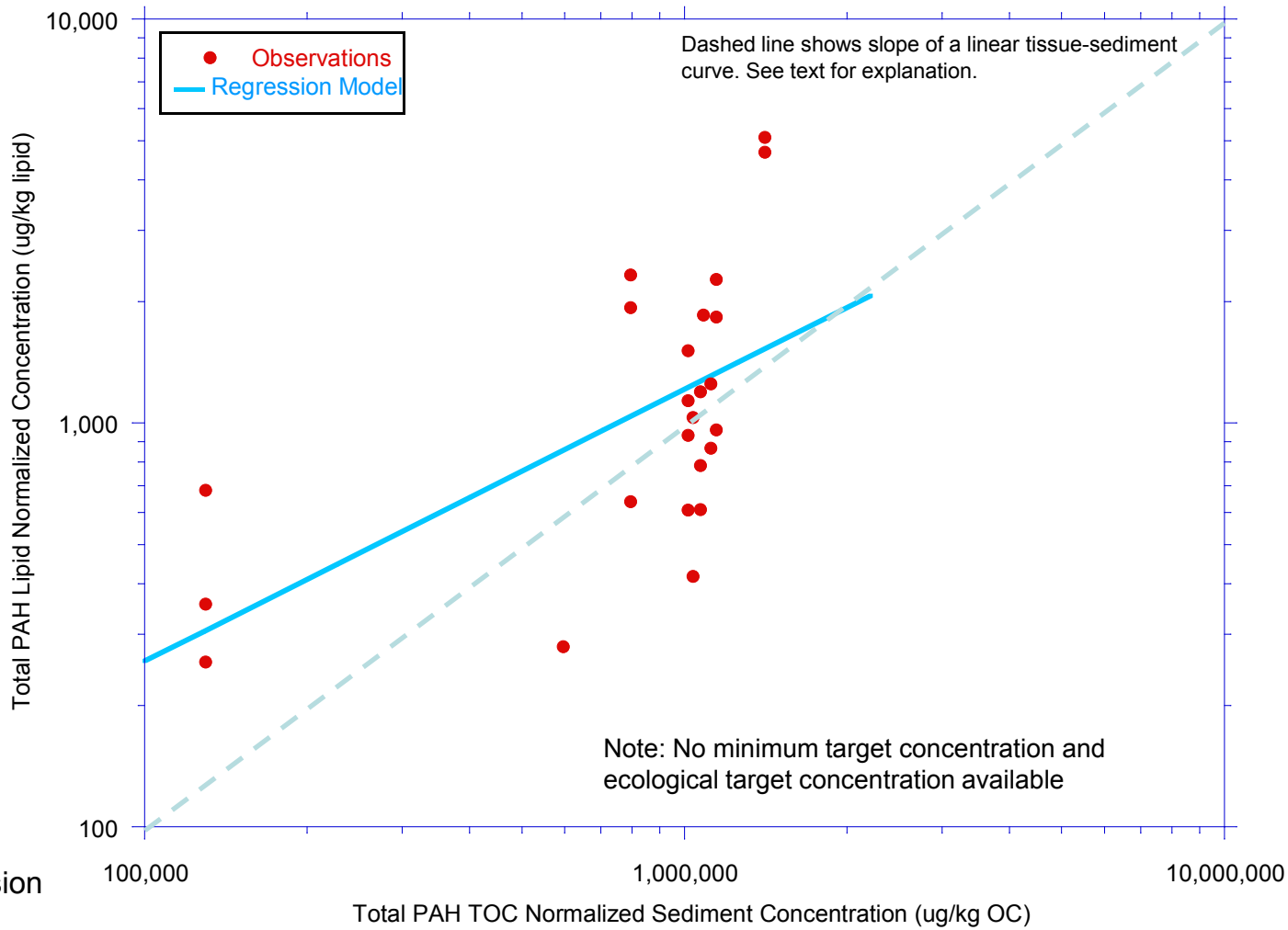
Regression Model

White Perch
High Molecular Weight PAH Lipid Normalized Concentration in Tissue vs. High Molecular Weight PAH TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-38d

2014

R2-0027748



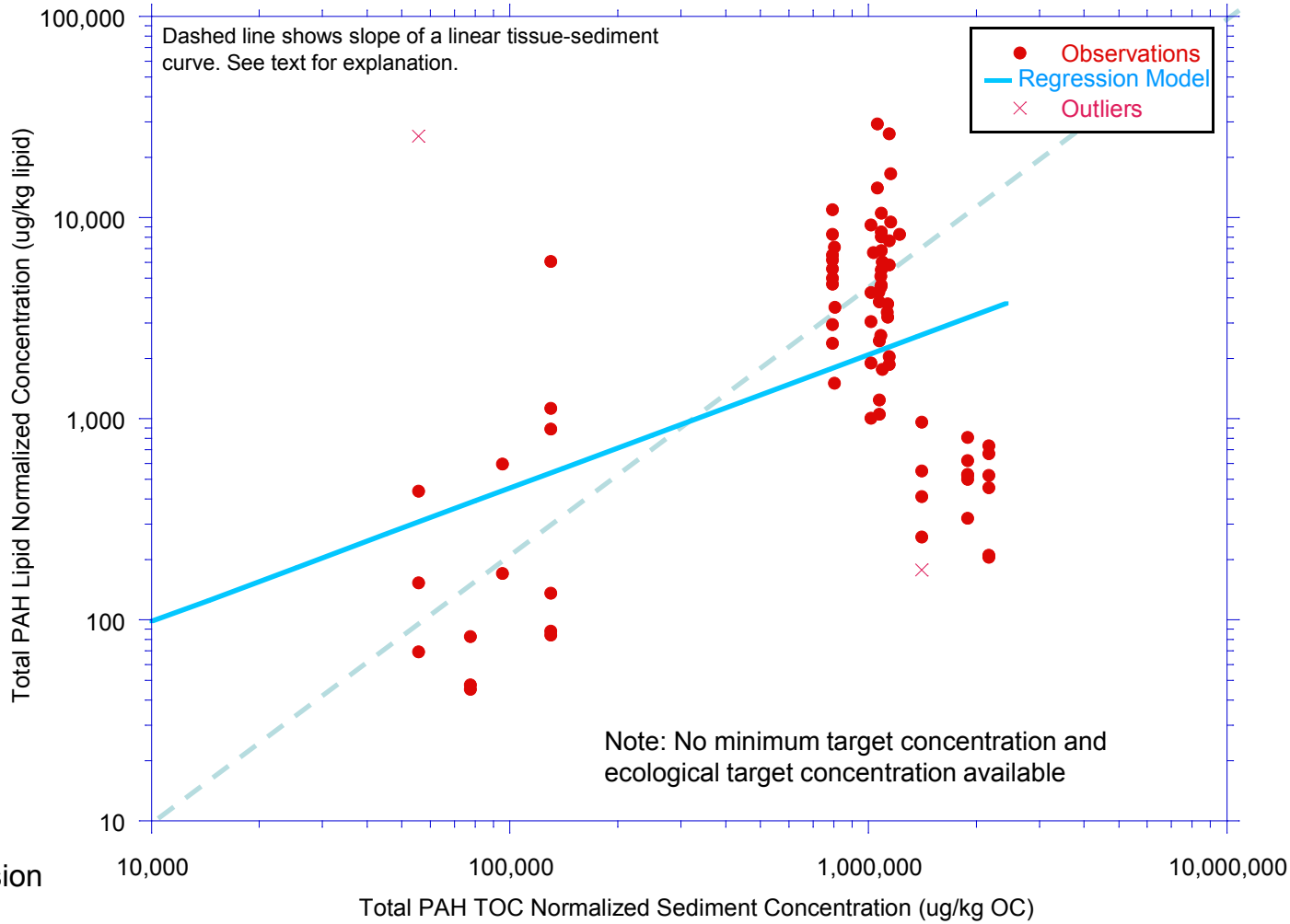
Regression Model

American Eel
Total PAH Lipid Normalized Concentration in Tissue vs. Total PAH TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-39a

2014

R2-0027749



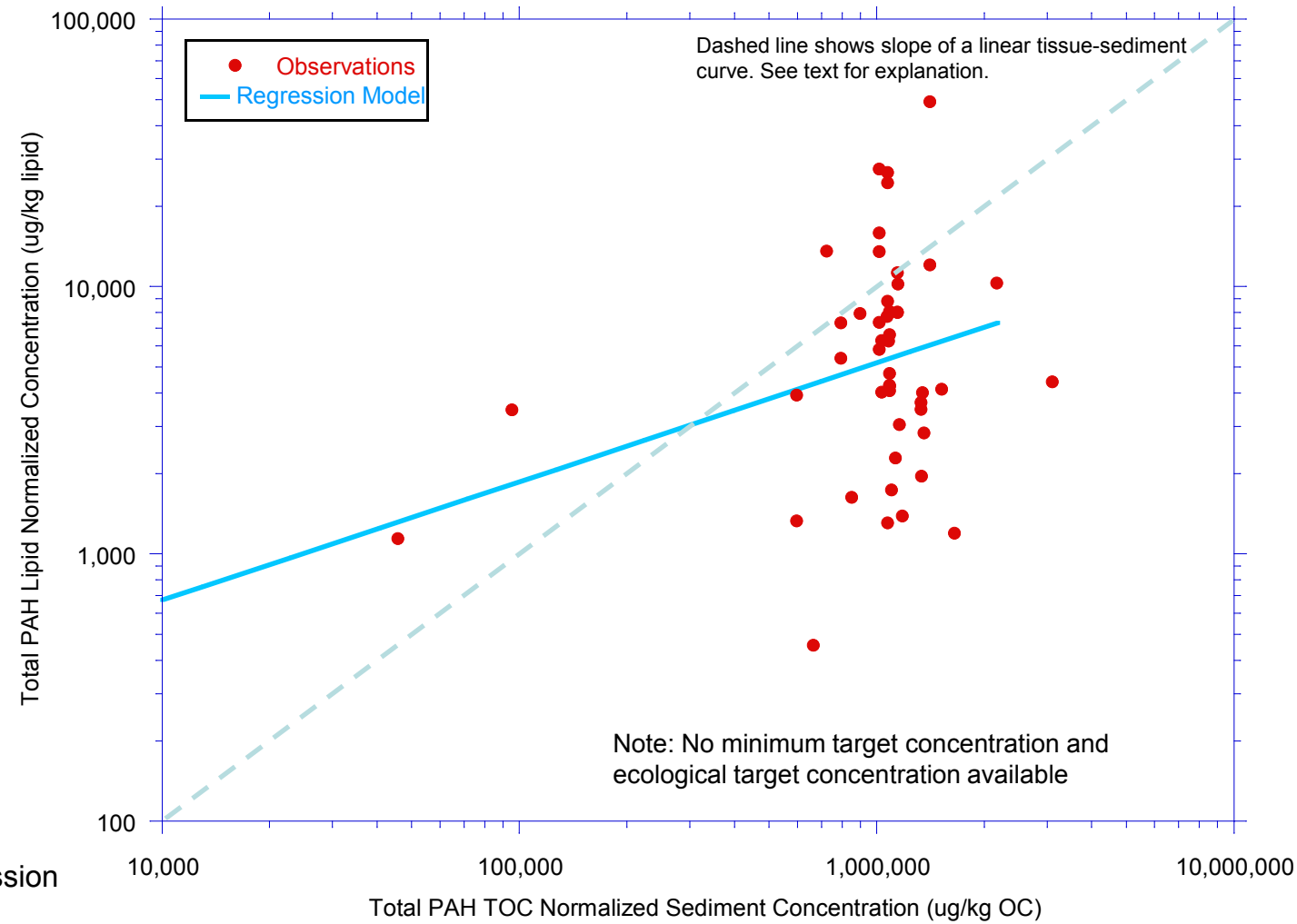
Regression Model

Blue Crab
Total PAH Lipid Normalized Concentration in Tissue vs. Total PAH TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-39b

2014

R2-0027750



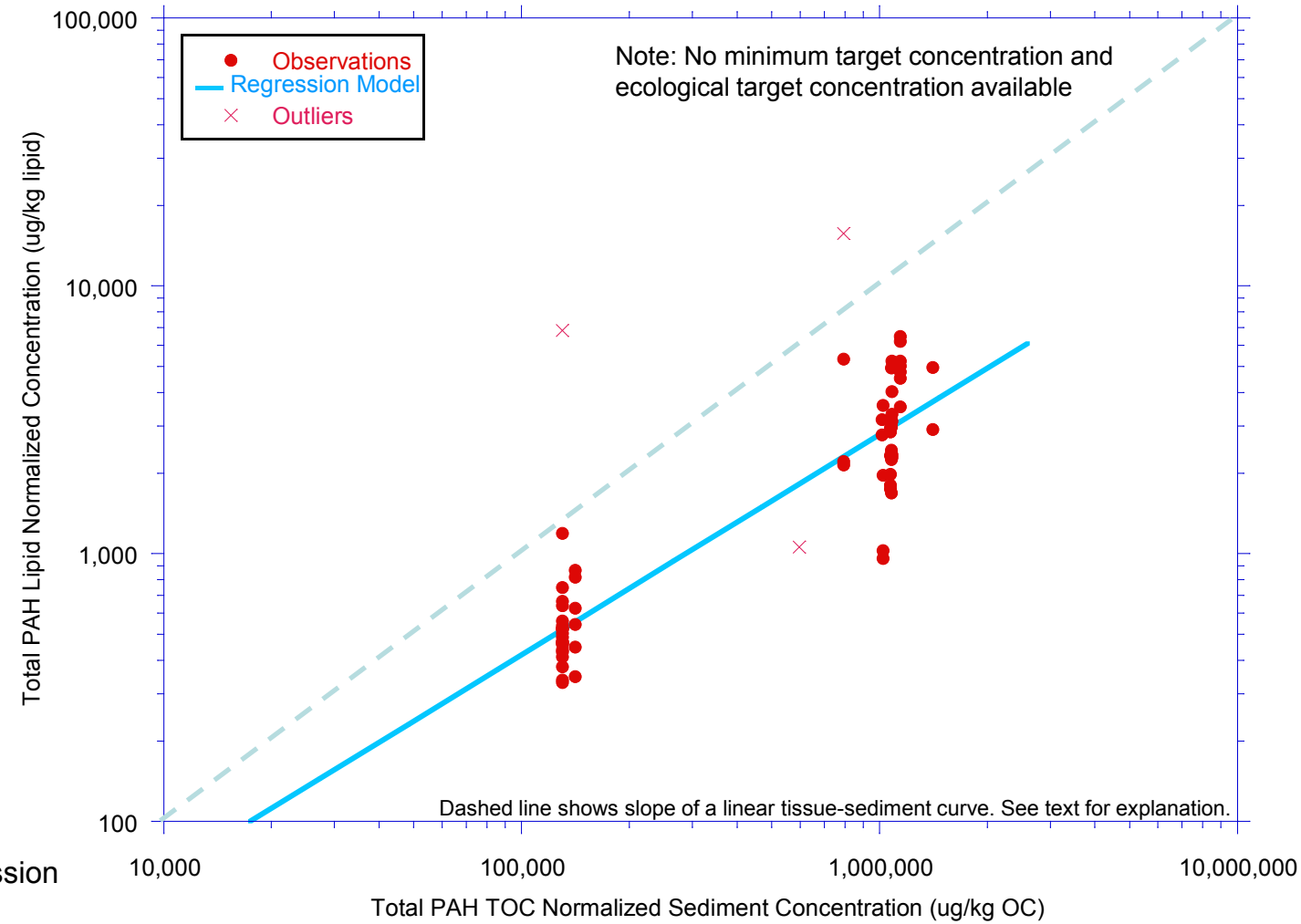
Regression Model

Mummichog
Total PAH Lipid Normalized Concentration in Tissue vs. Total PAH TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-39c

2014

R2-0027751



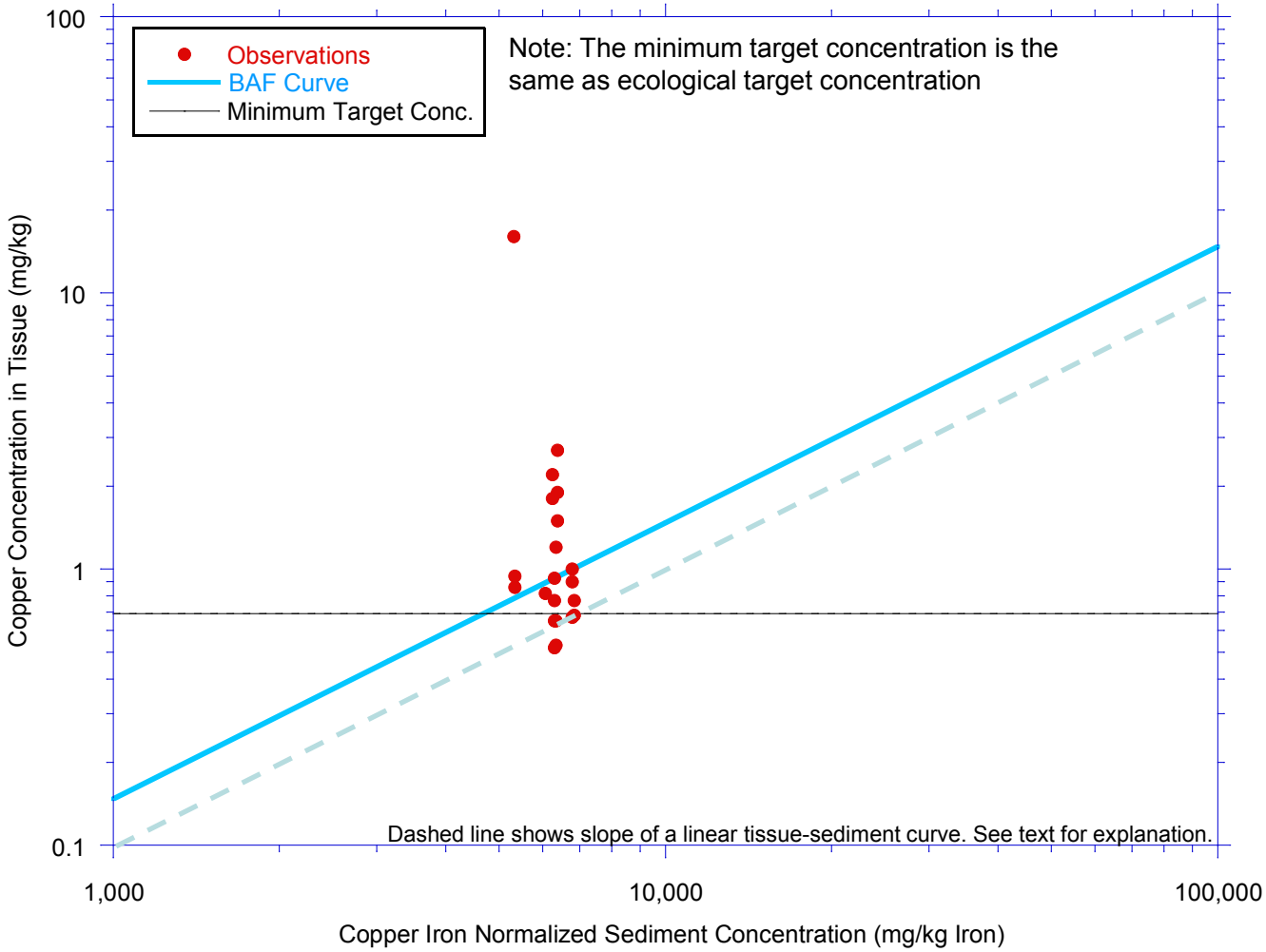
Regression Model

White Perch
Total PAH Lipid Normalized Concentration in Tissue vs. Total PAH TOC Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-39d

2014

R2-0027752



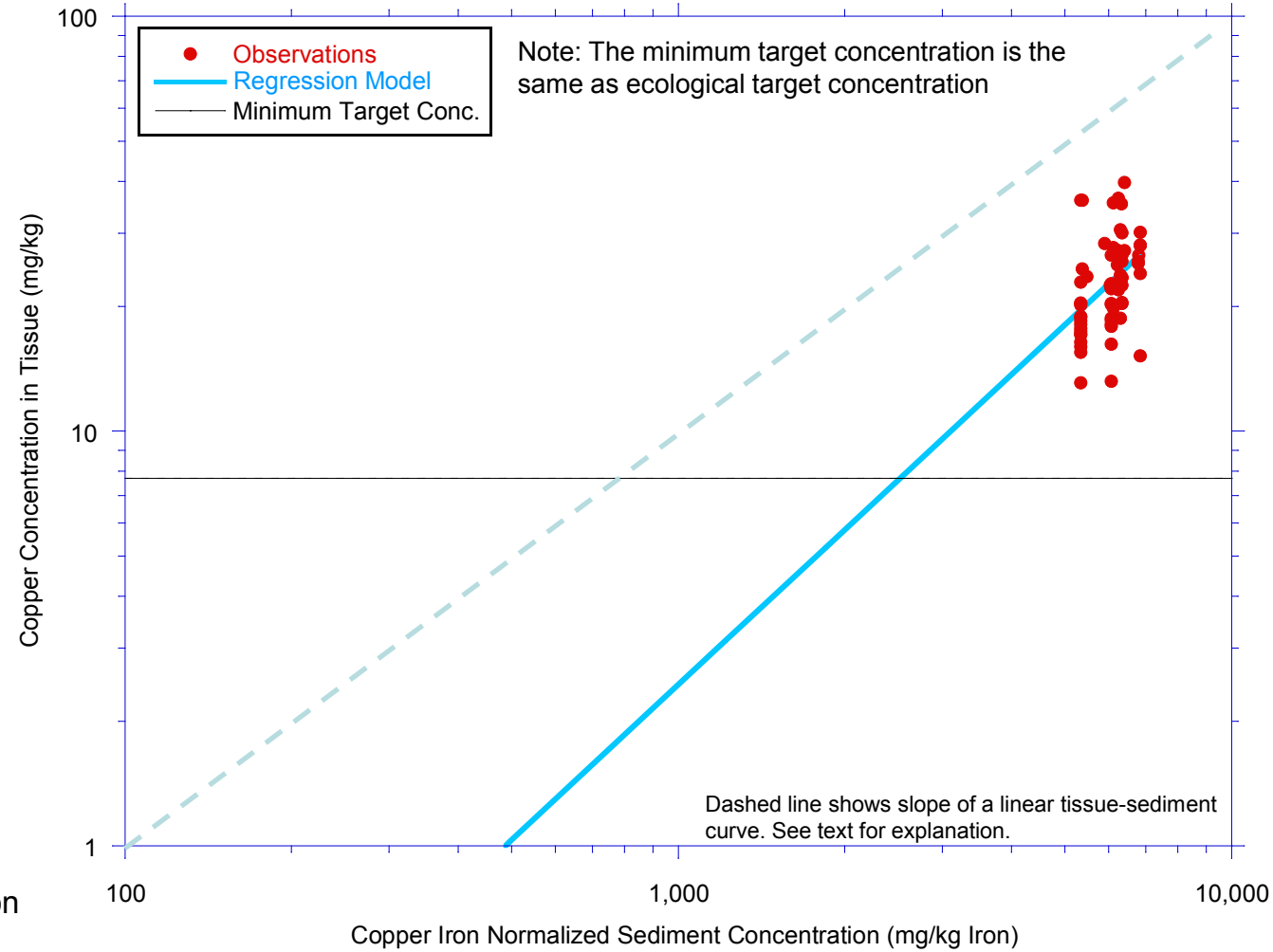
BAF Curve

American Eel
Copper Concentration in Tissue vs. Copper Iron Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-40a

2014

R2-0027753



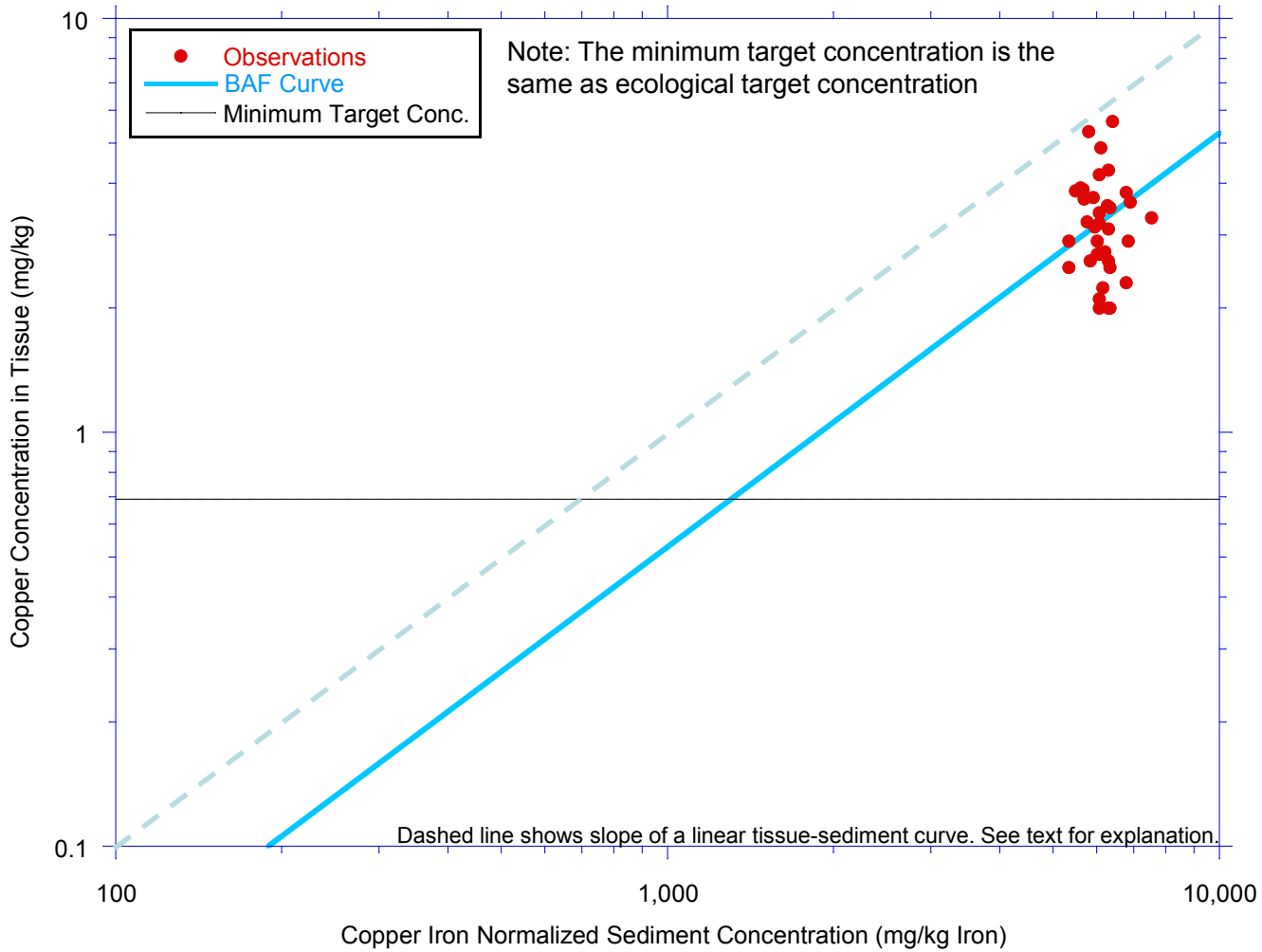
Regression Model

Blue Crab
Copper Concentration in Tissue vs. Copper Iron Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-40b

2014

R2-0027754



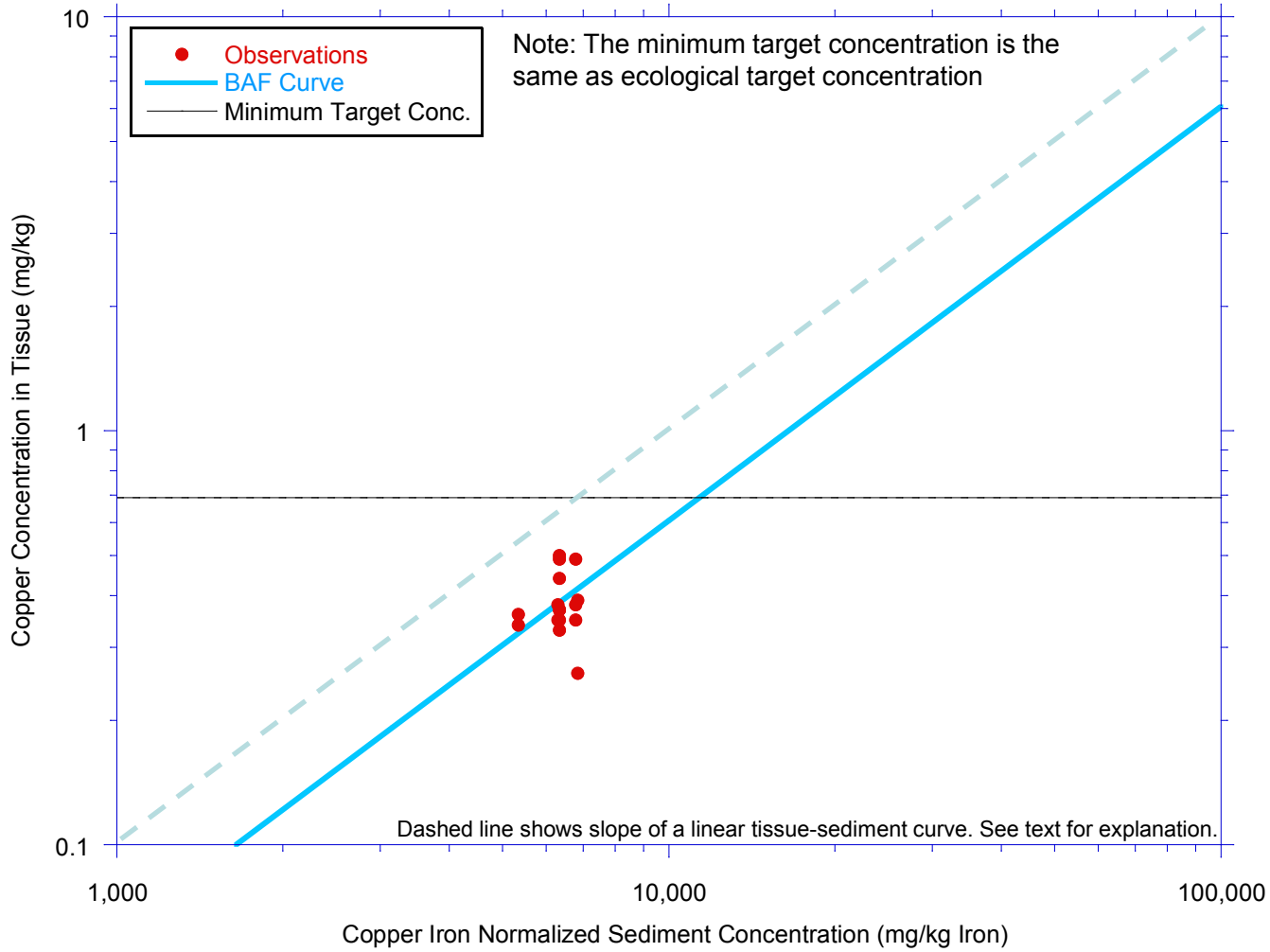
BAF Curve

Mummichog
Copper Concentration in Tissue vs. Copper Iron Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-40c

2014

R2-0027755



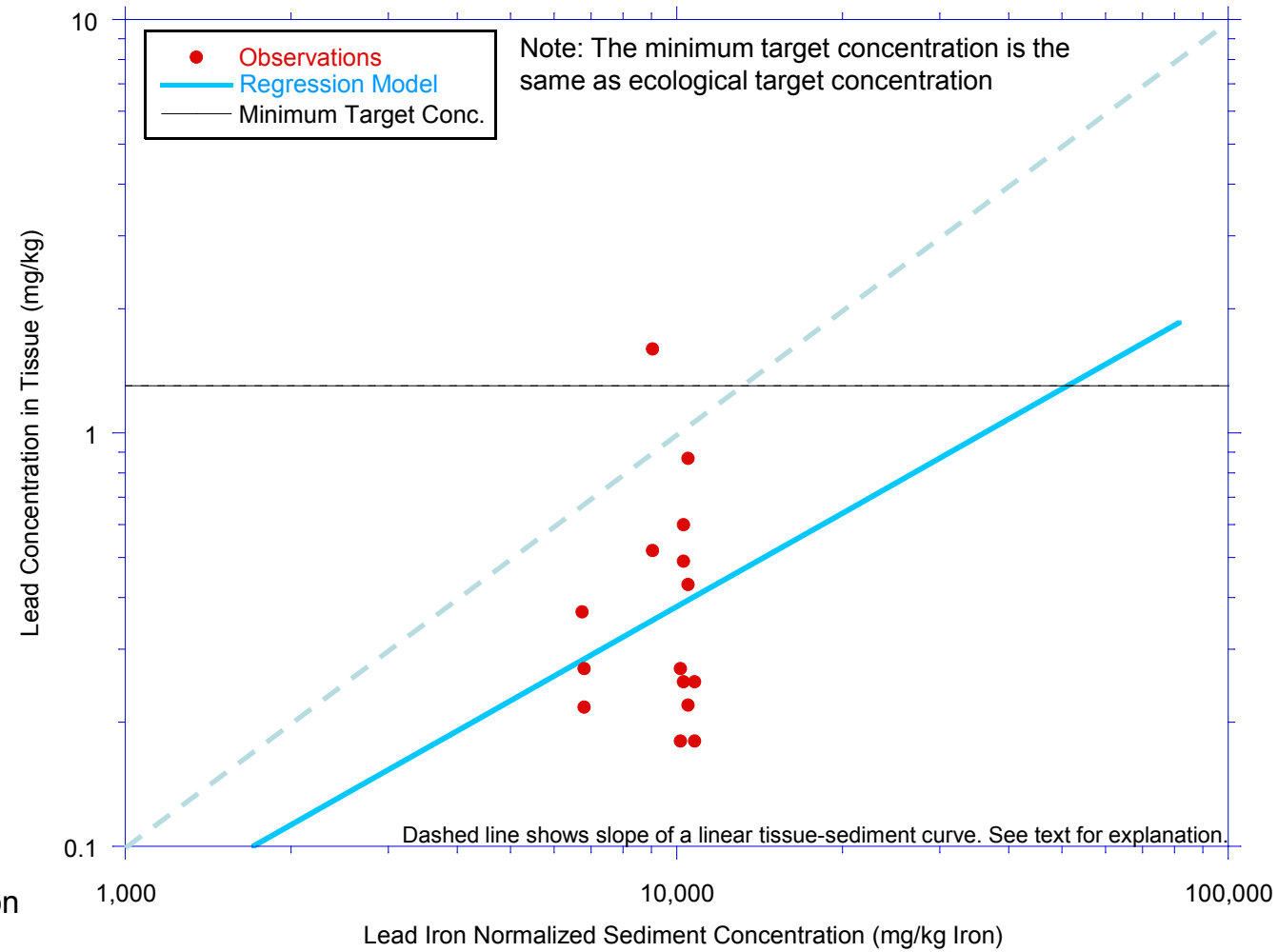
BAF Curve

White Perch
Copper Concentration in Tissue vs. Copper Iron Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-40d

2014

R2-0027756



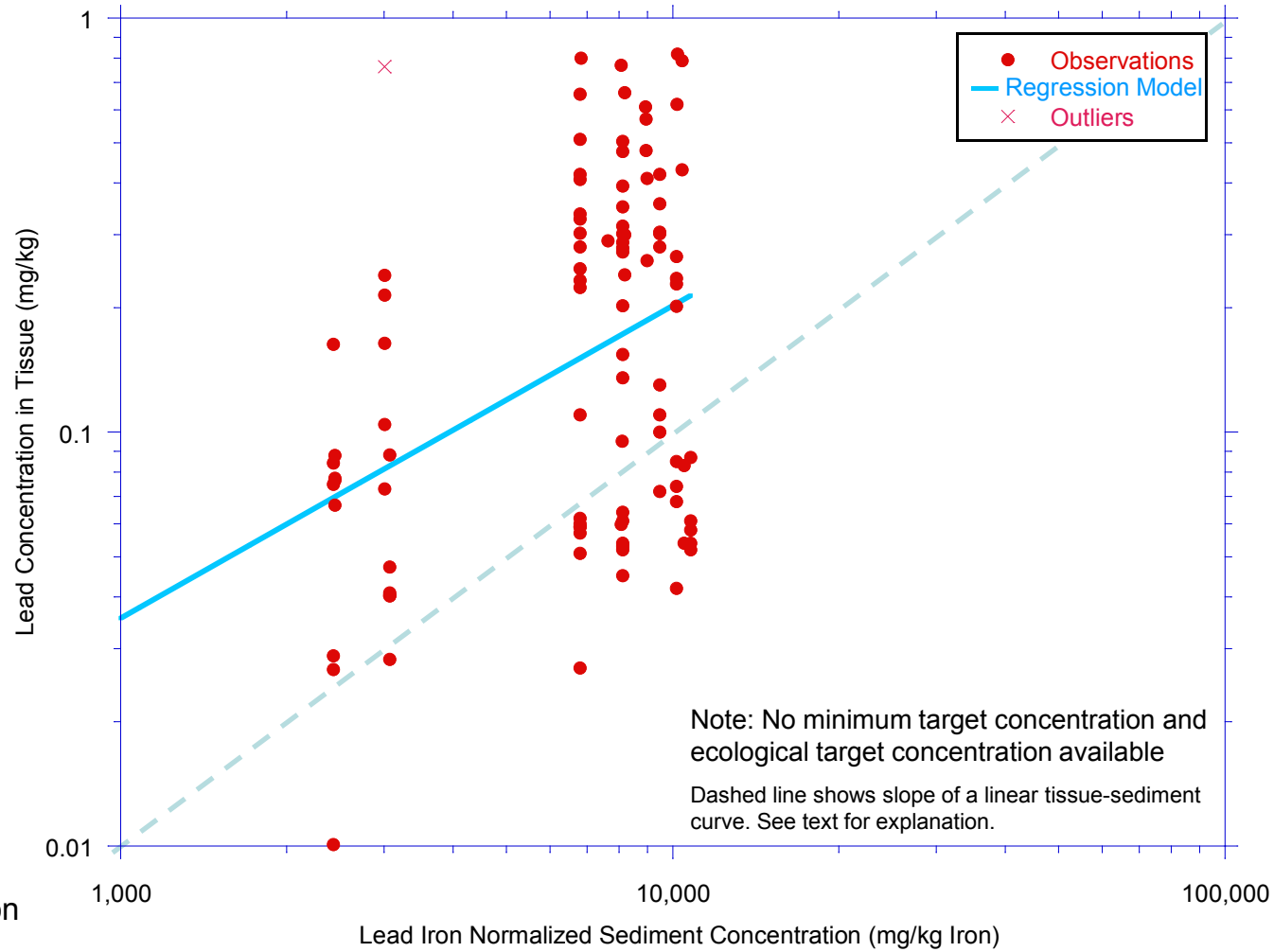
Regression Model

American Eel
Lead Concentration in Tissue vs. Lead Iron Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-41a

2014

R2-0027757



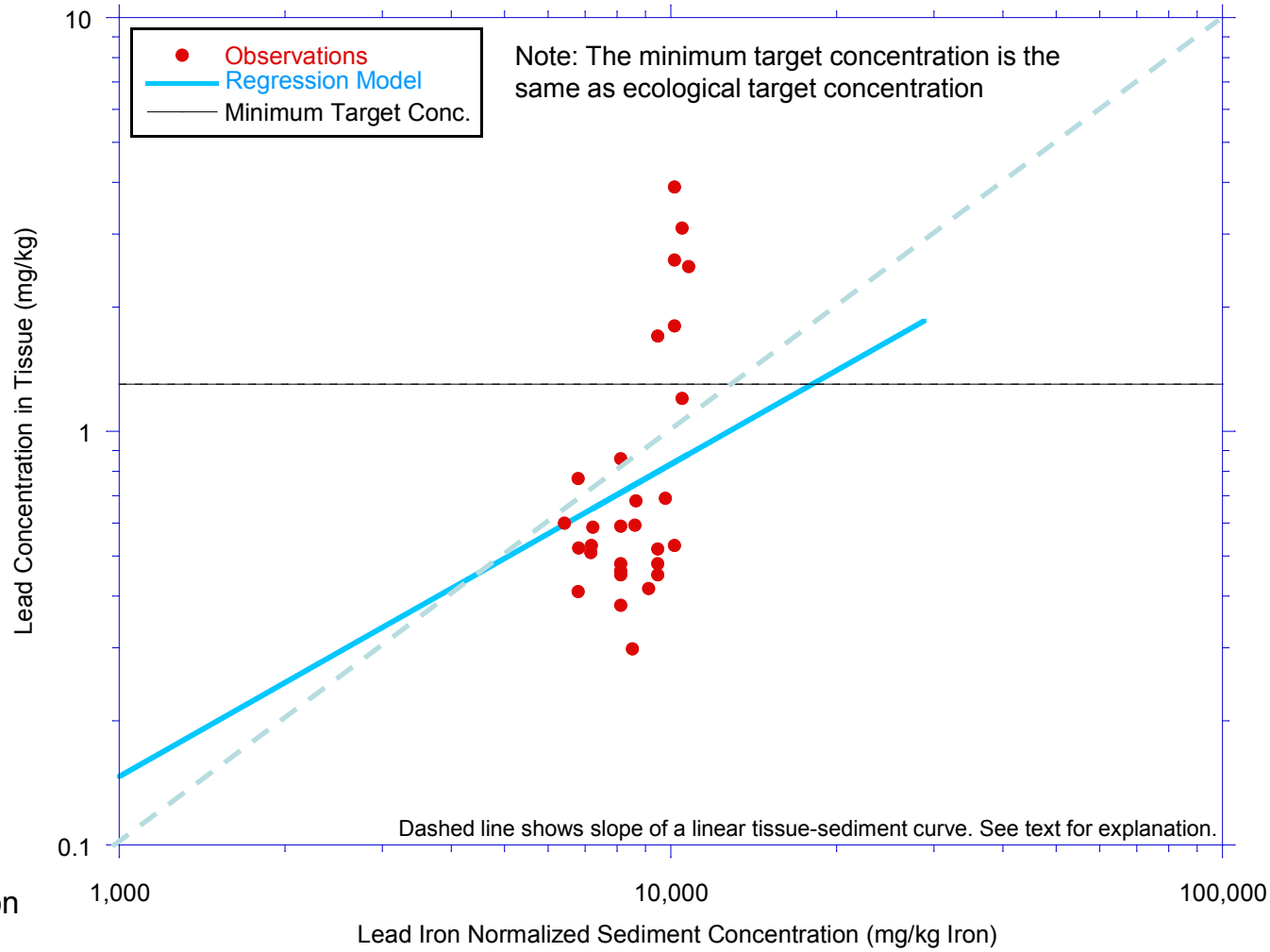
Regression Model

Blue Crab
Lead Concentration in Tissue vs. Lead Iron Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-41b

2014

R2-0027758



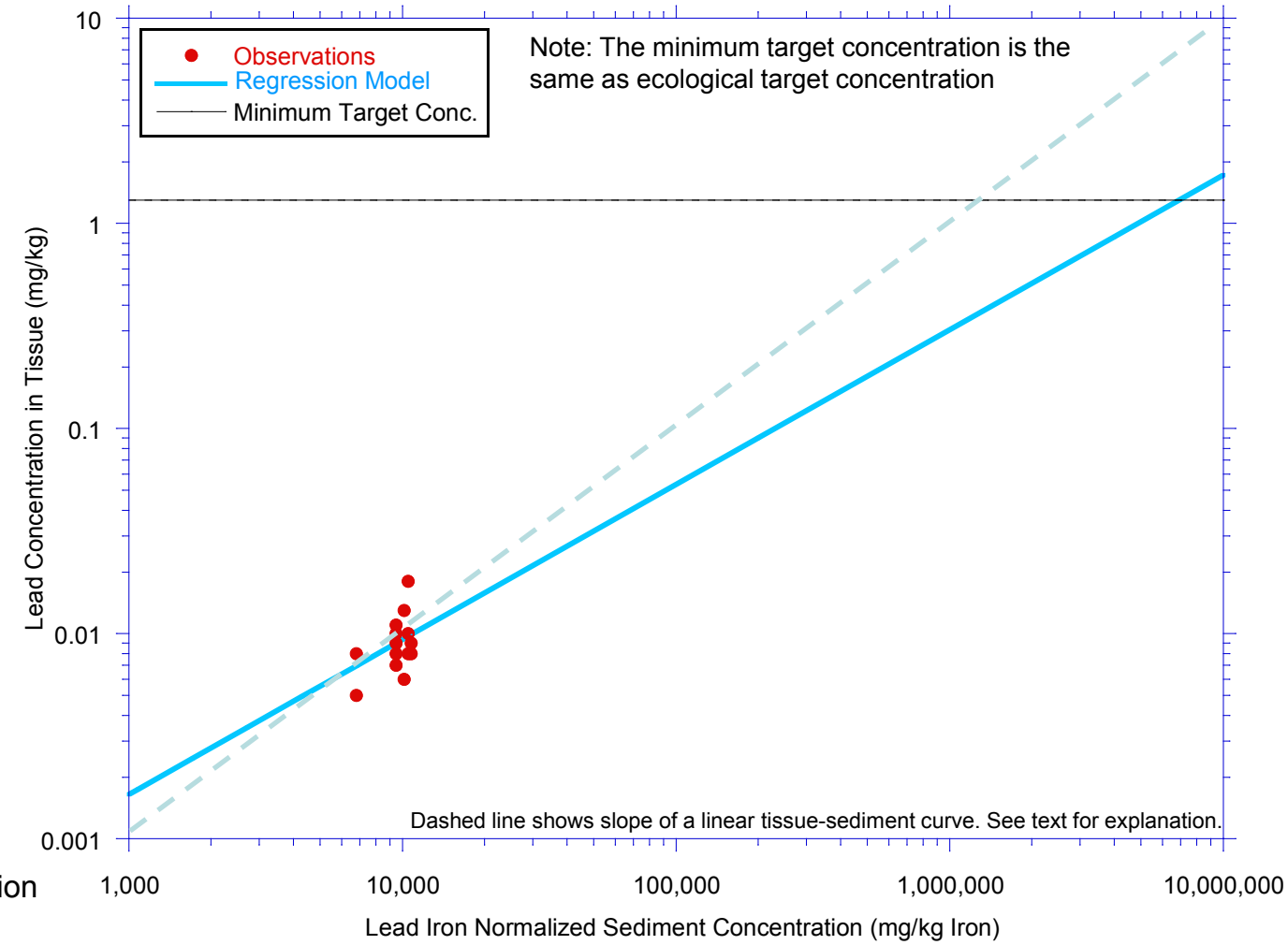
Regression Model

Mummichog
Lead Concentration in Tissue vs. Lead Iron Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-41c

2014

R2-0027759



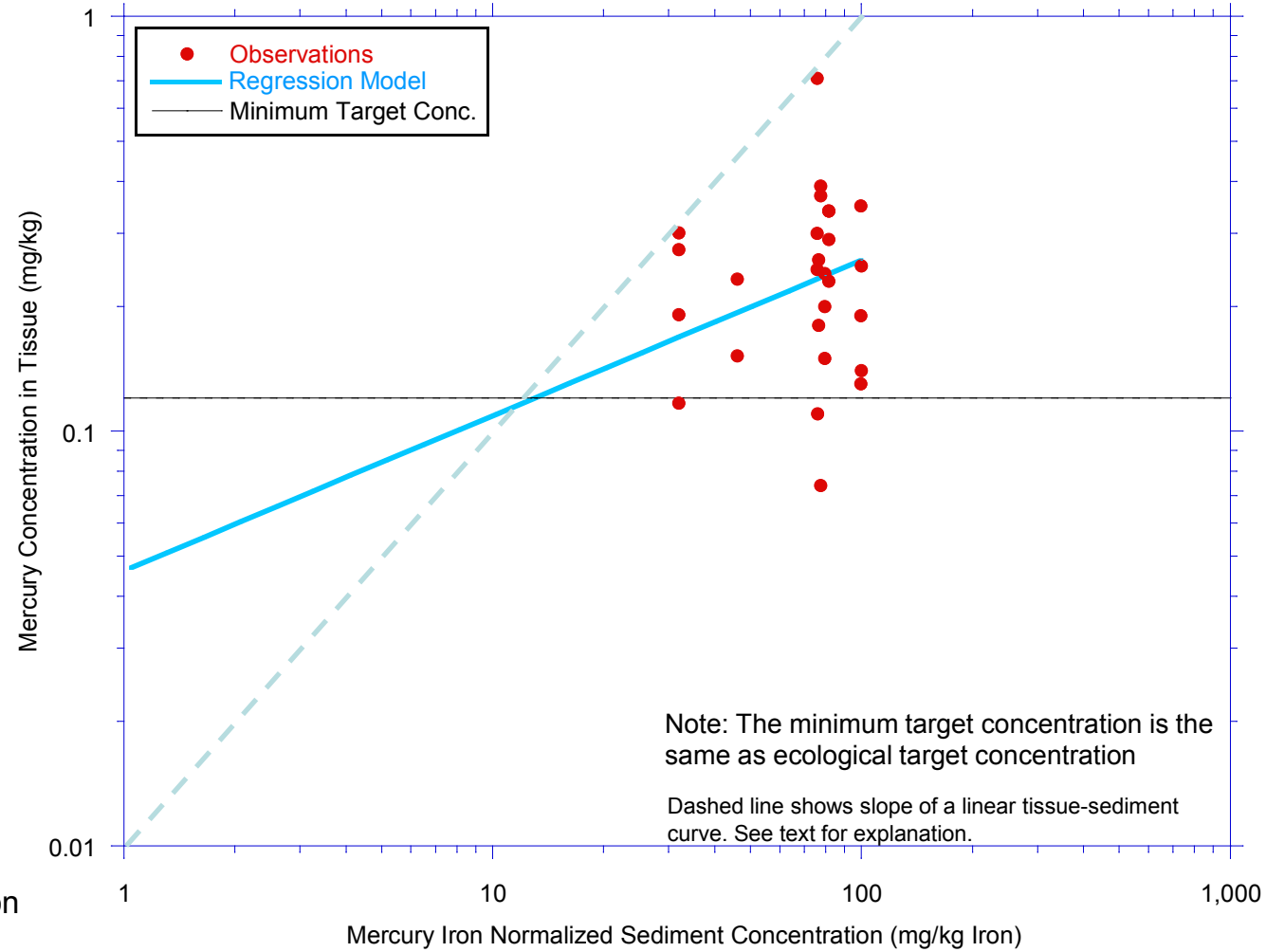
Regression Model

White Perch
Lead Concentration in Tissue vs. Lead Iron Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-41d

2014

R2-0027760



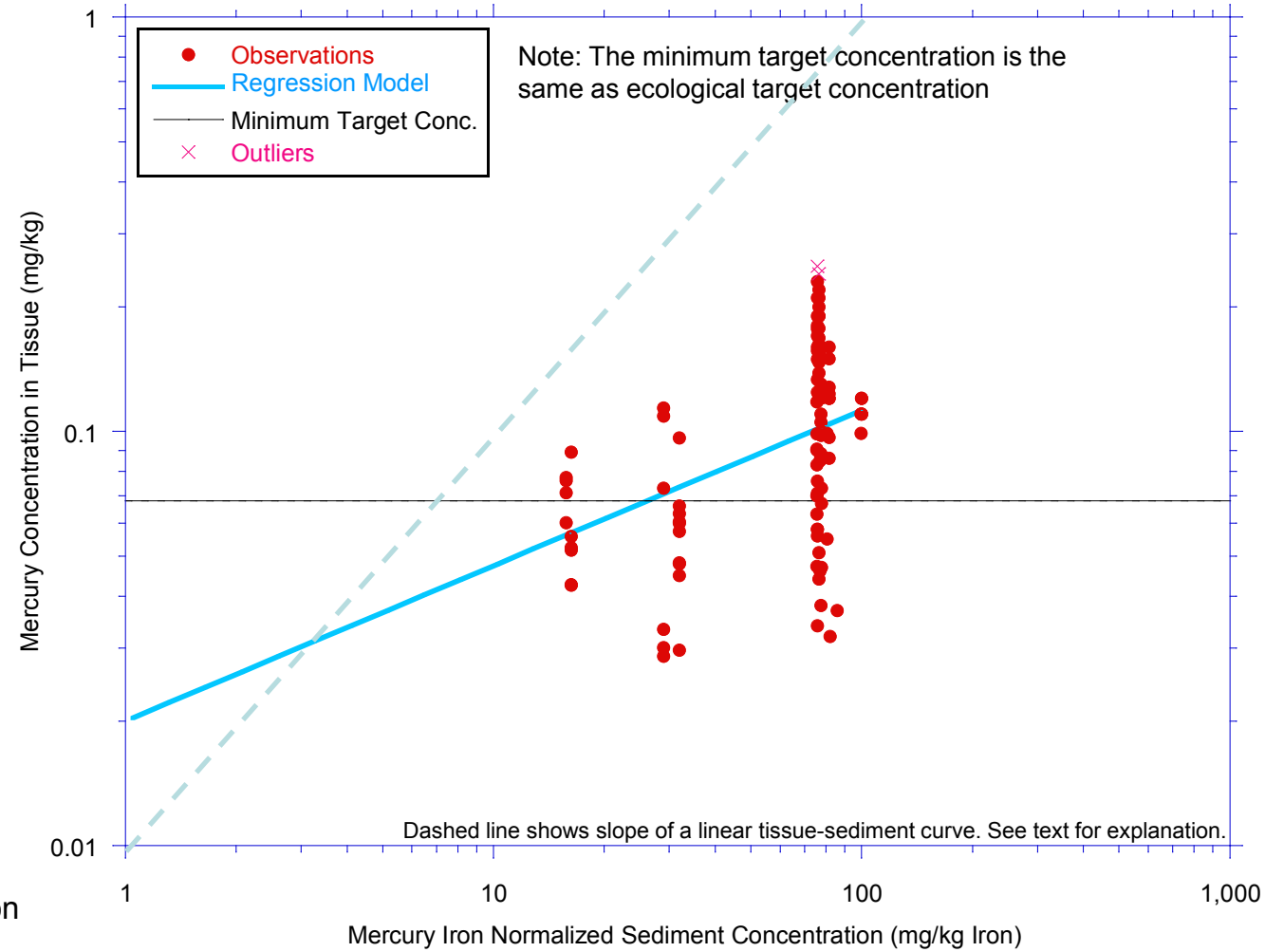
Regression Model

American Eel
Mercury Concentration in Tissue vs. Mercury Iron Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-42a

2014

R2-0027761



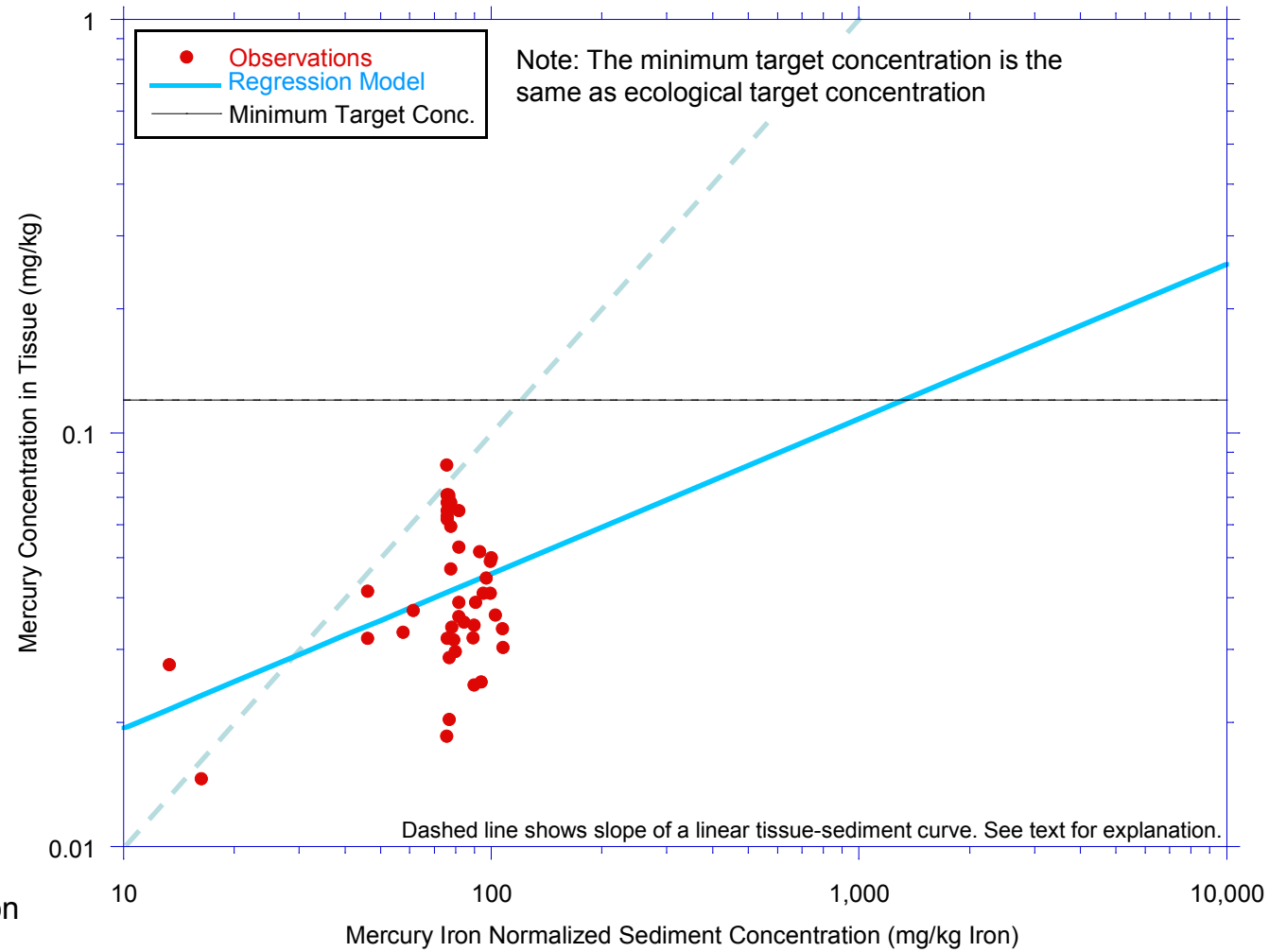
Regression Model

Blue Crab
Mercury Concentration in Tissue vs. Mercury Iron Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-42b

2014

R2-0027762



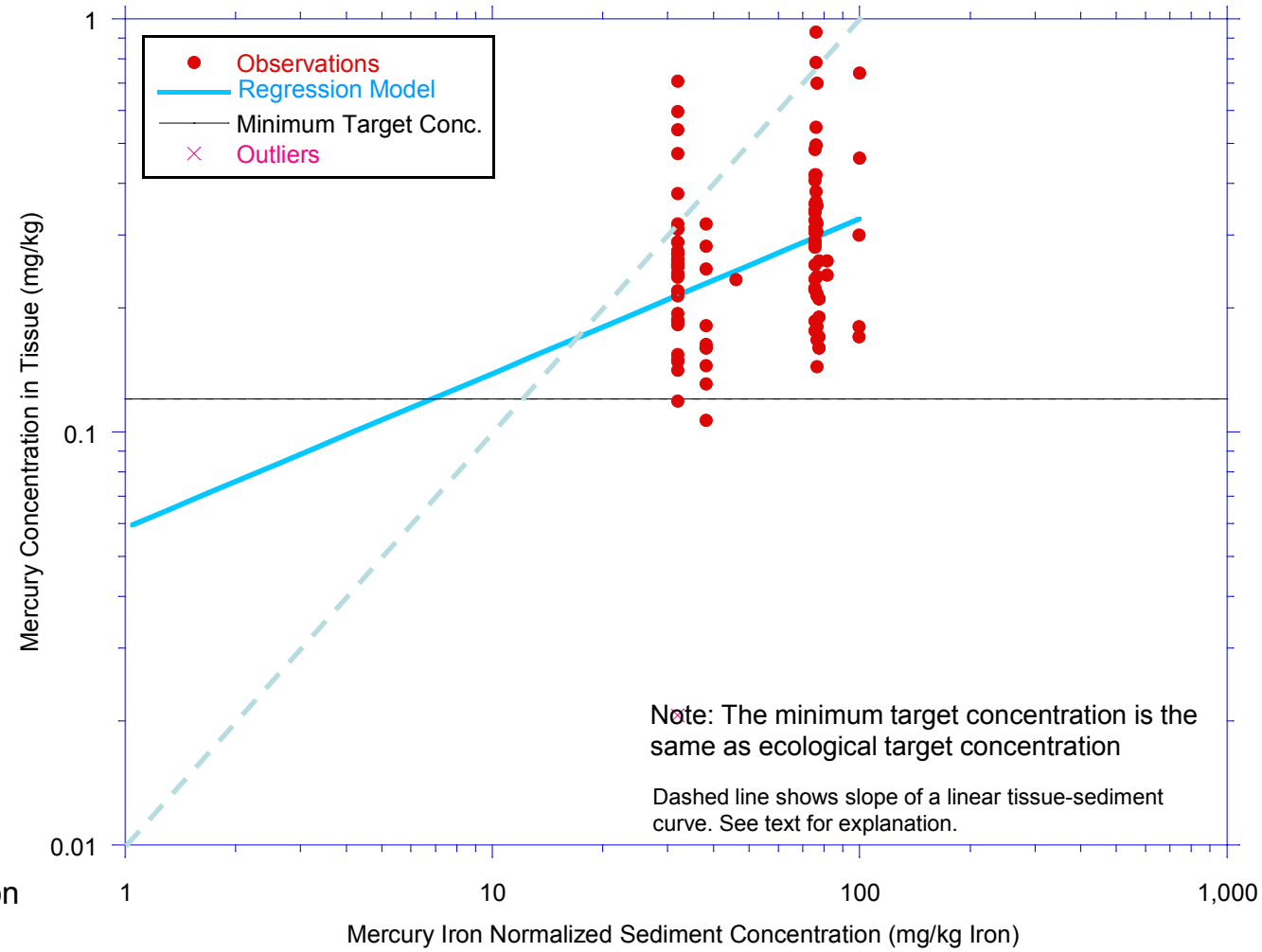
Regression Model

Mummichog
Mercury Concentration in Tissue vs. Mercury Iron Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-42c

2014

R2-0027763



Regression Model

White Perch
Mercury Concentration in Tissue vs. Mercury Iron Normalized Concentration in Sediment
Lower Eight Miles of the Lower Passaic River

Figure 3-42d

2014

R2-0027764