Lower Passaic River Restoration Project

Conceptual Site Model

In partnership with

February 2007

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Conceptual Site Model

PREPARED BY:
Malcolm Pirnie, Inc.
104 Corporate Park Drive
White Plains, NY 10602

MALCOLM PIRNIE

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1.0 INTRODUCTION

1.1 OBJECTIVE OF THE CONCEPTUAL SITE MODEL

A conceptual site model (CSM) expresses a site-specific contamination problem through a series of diagrams, figures, and narrative consistent with United States Environmental Protection Agency (USEPA) Office of Solid Waste and Emergency Response (OSWER) remedial investigation and feasibility study guidance (USEPA, 1988). These diagrams, figures, and the narrative are designed to illustrate the potential physical, chemical, and biological processes that transport contaminants from sources to receptors. A CSM is a tool for examining the contamination problem and provides the basis for identifying and evaluating the potential risks to human health and the ecosystem.

A CSM is prepared during the first step of the data quality objective (DQO) process (USEPA, 2000). The CSM continues to evolve throughout the project as historical and recently collected data are evaluated and as the risk assessments are refined. Typical components of a CSM include:

- Physical and chemical processes occurring naturally or anthropogenically at the site and in its environmental setting.
- Spatial variation in physical and chemical processes occurring across the site.
- Changes in physical attributes at the site over the historical period of contamination.
- Potential contamination source area(s).[1]
- Potentially contaminated media and types of contaminants expected.
- Contaminant fate and transport mechanisms and migration pathways.

[1] This CSM identifies geographical regions where sources may originate (*e.g.*, upriver of Dundee Dam, downriver of Dundee Dam, or a particular stretch of the river). Source areas are defined as locations from which contamination originates and becomes available for transfer to other media and other areas (refer to Section 6.0 "Source Area Analyses" for further discussion). This CSM does not identify specific entities that generated potential contaminant input to the Lower Passaic River.

- Potential exposure pathways.
- Potential human and ecological receptors.

Together, these CSM components present a current understanding of the contamination problem. They identify existing data gaps and the sampling necessary to address these gaps, and they identify potential exposures that may result in existing human and ecological risks. The CSM also provides guidance for future project decision-making. The CSM is a multi-faceted tool that serves a critical project role in risk assessment, numerical model development, project and sample planning, decision making, and ultimately in choosing a remedial strategy. For these reasons, a series of diagrams, figures, and a narrative, which make up the CSM, are necessary to describe the complex system fully, with each diagram or figure individually highlighting a different aspect of the system.

1.2 DEVELOPMENT OF CONCEPTUAL SITE MODEL FOR THE STUDY

The Lower Passaic River Restoration Project (herein referred to as the Study) is an interagency effort to remediate and restore the complex ecosystem of a portion of the Passaic River identified as the Lower Passaic River, which is the 17-mile, tidally-influenced portion of the river located in northeastern New Jersey. The Study Area (118 square miles) is defined as the Lower Passaic River and its basin, which comprises the tidally-influenced portion of the river from the Dundee Dam [River Mile (RM) 17.4] to Newark Bay and the watershed of this river portion, including Saddle River, Second River, and Third River (Figure 1-1).[2] The Upper Passaic River watershed (the area impacting the portion of the Passaic River located above the Dundee Dam) is represented as a point source with solids, water, and contaminants crossing over the dam into the Study Area. Refer to Section 2.0 "Hydro-Geographic Setting" for further discussion on

[2] RM0, which was established for this Study, 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, New Jersey just offshore of Newark and the other one in Hudson County, New Jersey just offshore of Kearny Point.

the Lower Passaic River and the relationship of the river with the larger Hudson-Raritan Estuary.

A preliminary CSM for the Study was presented in August 2005 version of the *Work Plan* (Malcolm Pirnie, Inc., 2005a). The objective of the 2005 CSM was to present the contamination problem of the Lower Passaic River by focusing initially on geochemical and transport processes understood at the time. Here, the CSM is updated according to the *Quality Assurance Project Plan* (QAPP; Malcolm Pirnie, Inc., 2005b) to summarize the studies conducted between September 2005 and September 2006.[3] This 2007 CSM represents our current articulation of the site contamination problem and river processes, including:

- Delineation and division of the Lower Passaic River into three river sections (Freshwater, Transitional, and Brackish) to capture important spatial variations in the river's character.
- Description of the major boundary conditions in the Study Area, including those at Dundee Dam and Newark Bay, as well as other boundary conditions that have less impact on the Lower Passaic River.
- Description of solids accumulation conditions and description of net depositional and net erosional areas in the Lower Passaic River.
- Characterization of potential source areas and contaminant inputs to the Lower Passaic River.
- Description of the fate and transport of target contaminants through preliminary mass balances.

This CSM is intended to support the overall remedial investigation and feasibility study for the Lower Passaic River as well as to assist in the development of other tasks. To continue developing a comprehensive understanding of the river, which addresses all

[3] The CSM synthesizes data evaluations that were published in other documents. Consequently, data gaps exist in the CSM where data from the different published documents do not overlap.

aspects of the Study, future iterations of the CSM should identify site-specific exposure pathways, measurement endpoints, and assessment endpoints as well as identify site-specific chemicals of potential concern (COPCs) and chemicals of potential ecological concern (COPECs). Pathways, endpoints, and contaminants presented in this CSM are preliminary and will be developed as part of the problem-formulation phase of the baseline ecological risk assessment (BERA) (USEPA, 1997).

In addition, the geochemical evaluations presented in this CSM should be further refined to integrate the remaining historical data and the data collected during recent and future field investigations that have not been included here. It is recognized that several other datasets are available; however, the work to date has focused on those datasets that provide the broadest representation of the Lower Passaic River. Currently, the datasets presented in the figures and tables of this CSM are listed in Table 1-1. These datasets are supplements with literature values that are referenced in Section 10 "References."

Table 1-1: Datasets Presented in the CSM

Study Name [a]	Sample Year	Number of Locations	River Mile or Water Body	Type of Sample
1990 Surficial Sediment Investigation	1990	3 [b]	Above Dundee Dam	Sediment Grab
1991 Core Sediment Investigation	1991	1 [b]	Above Dundee Dam	Sediment Core [c]
1995 Remedial Investigation Sampling Program	1995	97	RM0.9 to RM6.8	Sediment Core [c,d]
1999 Sediment Sampling Program	1999	1 [e]	RM6.2	Sediment Core [c]
1999 Late Summer/Early Fall Environmental Sampling Program	1999	45	RM1 to RM6.9	Sediment Grab
1999/2000 Minish Park Monitoring Program	1999	8	RM4.9 to RM5.1	Sediment Core [c]
2000 Spring Environmental Sampling Program	2000	15	RM1 to RM6.9	Sediment Grab
Newark Bay 2005 Remedial Investigation Work Plan Phase 1 Dataset	2005	69	Newark Bay	Sediment Core [c]
2005-2006 USEPA Sampling Program High Resolution Cores	2005	5	RM1.4 to RM12.6	Sediment Core [c,d]
2005-2006 USEPA Sampling Program Low Resolution Cores	2006	10	RM2.8 to RM6.8	Sediment Core [c]

a: Data are available at www.ourpassaic.org.
b: Only sample locations above the Dundee Dam were evaluated.
c: Only surface sediment samples are presented in the CSM.
d: All data from sediment core were evaluated to develop the CSM.
e: Only one sampling location was incorporated into CSM since the other samples were mis-projected.

Table 1-2 provides an additional list of datasets evaluated in the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a). The conclusions from these evaluations are summarized and presented throughout this CSM.

Table 1-2: Datasets Referenced in the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a)

Study Name [a]	Sample Year	Number of Locations	River Mile or Water Body	Type of Sample
1990 Surficial Sediment Investigation	1990	2 [b]	RM3.2 to RM7	Sediment Grab
1991 Core Sediment Investigation	1991	14 [b]	RM0.2 to 7	Sediment Core [c]
2004 Newark Bay Remedial Investigation Work Plan	1991-1998	32	Newark Bay	Sediment Core [d]
1992 Core Sediment Investigation	1992	4 [b]	RM1.1 to RM7	Sediment Core [d]
1993 Core Sediment Investigation – Part 1 (March 1993)	1993	8 [b]	RM0.3 to RM7	Sediment Core [c]
1993 Core Sediment Investigation – Part 2 (July 1993)	1993	11	RM0.5 to RM3	Sediment Core [c]
1994 Surficial Sediment Investigation	1994	18 [b]	RM3.5 to RM7.8	Sediment Grab
1995 Remedial Investigation Sampling Program	1995	97	RM1 to RM6.8	Sediment Core [c]
1995 Sediment Grab Sampling Program	1995	7	RM2.4 to RM2.7	Sediment Grab
1995 USACE Minish Park Investigation	1995	10	RM3.7 to RM5.5	Sediment Core [c]
1996 Newark Bay Reach A Sediment Sampling Program	1996	4	Newark Bay	Sediment Core [d]
1998 Newark Bay Elizabeth Channel Sampling Program	1998	3	Newark Bay	Sediment Grab and Sediment Core [d]
1999 Late Summer/Early Fall Environmental Sampling Program	1999	45	RM1 to RM6.9	Sediment Grab
1999 Newark Bay Reach ABCD Baseline Sampling Program	1999	10	Newark Bay	Sediment Grab
1999 Sediment Sampling Program	1999	1 [e]	RM6.2	Sediment Core [d]
1999/2000 Minish Park Monitoring Program	1999	8	RM4.9 to RM5.1	Sediment Core [d]
2000 Spring Environmental Sampling Program	2000	15	RM1 to RM6.9	Sediment Grab

a: Data are available at www.ourpassaic.org.
b: Only sampling locations between RM0 and RM7 were evaluated.
c: All data from the sediment core were evaluated in the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a).
d: Only surface sediment samples were evaluated in the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a).
e: Only one sampling location was incorporated into *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a) since the other samples were mis-projected.
USACE = United States Army Corp of Engineers

1.3 CONCEPTUAL SITE MODEL SUMMARY

This section summarizes the salient points of the CSM, including the history of the Lower Passaic River, its physical and chemical setting, inventories of selected contaminants, and its impacts on Newark Bay. Relevant section numbers are included throughout this summary to refer the reader to additional detail on the topics introduced.

1.3.1 HISTORY OF THE LOWER PASSAIC RIVER

The Lower Passaic River was one of the major centers of the American industrial revolution, with early manufacturing, particularly cotton mills, developing in the area around Great Falls in Paterson, New Jersey. In subsequent years, a multitude of industrial operations sprung up along the banks of the Passaic River, as the New Jersey cities of Newark and Paterson grew. These industrial developments included, but were not limited to, manufactured gas plants, paper manufacturing and recycling facilities, and chemical manufacturing facilities. These plants used the river for wastewater disposal. Moreover, the Lower Passaic River has been used as a major means of conveyance for municipal discharges from the middle of the nineteenth century to the present time. Together, these waste streams (industrial and municipal) have delivered a number of contaminants, including but not limited to 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD), polycyclic aromatic hydrocarbons (PAH) from manufacturing gas plants, polychlorinated biphenyls (PCB) from recycling carbon-less copying paper, DDT[4], mercury, and lead.

An important component of the river's development and urbanization was the channelization of the river to permit commercial vessels to travel into the city of Newark and beyond. Several large dredging projects were undertaken at the beginning of the twentieth century to create a ship channel to RM15. The federally mandated channel dimensions are given in Table 1-3 [depths are relative to mean low water (MLW)].

[4] DDT is a common name that refers to a industrially-produced, chlorinated pesticide. DDT is chemically known as dichlorodiphenyltrichloroethane; its metabolites include dichlorodiphenyldichloroethane (DDD) and dichlorodiphenyldichloroethylene (DDE). The term Total DDT refers the sum of the DDT, DDD, and DDE concentrations in a sample.

Table 1-3: Lower Passaic River Authorized Dimensions of the Federal Navigational Channel

River Mile [a]	Channel Depth (feet) [b,c]	Channel Width (feet)
RM -0.2 to RM2.2	30	300
RM2.2 to RM4.3	20	300
RM4.3 to RM6.9	20 (only constructed to 16 feet)	300
RM6.9 to RM7.9	16	200
RM7.9 to RM15.2	10	200

a: River miles are referenced to the Study-defined river mile scale (refer to Section 1.2 "Development of the Conceptual Site Model for the Study"). These river miles are offset from the scale that is used by the USACE by approximately 0.2 miles.
b: Obtained from the "Report of Channel Conditions 100 to 400 feet Wide" (USACE, 2002) and the USACE map "Newark Bay, Hackensack & Passaic Rivers, N.J. (Passaic River)" dated September 30, 1986 (USACE, 1986).
c: Channel depth relative to MLW

The volumes of sediments removed each year from dredging were recorded by the USACE (USACE, 1917; USACE, 1916; USACE, 1915; USACE, 1913; USACE, 1907; USACE, 1900; USACE, 1884; USACE, 1880) and summarized by Iannuzzi *et al*. (2002). This dredging data is presented in Figure 1-2 to show the total volume of sediment removed by dredging in 6-year increments. The figure also highlights the portion of the dredged volume removed from the Lower Passaic River below RM2. Over time, the total volume of sediments removed by dredging has declined. Since the 1940s, the vast majority of dredging has occurred below RM2. Consequently, the channel depths upriver of RM2 were not maintained and began to fill in (refer to Section 2.2.2 "Dredging History in the Lower Passaic River").

Channels fill by trapping sediments delivered from upland regions. In a typical estuary, sediment entrapment and deposition would occur most rapidly at the salt front via flocculation. These sediments would build up until a major storm or flow event of sufficient magnitude occurred. Then, sediments that were deposited since the last major event could be carried downriver. In this manner, a quasi-equilibrium bottom elevation of the estuary could be established over time reflecting the mass of solids delivered and the strength and frequency of major transport events.

In the case of the Lower Passaic River, however, any approximation of equilibrium has been greatly affected by anthropogenic activity in and around the river. Prior to the channel dredging of the early twentieth century, the Lower Passaic River was a relatively shallow estuary, probably not deeper than 15 feet in the center throughout much of its length (Chant and Fugate, 2006). Historical dredging served to create a deep channel relative to prior conditions, greatly enhancing the rate of sediment accumulation in the dredged areas. In particular, the dredged channel probably permitted a much more extensive and permanent salt intrusion, enhancing the rate of sediment trapping in the Lower Passaic River. Based on USACE records (Figure 1-2), it does not appear that this channel was regularly maintained, permitting a large volume of sediment to accumulate over time.

Since the 1940s, the river has delivered sufficient material to build up many feet of deposition, yielding an average rate of deposition substantially greater than what would "naturally" occur. The coincidence of chemical disposal in the river along with the construction and subsequent limited maintenance of the navigation channel created an ideal situation for the accumulation of thick beds of contaminated sediments. The magnitude of this deposition is illustrated in Figure 1-3, which shows the current depth of the river channel as well as the original dredged elevations as reported in USACE records. For the region below RM8, the river has accumulated thick sediment beds, over 15 feet or more in some areas, while no substantive channel deposition occurred above RM8. This evidence is consistent with the observations of recent deposition rates and sediment texture, which change markedly across RM8. Perhaps the most important consideration for the spread of current contamination is that sufficient solids deposition has occurred below RM8 to affect channel flow. Moreover, the rise in the river floor probably hinders the movement of the salt front (the upriver-most, saltwater-fresh water interface) under all but the driest conditions (refer to Section 2.2.2 "Dredging History in the Lower Passaic River").

1.3.2 PHYSICAL ENVIRONMENT OF THE LOWER PASSAIC RIVER

The Lower Passaic River is a partially stratified estuary wherein the degree of stratification and the location of the salt front at any point in time reflect a dynamic balance between the freshwater flow and the tidal exchange with Newark Bay. Tidal displacement in the Lower Passaic River is quite large, with the salt front moving several miles during each tidal cycle. The combination of a relatively narrow river cross-sectional area and the strong tidal flows yield tidal velocities that are quite high, reaching several feet per second, homogenizing sediments over much of the Lower Passaic River prior to deposition.

Tidal and freshwater flows also combine to cause highly variable rates of annual deposition, with some years showing a net loss of solids from the Lower Passaic River while other years showing a net solids gain (Malcolm Pirnie, Inc., 2006a). Since the construction of the navigation channel, the river bottom has been and continues to be net depositional. A series of bathymetric surveys of the river bottom provides a basis to assess the annual rates of deposition across the period of 1989 through 2004. Annual sediment deposition averaged approximately 67,000 cubic yards during this period, which is roughly equivalent to 1 inch of sediment accumulation over the Lower Passaic River bottom (RM0 to RM17) or 1.5 inches over the lower 7 miles. Approximately 90 percent of this accumulation occurs from RM0 to RM7 (refer to Section 5.2 "Solids Mass Balance").

For the purposes of the following discussion, fine-grained sediment refers to areas identified as silt or silt/fine sand as interpreted from the side-scan sonar images; medium-grained sediment is defined as areas identified as sand; and coarse-grained sediment refers to areas identified as gravel/coarse sand and rock/coarse gravel. The identification of these areas was primarily derived from a side-scan sonar survey conducted in 2005 (Aqua Survey, Inc., 2006). Figure 1-4 presents an example of the side-scan sonar output (Attachment A contains sediment texture maps as interpreted from side-scan sonar images for RM0 to RM16).

The river bed of the Lower Passaic River can be divided into three main domains with respect to sediment texture (Figure 1-5). The upper region (RM17.4 to RM14) is largely comprised of coarse-grained sediments, with relatively few areas of fine-grained sediments. This region is largely non-depositional. Sediments between RM14 to RM8 transition from coarse-grained to fine-grained progressing downriver. The lower region (RM0 to RM8) is primarily comprised of fine-grained sediments, which are found over more than 80 percent of the river bottom. (Figure 1-4 shows side-scan sonar output near the boundary between these two of the domains at RM8.) For cross-sectional areas greater than about 3,500 square feet (marked as a dotted line on Figure 1-5), the river bottom is greater than 80 percent fine-grained sediments. For cross-sectional areas less than this value, the river bottom can vary but tends to be primarily coarse-grained. Notably, cross-sectional areas below RM8 are nearly always greater than 3,500 square feet (marked as a dotted cross-hair on Figure 1-6), correlating with the high percentage of fine-grained sediment in this region. Above RM8, cross-sectional areas tend to be less than 3,500 square feet and correspondingly high in coarse-grained sediment areas. This observation suggests a relationship between cross-sectional area and depositional environments, possibly related to the existence of stronger currents in areas of smaller cross-sectional area (refer to Section 3.5 “Upriver Extent of the Salt Front”).

Given the high percentage of fine-grained sediment areas below RM8, a series of more limited bathymetric surveys (1995 to 2001) were used to identify those areas in RM0.9 to RM7 that appear to be net depositional, net erosional, or bathymetrically neutral from year-to-year in the time period examined (refer to Section 5.3 “Depositional Environments in the Lower Passaic River”). The results show that most of the area between RM0.9 and RM7 is routinely net depositional, although scattered areas may be undergoing net erosion (Figure 1-7). In particular, the river bends between RM2.5 and RM3.5 contain several large areas of erosion. However, the occurrence of erosional areas throughout RM0.9 to RM7 reflects the very dynamic nature of sediment deposition and erosion in the river. Some or all of these erosional areas are responsible for the on-going release of contaminants from the river bed.

A detailed examination of net sediment accumulation rates between RM0.9 and RM7 indicates a high degree of spatial heterogeneity, with local rates varying from about 6 inches/year of erosion to about 8 inches/year of deposition (Malcolm Pirnie, Inc., 2006a). Historical deposition rates were probably higher than current rates because of the more extensive salt intrusion present immediately after the initial channel dredging, which enhanced trapping of suspended matter. Based on solids balance considerations, current head-of-tide solids load to the Lower Passaic River is likely greater than the annual average rate of accumulation in the river (Malcolm Pirnie, Inc., 2006a). Excess solids delivered at the head-of-tide represent the net solids load delivered to Newark Bay. However, the historical rates of sediment accumulation in the Lower Passaic River were probably too large to be sustained solely by the Passaic's head-of-tide solids loads, suggesting that a net solids transport from Newark Bay supplied the additional solids. This observation is based on the estimated volume of contaminated sediments that accumulated between RM0.9 and RM7 after 1940, roughly 6.5 million cubic yards as of 1995. The estimated solids load at the head-of-tide would not deliver the estimated 6.5 million cubic yards (refer to Section 4.2 "Newark Bay Boundary Condition" and Section 5.2 "Solids Mass Balance").

The historical contaminated sediment deposits, which were created when the channel was deeper, may now be undergoing erosion as a result the changes in the channel geometry. The lines of evidence for this suggestion include the volume of sediments deposited, the high tidal velocities observed, the presence of erosional areas throughout the lower 7 miles of the Lower Passaic River, and the continued presence of several historical contaminants in very recently deposited sediments. A particular area of concern is the area near RM3.5 where the river turns sharply and erosional areas are observed on the outsides of the bends (Figure 1-7; refer to Section 5.3 "Depositional Environment in the Lower Passaic River"). The reworking of the historical sediments is an on-going source of contamination to other areas of the Lower Passaic River.

1.3.3 CHEMICAL ENVIRONMENT IN THE LOWER PASSAIC RIVER

The chemical contamination associated with the Lower Passaic River is primarily driven by the contaminant burdens contained within the sediments. While on-going external inputs may exist, the concentrations within the sediments are responsible for much of the contamination within the water column (Miller *et al*., 2007). In fact, the legacy of contamination in the sediments probably extends back at least to the beginning of the twentieth century. Based on observations made with dated sediment cores, historical loads of mercury and lead may predate or coincide with the original channel construction. The sand layer that underlies the thick silt beds is contaminated with these compounds (refer to Section 7.2 "Nature and Extent of Contamination"). This contamination may extend to a prehistoric sediment horizon, referred to as the red-brown clay.

Dated sediment cores also provide a record of contaminant load to the Lower Passaic River. For example, initial loads of Total DDT occur in the late 1940s and early 1950s and predate the appearance of major loads of 2,3,7,8-TCDD. Initial loads of 2,3,7,8-TCDD appear in the late 1940s to early 1950s and peak in the late 1950s to early 1960s. This peak occurs after the peak loads of Total DDT. Meanwhile, Total PCB loads appear in the middle 1950s, peaking in the late 1960s, making PCB the most recent of the contaminants. These cores also date the histories of mercury and cadmium, with peak releases of these metals occurring in the early 1960s. However, both metals are present well above background concentrations throughout the core record, predating the appearance of Total DDT. Total PAH contamination is unique in its temporal distribution, with the highest concentrations observed in the deepest core layers, gradually declining to the most recent deposition. The presence of Total PAH contamination in the sand layer underneath the thick silt deposits may represent historic deposition or alternatively a contaminated groundwater source.

Dated cores collected above the head-of-tide on the Upper Passaic River do not provide as extensive a historical record. Nonetheless, the core data are sufficient to suggest that the majority of historical loads of cadmium, lead, mercury, and Total PCB to the Lower Passaic River originated in the Upper Passaic River above the Dundee Dam. Historical loads of copper were more evenly split between Upper Passaic and Lower Passaic sources. Dated sediment cores from the Upper and Lower Passaic River further indicate that relatively little of the Total DDT and less than 1 percent of the 2,3,7,8-TCDD contamination in the Lower Passaic River historically originated above the Dundee Dam.

The same dated cores that document the magnitude of the historical loads show that current loads throughout the Lower Passaic River are substantively lower. Figure 1-8 shows that the 2,3,7,8-TCDD profiles of three dated cores (RM1.4, RM2.2 and RM11). Evident in each core is a nearly two order of magnitude decline in 2,3,7,8-TCDD concentrations from the late 1950s to the present. In addition, despite the distance separating the cores, the cores record similar contaminant loading histories at similar concentrations. This observation is direct evidence of the effectiveness of tidal mixing in the Lower Passaic River, where sediments are well homogenized prior to deposition (refer to Section 6.2.2 "Tidal Mixing of Sediments"). Moreover, the presence or absence of an interval of high concentration within the sediments at a given location is a function of the depositional history and is not controlled by proximity to source. Thus, thick sequences of contaminated sediments will tend to have similar inventories of contaminants throughout the Brackish River Section and even into the Transitional River Section (refer to Section 6.2.1 "Surface Sediment Concentrations and Gradients").

Further evidence for tidal mixing can be observed in Figure 1-9, which shows the ratio of 2,3,7,8-TCDD to total tetrachlorodibenzodioxin (Total TCDD). Based on the work of Chaky (2003), this ratio is diagnostic of Lower Passaic River 2,3,7,8-TCDD contamination. The consistency of this ratio throughout these cores (post-1945) is indicative of a single source of 2,3,7,8-TCDD, distributed by tidal mixing throughout the Lower Passaic River. In contrast to the ratio for Lower Passaic River sediments, the 2,3,7,8-TCDD/Total TCDD ratios for sewage effluent and atmospheric deposition are less than 0.06. Notably, ratios approaching these levels are observed in the pre-1940s sediments, and these concentrations are orders of magnitude lower than the post-1940s deposition (refer to Section 2.2.1 "Relationship of the Lower Passaic River with the Estuary").

Ratio analysis has provided additional insight on other contaminants as well. Ratio analysis of metal contamination between RM0.9 and RM7.0 showed little variation in the metals pattern. Similarly, analysis of surface metal concentrations also showed relatively little trend with river mile. Like the 2,3,7,8-TCDD results, this evidence demonstrates the general homogeneity of surficial sediments in depositional areas of the Lower Passaic River and indicates the effectiveness of tidal mixing (refer to Section 6.2.1 “Surface Sediment Concentrations and Gradients”).

Ratio analysis of Total PAH shows that the majority of PAH contamination in the sediments is derived from combustion-related processes. The ratio “fingerprint” suggests that Total PAH originates from two sources: coal tar residue (a by-product of manufactured gas plants) and urban background combustion. Of these sources, coal tar wastes are the dominant source to the Lower Passaic River based on the prevalence of coal tar-like PAH ratios in more-contaminated sediments. The same analysis essentially rules out creosote-derived contamination and suggests that only minor portions of the sediment PAH contamination are derived from a petrogenic source (*e.g.*, oils spills).

Core top samples (collected in 1986 and 1991) from above the Dundee Dam suggest that the Upper Passaic River may still represent an important source of cadmium, mercury and lead to the Lower Passaic River, unlike 2,3,7,8-TCDD and Total DDT, which primarily originate downriver of the dam. A source upriver of the Dundee Dam may have accounted for much of the historic Total PCB load to the Lower Passaic River (Bopp *et al*., 1991b). However, evidence suggests that *circa* 1995, the Upper Passaic River Total PCB source had become less important relative to the Total PCB load occurring within the Lower Passaic River. Nevertheless, the Upper Passaic River source may still comprise one-third of the Total PCB loading in the Lower Passaic River (refer to Section 7.2.5 “Total PCB Contamination”).

1.3.4 CONTAMINANT INVENTORIES IN THE LOWER PASSAIC RIVER

The combination of the navigational dredging activities and the long and extensive history of contaminant discharges to the Lower Passaic River have served to create a uniquely large inventory of highly contaminated sediments contained within a relatively small area. Other major Superfund sites may have similar volumes of contaminated sediments [*e.g.*, Hudson River PCB site at 2.6 million cubic yards (USEPA, 2002) and Fox River PCB site at 8 million cubic yards (USEPA, 2003a)], but these inventories are spread over much greater distances than the 17 miles of the Lower Passaic River. While data are not sufficient to assess the volume of contaminated sediment for the entire Lower Passaic River, the volume is estimated at 5 to 8 million cubic yards for RM0.9 to RM7, with an average depth of contamination ranging from 7 to 13 feet. The evidence from the side-scan sonar and bathymetric surveys suggests that the conditions observed in RM0.9 to RM7 probably also apply over the area of RM0 to RM8, suggesting that the actual inventory of contaminated sediments is least one-third greater than the values obtained in the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a). The volume of 2,3,7,8-TCDD-contaminated sediments is somewhat smaller than the overall contaminated sediment volume since several contaminants are present at greater depths than 2,3,7,8-TCDD. The estimate of 2,3,7,8-TCDD-contaminated sediment volume ranges from 5 to 6.5 million cubic yards for RM0.9 to RM7 (refer to Section 7.3.1 "Estimates of the Volume of Contamination").

The mass of contaminants contained within the sediments is also quite large (Table 1-4). Moreover, the mass of 2,3,7,8-TCDD represents one of the largest site inventories in the United States.

Table 1-4: Summary of Contaminant Inventory Estimates for RM0.9 to RM7

Inventory Estimate [a]	Total DDT (metric tons)	2,3,7,8-TCDD (kilograms)	Mercury (metric tons)	Total PCB (metric tons)
Based on measured core intervals only	6.4	20	24	6
Based on measured and extrapolated core profiles	11	29	37	8

a: Based on information provided in *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a)

The range in volume estimates given above (5 to 8 million cubic yards) reflects the uncertainty related to horizontal interpolation and vertical extrapolation, with the lower value based only on the measured core intervals, and the larger value incorporating the vertically extrapolated mass estimates. This range does not include the volume related to horizontal extrapolation from RM7 to RM8 and from RM0 to RM0.9. To estimate the sediment volume from RM7 to RM8 and from RM0 to RM0.9, the conditions in the one-mile lengths of river adjacent to these stretches were extrapolated. These calculations were performed for mercury to obtain the total volume of contaminated sediment as well as the entire mass of mercury, because mercury is one of the oldest (deepest) contaminants (Table 1-5). They were also performed for 2,3,7,8-TCDD to obtain an estimate of the 2,3,7,8-TCDD inventory for the lower 8 miles in total (Table 1-5). The estimated volume of contaminated sediment from RM0 to RM8 thus calculated approaches 10 million cubic yards. This represents an increase of 25 to 50 percent over the original estimates of contaminated sediments in RM0.9 to RM7. The inventory of mercury in the sediments between RM0 to RM8 is estimated at 50 metric tons, and the inventory of 2,3,7,8-TCDD is estimated at 33 kilograms.

Table 1-5: Estimated Mass and Estimated Volume of Contaminated Sediments in RM0 to RM8

Analyte	Average Extrapolated MPA	Extrapolated Mass	Average Extrapolated Depth (feet)	Extrapolated Volume of Sediment (cubic yards)
Mercury	20 g/m^2	50 metric tons	13	9,500,000
2,3,7,8-TCDD	16 mg/m^2	33 kilograms	11	8,700,000

MPA = mass per unit area
g/m^2 = grams per square meter
mg/m^2 = milligrams per square meter

A separate inventory estimate was created for the region above RM8, based solely on the extent of fine-grained sediments as estimated from interpreted side-scan sonar images (Aqua Survey, Inc., 2006) and the depth penetrated by geotechnical borings collected in June 2005. In this region of the river, fine-grained sediments represent only about one-third of the river bottom, as compared to more than 80 percent below RM8. The volume and mass estimates are obtained by multiplying the average MPA for RM6 to RM7 times the nominal thickness of fine-grained sediment determined from the geotechnical cores (*i.e.*, 4 feet). This observation suggests that the fine-grained sediments outside of RM0 to RM8 represent only about 6 percent of the volume of contaminated sediment below RM8. No estimate of the inventory in coarse-grained areas was created due to lack of appropriate data (Table 1-6).

Table 1-6: Estimated Mass and Estimated Volume of Contaminated Fine-Grained Sediments in RM8 to RM15

Analyte	Average Extrapolated MPA	Extrapolated Mass	Average Extrapolated Depth (feet)	Extrapolated Volume of Sediment (cubic yards)
Mercury [a]	5.2 g/m^2	1.8 metric tons	4 [b]	550,000
2,3,7,8-TCDD	3.1 mg/m^2	1.1 kilograms	4 [b]	550,000

a: The inventory in the coarse-grained areas was not calculated.
b: Geotechnical and high resolution cores collected above RM8 indicate that the average depth of contamination is approximately 4 feet.

The contaminant inventories are not evenly distributed and vary along the length of the Lower Passaic River, with maximum values occurring near the areas encompassing RM1 to RM2, RM3 to RM4, and RM6 to RM7. However, the coring data that forms the basis for these inventories indicate a high degree of local spatial heterogeneity, suggesting that localized areas of relatively higher concentrations typically described as “hot spots” do not exist. Instead, “hot regions” of the river typically exist on the scale of a mile or more, nearly bank to bank in lateral extent. This conclusion does not, however, diminish the significance of potential historic and/or current point sources as the origin of contaminant inventory in the Lower Passaic River. Estuarine mechanisms are believed to quickly render contaminant concentration gradients indistinct on the scales examined here. It is possible that environmental sampling on a finer scale (on the order of less than a quarter mile) would identify localized gradients near prominent historical and/or current source areas.

Despite the observations of local spatial heterogeneity, the inventories of four contaminants (mercury, 2,3,7,8-TCDD, Total PCB, and Total DDT) examined in detail were shown to correlate, indicating that their inventories coincide in space and are consistent with the anticipated geochemical behavior of the compounds (Figure 1-10). Essentially, when a location has a locally high inventory of any one of these four contaminants, the other contaminants will also be concentrated at that location. It is anticipated that similar behavior will be exhibited by any hydrophobic compound in the Lower Passaic River. As noted previously, the variations in inventory are not believed to represent proximity to external point sources. Rather, variations in inventory may represent variations in the rate of deposition, with sites having higher rates of deposition generating larger contaminant inventories. Both the coring data and the bathymetric survey analyses performed for the Lower Passaic River suggest a high degree of spatial heterogeneity in inventory and deposition rate, supporting this premise (refer to Section 7.3.2 “Distribution of Inventory with River Mile”).

1.3.5 IMPACTS OF THE LOWER PASSAIC RIVER ON NEWARK BAY

The Lower Passaic River is the main source of freshwater to Newark Bay and a major source of contaminants to the bay as well. Solids delivered from the Lower Passaic River to Newark Bay contain contaminant levels similar those found in surficial sediments of the Lower Passaic River. As a result, for several contaminants examined, the history of contamination observed in the Lower Passaic sediments is also observed in Newark Bay. For example, dated sediment cores for the Lower Passaic River (RM0.9 to RM7) are consistent with the observations by Bopp *et al*. (1991a and 1991b) and Chaky (2003) for Newark Bay, specifically that the major releases of 2,3,7,8-TCDD begin in the late 1940s to early 1950s and peak around the late 1950s to early 1960s. The history of Total DDT releases observed in the Lower Passaic River was also consistent with the observations for Newark Bay made by Bopp *et al*. The diagnostic ratio of 2,3,7,8-TCDD/Total TCDD of 0.7 to 0.8 can be used to trace Lower Passaic River 2,3,7,8-TCDD contamination throughout the Newark Bay complex. Recent surficial samples from Newark Bay suggest the mixing of high ratio, high 2,3,7,8,-TCDD concentration sediments from the Lower Passaic River with somewhat lower ratio, lower concentration sediments from the Arthur Kill and Kill van Kull, creating gradients in the ratio and the 2,3,7,8,-TCDD concentration across Newark Bay (Figure 1-11; refer to Section 7.2 “Nature and Extent of Contamination”).

Using the historical observations of 2,3,7,8-TCDD concentrations and the 2,3,7,8-TCDD/Total TCDD ratio, it was possible to construct concurrent mass balances for solids, 2,3,7,8-TCDD and Total TCDD in Newark Bay, refining the solids balance analysis performed by Lowe *et al*. (2005). Based on the concurrent mass balances, the Lower Passaic River comprises approximately 10 percent of the total amount of solids accumulating in the Newark Bay and more than 80 percent of the 2,3,7,8-TCDD accumulating in the bay. No other single source delivers more than 10 percent of the total 2,3,7,8-TCDD load (refer to Section 7.4.1 "2,3,7,8-TCDD Mass Balance").

The solids mass balance framework constrained by the 2,3,7,8-TCDD mass balances provided a means to examine mercury in Newark Bay. The mercury mass balance shows that, despite the high mercury concentrations in the sediments of the Lower Passaic River, they are only responsible for approximately 20 percent of the total mercury load to Newark Bay. Moreover, the known sources of mercury to Newark Bay cannot account for the annual accumulation of mercury in the sediment beds of the bay. The "missing" mercury source represents the largest single "source" of mercury to Newark Bay, constituting approximately 35 percent of the annual mercury load. The next largest "source" is the solids delivered by the Kill van Kull, which represent about 30 percent of the annual mercury load to Newark Bay. Note that these percentages are subject to revision when more data for Newark Bay and the Kills become available. Another potential source of mercury is exchange of particles from the Hackensack River, although net transport of particles from this tributary is low (refer to Section 7.4.2 "Mercury Mass Balance).

The 2,3,7,8-TCDD mass balance documents the solids contribution that must arise specifically from the Lower Passaic River. Despite the observation that the Lower Passaic River has experienced a net deposition of sediment for a long period of time, the *circa* 1995 solids mass balance indicates that upriver solids are transported through the Lower Passaic River into Newark Bay and potentially beyond. Estimates suggest that 20 to 50 percent of the upriver solids are eventually transported out of the Lower Passaic River. The estimated *circa* 1995 total annual loads of mercury and 2,3,7,8-TCDD to Newark Bay are approximately 400 kilograms and 14 grams, respectively (refer to Section 7.4 "Initial Mass Balance for the Lower Passaic River and Newark Bay").

1.4 DOCUMENT OVERVIEW

This document is divided into the following sections to describe the CSM.

Section 1.0, INTRODUCTION: explains the objectives of the CSM, provides a brief description of the Study, and summarizes the salient points of the CSM.

Section 2.0, HYDRO-GEOGRAPHIC SETTING: provides an overview of the larger Hudson-Raritan Estuary and the relationship of the Lower Passaic River with the estuary.

Section 3.0, RIVER SECTIONS: describes the division of the Lower Passaic River into three sections to capture important spatial variations in the river's character along its length. These sections are the Freshwater River Section, the Transitional River Section, and the Brackish River Section.

Section 4.0, BOUNDARY CONDITIONS: describes and defines the major boundary conditions (at Dundee Dam and at Newark Bay) of the Study Area as currently understood.

Section 5.0, SEDIMENT TRANSPORT: describes the solids accumulation and sedimentation rates occurring within the Lower Passaic River.

Section 6.0, SOURCE AREA ANALYSES: describes geochemical evaluations conducted to identify contaminant inputs and media.

Section 7.0, CONTAMINANT FATE AND TRANSPORT: describes the fate and transport for chemical classes over time and presents a current preliminary mass balance for selected compounds.

Section 8.0, UNCERTAINTIES AND FUTURE UPDATES: describes the uncertainties in the CSM and provides a process for addressing data gaps and updating the CSM as the Study proceeds.

Section 9.0, ACRONYMS: lists and defines the acronyms used in this document.

Section 10.0, REFERENCES: lists the references used in this document.

2.0 HYDRO-GEOGRAPHIC SETTING

The following section provides an overview of the Lower Passaic River and its relationship to the Hudson-Raritan Estuary (Figure 2-1). The purpose of this section is to discuss the basic processes occurring in the estuary and those processes that impact the Lower Passaic River. Technical details supporting an understanding of these processes are provided in the remainder of this document.

The Lower Passaic River and the Hudson-Raritan Estuary are a unique hydrologic system that encompasses a major metropolitan area in the United States, which includes two major cities: New York City, New York and Newark, New Jersey. Since the American industrial revolution, this area has experienced significant urbanization and industrial development, which has consequently impacted the surrounding ecosystems and waterways. Accidental and intentional discharges of industrial waste and municipal sewage have degraded sediment and water quality in the estuary. As contaminated solids and water enter the system, they are diluted and are disseminated throughout the estuary by the incoming and outgoing tides. These tides cause twice-daily mixing of surficial sediments through the resuspension and redeposition of solids. Over time, solids that originated from one end of the estuary (*e.g.*, the Lower Passaic River) are transported to other regions of the estuary (*e.g.*, the Hudson River). Understanding how the estuary operates (*i.e.*, how the Lower Passaic River connects to the estuary and how contaminated solids are transported through the system) is an important tool in discerning how to effectively remediate and restore the Lower Passaic River.

2.1 THE HUDSON-RARITAN ESTUARY

The Hudson-Raritan Estuary encompasses an area of over 42,000 square kilometers, making it one of the largest estuaries on the east coast of the United States. The estuary encompasses several major water bodies, such as the Hudson River, Raritan River, Upper and Lower New York Bay, as well as Newark Bay and its tributaries, including the Lower Passaic River (Figure 2-1). The Hudson River flows south through New York

State and into Upper New York Bay, which is located between Manhattan Island and New Jersey. Lower New York Bay is bounded on the north by Staten Island and Brooklyn, New York and on the south by New Jersey. (New York Bay connects to the New York Bight and the Atlantic Ocean between Sandy Hook, New Jersey and Rockaway Point, New York.) Historically, Lower New York Bay has been the primary means of marine access to Upper New York Bay and more recently to Port Newark-Elizabeth Marine Terminal in Newark Bay.

Besides the Hudson River, the Hudson-Raritan Estuary is connected to the Lower Passaic River and the Hackensack River through Newark Bay. This bay (approximately 6 miles long and 1 mile wide) is formed by the confluence of these two rivers and is connected to Upper New York Bay by the Kill Van Kull and to Raritan Bay by the Arthur Kill. Newark Bay is enclosed on the west by the New Jersey cities of Newark and Elizabeth and on the east by Jersey City and Bayonne. It is bordered on the south by Staten Island, New York. The banks of Newark Bay are home to numerous active and abandoned commercial and industrial properties. These banks are extensively developed and consist of miles of paved shoreline. Although originally a shallow tidal estuary, deep navigational channels are maintained in Newark Bay to accommodate ocean-going container ship access to Port Newark-Elizabeth Marine Terminal along its western side. There are also federally authorized navigational channels extending from Newark Bay into the Lower Passaic River and the Hackensack River.

2.2 THE LOWER PASSAIC RIVER

2.2.1 RELATIONSHIP OF THE LOWER PASSAIC RIVER WITH THE ESTUARY

The Passaic River, located in northern New Jersey, is approximately 80 miles long. Dundee Dam (which was built in 1845) is located at RM17.4 and divides the Upper Passaic River from the Lower Passaic River (refer to Figure 1-1 and Section 1.2 "Development of Conceptual Site Model for the Study" for discussion on Study Area and river mile definition). The Upper Passaic River meanders across several geologic settings, draining urban, suburban, and rural portions of New Jersey. The Upper Passaic River watershed includes 16 Superfund sites and 2,216 New Jersey Known Contaminated

Sites in New Jersey.[5] Soils and groundwater at these sites are contaminated with an array of chemicals. For example, Witco Chemical Corporation (Bergen, New Jersey) operated a facility that discharged wastewater in a network of unlined subsurface seepage pits. This discharge resulted in groundwater contaminated with petroleum hydrocarbons and soils contaminated with pesticides and heavy metals, including mercury, cadmium, and lead (USEPA, 2006a). Another site is Caldwell Trucking Corporation (Fairfield, New Jersey), which is contaminated with residential, commercial, and industrial septic waste. Soils were reported to contain Total PAH, Total PCB, and heavy metals (USEPA, 2006b).

The Lower Passaic River is divided into three river sections and is bounded by the Dundee Dam and Newark Bay (Figure 2-2). In general, freshwater and solids flow over the Dundee Dam, enter the Freshwater River Section and flow downriver to Newark Bay. Saline water from Newark Bay moves upriver beneath the freshwater flow. The mixing of fresh and saline waters creates the Brackish and Transitional River Sections (refer to Section 3.0 "River Sections"). Solids originating above the dam, solids eroding along the length of the river, and those solids discharged from other sites (including CSOs and tributaries) are continuously mixed by tidal action, resuspending and redepositing surface sediment (refer to Section 5.0 "Sediment Transport"). These processes cause the continuous re-working of fine-grained sediments on the surface of the river bed.

The Lower Passaic River flows through some of the most urbanized and industrialized areas of the state, including the city of Newark. According to the 2000 United States Census, approximately 2.8 million people reside in the New Jersey counties of Essex, Bergen, Hudson, and Passaic, which encompass the Study Area (United States Census Bureau, 2007). [Refer to Section 1.4 "Community Profile" in the *Community Involvement Plan* (Malcolm Pirnie, Inc., 2006b) for further discussion on population and

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[5] Geographic information system data for the 2007 National Priority List were obtained from the USEPA at www.epa.gov/superfund/sites/phonefax/products.htm. Data for the list of 2005 Known Contaminated Sites were obtained from New Jersey Department of Environmental Protection (NJDEP) at www.state.nj.us/dep/gis/lists.html.

demographics.] The Lower Passaic River, as described in the *Work Plan* (Section 1.2 "Site Background and History;" Malcolm Pirnie, Inc., 2005a), was heavily developed and became a focal point for the American industrial revolution in the 1800s. By the twentieth century, urban and industrial development surrounding the Lower Passaic River resulted in poor water quality, contaminated sediments, bans on fish and shellfish consumption, lost wetlands, and degraded habitats (USACE *et al*., 2003). The watershed of the Lower Passaic River includes 14 Superfund sites and 1,716 New Jersey Known Contaminated Sites. Location maps for these sites are provided in the *Work Plan*.

Several contaminants were identified in the *Pathways Analysis Report* (Battelle, 2005) as potentially posing risk to human health and the ecosystem of the Lower Passaic River. These contaminants represent the following chemical classes: polychlorinated dibenzodioxins/furans (PCDD/F), PCB, PAH, pesticides, metals, and semivolatile organic compounds (SVOC). Contamination in the Lower Passaic River, which is being addressed through the Study, originated from numerous inputs over the past 100 years or more. These inputs, including sources upriver of the Dundee Dam, may include point discharges such as spills, sewers, and wastewater outfalls and non-point discharges through runoff and groundwater migration (refer to Section 6.0 "Source Area Analyses"). External loads of particle-reactive contaminants from these discharges contaminated sediments prior to their deposition on the river bottom.

Maps provided in Figure 2-3 display available historical surface sediment concentrations measured over the past decade (1997 to 2006) for a select group of contaminants (cadmium, copper, lead, mercury, Total PCB, and 2,3,7,8-TCDD). Due to the combination of sediment bed erosion and surficial sediment mixing during each tidal cycle, highly contaminated surface sediments continue to be detected throughout the Lower Passaic River. In fact, while the original sources of some of these contaminants may have been discontinued, surface sediment contaminant concentrations have remained relatively constant over the last decade (1997 to 2006) over a distance of 8 miles (RM0 to RM8). Table 2-1 provides the average concentrations for the analytes displayed in Figure 2-3.

Table 2-1: Average Surface Sediment Concentrations for Sampling Programs Occurring Between 1997 and 2006

Study Name [a]	Total PCB (µg/kg) [b]	2,3,7,8 TCDD (ng/kg) [b]	Cadmium (mg/kg) [b]	Copper (mg/kg) [b]	Mercury (mg/kg) [b]	Lead (mg/kg) [b]
1997 Outfall Sampling Program	1,200 ± 720 (N = 3)	NA	NA	NA	NA	NA
1999 Sediment Sampling Program	3,200 (N = 1)	810 (N = 1)	7.1 (N = 1)	290 (N = 1)	5.1 (N = 1)	530 (N = 1)
1999 Late Summer/Early Fall Environmental Sampling Program	1,600 ± 1,000 (N = 45)	490 ± 670 (N = 45)	4.2 ± 1.4 (N = 45)	190 ± 340 (N = 45)	2.8 ± 0.88 (N = 45)	260 ± 510 (N = 45)
1999/2000 Minish Park Monitoring Program	1,500 ± 550 (N = 8)	340 ± 100 (N = 8)	4.3 ± 0.74 (N = 8)	210 ± 360 (N = 8)	3.3 ± 1.6 (N = 8)	270 ± 37 (N = 8)
2000 Spring Environmental Sampling Program	2,100 ± 1,500 (N = 15)	310 ± 130 (N = 15)	3.9 ± 1.0 (N = 15)	190 ± 410 (N = 15)	2.3 ± 0.69 (N = 16)	240 ± 540 (N = 15)
2005-2006 USEPA Sampling Program (high resolution cores)	280 ± 60 (N = 3)	280 ± 80 (N = 3)	3.5 ± 7.3 (N = 3)	150 ± 30 (N = 3)	2.0 ± 0.5 (N = 3)	280 ± 150 (N = 3)
2005-2006 USEPA Sampling Program (low resolution cores)	560 ± 500 (N = 8)	3,100 ± 5,900 (N = 10)	7.2 ± 7.0 (N = 10)	200 ± 130 (N = 10)	470 ± 320 (N = 10)	290 ± 150 (N = 10)

a: Sample locations displayed in Figure 2-3. Sample represent either sediment grab samples or the top segment of a sediment core with depth of 0 foot to less than 1 foot (except for the 2006 low resolution coring program with core tops thicknesses ranging from 1.1 feet to 2.3 feet).
b: Arithmetic average and standard deviation (± 1 sigma) based on a normal distribution of sample size; nondetected values are incorporated into the average as half the reported detection limit. Results rounded to two significant figures, whenever possible.
NA = not available
µg/kg = micrograms per kilogram of sediment
mg/kg = milligrams per kilogram of sediment
ng/kg = nanograms per kilogram of sediment

Because of the relationship between the Lower Passaic River and the Hudson-Raritan Estuary, contaminated solids originating in the Lower Passaic River can be distributed throughout the estuary. This phenomenon is reported by Chaky (2003), who identified a tracer of Passaic-contaminated solids, specifically the unique ratio 2,3,7,8-TCDD/Total TCDD. In the Chaky model, Passaic-contaminated solids have a ratio value of approximately 0.7, representing one end member, while sewage, atmospheric, and Upper Hudson River sources have a ratio of 0.06 or less, representing "other" end members. The mixing of solids between these end members is observed throughout the Hudson-Raritan Estuary by the variation of this ratio [Figure 2-4; 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 (Figure 2-5). For example, surface sediment samples collected in 2005 exhibited a 2,3,7,8-TCDD/Total TCDD ratio of 0.7 ±0.1 [sample size (N) = 5]. This ratio is then observed to steadily decline across Newark Bay (north to south, towards the Goethals Bridge; refer to Figure 2-1) from a ratio of 0.6 to 0.3 at net depositional sites[6] located throughout the bay (Figure 2-6), tracing the mixing of Passaic-contaminated sediments with solids from other areas.

While the source of the Lower Passaic River 2,3,7,8-TCDD contamination has not been quantitatively identified, the primary candidate is the upland area at RM3.2 and the associated chemical manufacturing facility and Superfund sites (USEPA, 2007). It is unlikely that the source of 2,3,7,8-TCDD contamination to the Lower Passaic River originates above the Dundee Dam since the levels of 2,3,7,8-TCDD above the dam are approximately 40 times lower than those concentrations reported in the Lower Passaic River (Bopp *et al*., 1998; Figure 2-7). Further evidence supporting this hypothesis is provided in a surface sediment sample from a 1991 USEPA sediment core located approximately 0.3 miles above Dundee Dam (refer to Section 4.1.2 "Surficial Sediment Chemistry Above Dundee Dam" for other sediment chemistry results). This sample exhibited a ratio of 2,3,7,8-TCDD/Total TCDD equal to 0.1 with a 2,3,7,8-TCDD concentration on the order of 10 ng/kg.[7] For comparison, sediments deposited in the 1990s in Central Park, New York (which represent atmospheric fallout) had a 2,3,7,8-TCDD concentration of 11 ng/kg and a 2,3,7,8-TCDD/Total TCDD ratio of 0.06 (Chaky, 2003). Note that the solids transport over the Dundee Dam represents much more than simple atmospheric fallout. Although the 2,3,7,8-TCDD concentration is comparable to

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[6] Depositional sites are defined as surficial sediment (0-1 inch) having detectable beryllium-7 concentrations that are greater than 0.5 picocuries per gram of sediment (pCi/g).

[7] At the time of collection, PCDD/F analytical techniques were not as sensitive as they are currently. The 2,3,7,8-TCDD/Total TCDD ratio for the 1991 surficial material was approximately 0.1, greater than the sewage, atmospheric fallout, and Upper Hudson River sources of approximately 0.06. However, the proximity of the reported values to their detection limits suggests that this ratio is not well known and is probably not statistically different from the sewage end member ratio. Similarly, the high detection limits reported deeper in the sediment core restricted the quantification of 2,3,7,8-TCDD; hence, no ratio could be calculated for these deeper sediments. Nonetheless, the very low concentrations in the 1991 core samples strongly support the absence of a significant source of 2,3,7,8-TCDD above the Dundee Dam.

atmospheric fallout, atmospherically derived solids are a very small fraction of the total solids load over the dam. The magnitude of the 2,3,7,8-TCDD concentration implies the occurrence of loads much greater than atmospheric fallout. Nonetheless, the low ratio and low concentration observed above the Dundee Dam relative to the values observed in the Lower Passaic River rule out the Upper Passaic River as a significant load of 2,3,7,8-TCDD to the Lower Passaic River (refer to Section 6.0 "Source Area Analyses" and Section 7.0 "Contaminant Fate and Transport").

2.2.2 DREDGING HISTORY IN THE LOWER PASSAIC RIVER

An important component of the development and urbanization of the Lower Passaic River was the channelization of the river, which permitted commercial vessels easier access into the city of Newark. Several large dredging projects were undertaken at the beginning of the twentieth century to create a ship channel to RM15. The USACE is responsible for delineating and maintaining navigation channels in the Lower Passaic River. Table 2-2 provides a summary of the federally mandated channel depths and widths as wells the years that the river was dredged.

Table 2-2: Lower Passaic River Authorized Dimensions of the Federal Navigational Channel and Dredging Years

River Mile [a]	Channel Depth (feet) [b, c]	Channel Width (feet)	Years Dredged
RM -0.2 to RM2.2	30	300	1907, 1911, 1912, and 1930 (USEPA, 1995) 1940, 1946, 1957, 1965, and 1971 (IT Corporation, 1986) 1884, 1917, 1921, 1922, 1932, 1933, 1941, 1946, 1951, 1953, 1957, 1962, 1965, 1971, 1972, 1977, and 1983 (Iannuzzi *et a*l., 2002)
RM2.2 to RM4.3	20	300	1949 (USEPA, 1995) 1884, 1916, 1921, and 1937 (Iannuzzi *et al*. 2002)
RM4.3 to RM6.9	20 (only constructed to 16 feet)	300	1949, 1950 (USEPA, 1995) 1913, 1919, 1933, and 1950 (Iannuzzi *et al*. 2002)
RM6.9 to RM7.9	16	200	1950 (USEPA, 1995) 1874, 1876, 1878, 1879, 1883, 1899, 1906, 1915, 1916, 1927, 1929, 1930, 1931, 1932, 1934, 1938, 1939, 1940, 1945, 1949, and 1956 (Iannuzzi *et al*. 2002)
RM7.9 to RM15.2	10	200	Record of dredge maintenance not available

Table 2-2 footnotes (continued)

a: River miles are referenced to the Study-defined river mile scale (refer to Section 1.2 “Development of the Conceptual Site Model for the Study”). These river miles are offset from the scale that is used by the USACE by approximately 0.2 miles.
b: Obtained from the “Report of Channel Conditions 100 to 400 feet Wide” (USACE, 2002) and the USACE map “Newark Bay, Hackensack & Passaic Rivers, N.J. (Passaic River)” dated September 30, 1986.
c: Channel depth is relative to MLW.

The Federal Project Limits to maintain a channel that is 30 feet deep (relative to MLW) and 300 feet wide from RM-0.2 to RM2.2 were originally adopted in 1907. These dimensions were modified in 1911, 1912, and 1930 (USEPA, 1995). The channel was last dredged in 1983 to the Project Depth of 30 feet. Other dredging events are listed in Table 2-2.

The Federal Project Limits from approximately RM2.2 to RM4.3 are a 300-foot wide channel with a Project Depth of 20 feet MLW. Dredging was performed in 1949 to a Project Depth of 20 feet (USEPA, 1995). Other dredging events are listed in Table 2-2.

The USACE has designated the Federal Project Limits from approximately RM4.3 to RM6.9 as a 300-foot wide channel with a Project Depth of 20 feet MLW. Dredging was performed in 1949, but only to a depth of 16 feet MLW (USEPA, 1995).

The USACE has delineated the Federal Project Limits from approximately RM6.9 to RM7.9 as a 200-foot wide channel with a project depth of 16 feet MLW and the Federal Project Limits from approximately RM7.9 to RM15.2 as a 200-foot wide channel with a Project Depth of 10 feet MLW. Dredging in the navigable portion of RM6.9 to RM7.9 was performed in 1950 to a Project Depth of 16 feet MLW (USEPA, 1995). Other dredging events are listed in Table 2-2.

The volumes of sediments removed each year from dredging was recorded by the USACE (USACE, 1917; USACE, 1916; USACE, 1915; USACE, 1913; USACE, 1907; USACE, 1900; USACE, 1884; USACE, 1880) and summarized by Iannuzzi *et al*. (2002). This dredging data is presented in Figure 2-8 to show the total volume of sediment removed by dredging in 6-year increments. The figure also highlights the portion of the dredged volume removed from the Lower Passaic River below RM2. Over time, the total volume of sediments removed by dredging has declined over time. Since the 1940s, the vast majority of dredging has occurred below RM2. Based on USACE records (Figure 2-8), it does not appear that this channel was regularly maintained, permitting a large volume of recent sediment to accumulate over time.

Since the 1940s, the river has delivered sufficient material to build up many feet of recent deposition, yielding an average rate of deposition substantially greater than what would normally occur. The coincidence of chemical disposal in the river along with the construction and subsequent limited maintenance of the navigation channel created an ideal situation for the accumulation of thick beds of contaminated sediments in the Lower Passaic River.

Perhaps the most important concern to current contamination is that sufficient solids deposition has occurred in the Lower Passaic River and is now affecting channel flow. The magnitude of the recent deposition is illustrated in Figure 2-9, which shows the current depth of the river channel as well as the original dredged elevations as reported in USACE records. For the region below RM8, the river has accumulated thick sediment beds, over 15 feet or more in some areas, while substantive channel deposition occurred above RM8 (approximately 10 feet). This evidence is consistent with the observations of recent deposition rates and sediment texture, which change markedly across RM8. As noted in Table 2-2, the constructed channel depth was substantially shallower above RM8 (10 feet) than below RM8 (16 feet or more). Historical dredging greatly enhanced the rate of sediment accumulation in the dredged areas because of the deeper water depths that existed after dredging. Consequently, historical deposition rates were probably higher than those currently observed as the navigation channel has not been maintained.

3.0 RIVER SECTIONS

For the purposes of the Study, the Lower Passaic River has been divided into three river sections based on their relationship to the typical upriver extent of the salt front, which forms as a result of freshwater flowing downriver from Dundee Dam and the saline waters flowing upriver from Newark Bay (refer to Section 4.0 “Boundary Conditions”). The following discussion defines these river sections and provides a preliminary qualitative discussion of related physical features, such as sediment texture, sedimentation rates, and shoreline characterization.

3.1 SALT FRONT DEFINITION

The farthest upriver extent of saline water in an estuary is referred to as the salt front. This location occurs where “sea salt” is first easily detected in the river and defined as a measured salinity of 0.5 parts per thousand, or “per mil” (‰) (USEPA, 2003b). The location of the salt front varies in response to the volume of freshwater flow as well as the twice-daily tidal oscillations. In the Lower Passaic River, the salt front typically moves several miles upriver and downriver with each tidal cycle. Higher freshwater flow events can even push the salt front completely out of the Lower Passaic River while relatively low freshwater flows will allow the salt front to move farther upriver.

The typical range of salinity conditions is used to define three river sections. The Freshwater River Section (RM10 to RM17.4) is the region just above the salt front at its typical farthest upriver location [*i.e.*, this section remains freshwater (less than 0.5 ‰) under all but the lowest flow conditions]. The Transitional River Section (RM6 to RM10) is characterized by the most frequent location of the salt front with water conditions varying from slightly brackish (or oligohaline with salinity values ranging from 0.5 ‰ to 5 ‰) to moderately brackish (or mesohaline with salinity values ranging from 5 ‰ to 18 ‰). The Brackish River Section (RM0 to RM6) lies below the typical farthest downriver location of the salt front. Hence, this section is nearly always mesohaline or polyhaline (salinity values ranging from 18 ‰ to 32 ‰).

3.2 SALINITY DATA AVAILABLE TO DEFINE THE RIVER SECTIONS

Salinity data were collected between July 2004 and September 2005 from nine mooring stations, which were located between RM1 and RM10 (Table 3-1).[8] Since river conditions change between seasons, the seasonal position of the salt front was discerned using these data over the period of record. The range of the salt front position was then used to define the river sections, as described below.

Table 3-1: Available Salinity Data

River Mile	Buoy Identification	Date of Sample Collection	Owner of Buoy
1	M1	11/20/04 to 1/25/05	Rutgers University [a]
3.1	M2a	11/20/04 to 1/25/05	Rutgers University
3.1	M2b	11/20/04 to 1/25/05	Rutgers University
4.1	M3	11/20/04 to 1/25/05	Rutgers University
5.3	M4	11/20/04 to 1/25/05	Rutgers University
6.7	M5	7/8/04 to 9/10/04 11/20/04 to 1/25/05	Rutgers University
8	M6	7/8/04 to 9/10/05 11/20/04 to 1/25/05	Rutgers University
8.5	3	12/15/04 to 2/21/05	Malcolm Pirnie, Inc. [b]
10	2	12/15/04 to 9/30/05	Malcolm Pirnie, Inc.
Little Falls, New Jersey	USGS Gauge	7/30/62 to 8/19/04	USGS [c]

a: Rutgers University mooring data available at marine.rutgers.edu/cool/passaic
b: Malcolm Pirnie, Inc. mooring data available at www.ourpassaic.org
c: USGS gauging data available at http://waterdata.usgs.gov/nj/nwis/uv/?site_no=01389500&amp. (Site last accessed February 2, 2007).
USGS = United States Geological Survey

Winter Conditions: Downriver of RM5.3, the salinity data indicate that river conditions were mesohaline or polyhaline (Figure 3-1a and 3-1b), representing brackish waters during December 2004 to January 2005. During the same time period, the upriver extent of the salt front ranged between RM5.3 and a point below RM6.7. This characterization is indicated by the presence of oligohaline conditions at RM5.3 and freshwater conditions at RM6.7 (Figure 3-1c). These observations are consistent with data collected during the winter months upriver of RM8.5. These data indicate that, during the winter, salinities at the RM8.5 and RM10 stations were less than 0.5 ‰ (Figure 3-1d). The presence of freshwater at these two sampling locations indicates that the upriver reach of the salt front

[8] Salinity data from fall 2004 to spring 2005 are plotted in Figure 3-1. Salinity data were not continuously measured at all buoys, and gaps exist in the record.

was consistently below RM8.5 during these winter months. Furthermore, the salinity levels measured at RM8.5 and RM10 are similar in magnitude to readings of less than 0.4 ‰ observed during the same period at the USGS gauge at Little Falls, New Jersey (Figure 2-1), located upriver of the Dundee Dam (Figure 3-1e).

Summer Conditions: In contrast, during the summer months, the salt front was observed farther upriver, reflecting the lower freshwater flow conditions typical of that season. For example, data collected between July 8, 2004 and September 10, 2004 at RM8 show that river salinity was consistently at least oligohaline and was regularly mesohaline (Figure 3-1f; upper right-hand graph). These data indicate that the upriver extent of the salt front was above RM8. Salinity data at RM10 (presented in Figure 3-1d) show temporal trends from fall 2004 to summer 2005 (Figure 3-1g). Similar to the station at RM8, oligohaline conditions (approximately 4 ‰) were detected during the summer months at RM10. No salinity data are available upriver of RM10 precluding a precise determination of the extreme range of the salt front.

Hence, the boundaries of the Transitional River Section have been tentatively defined as RM6 to RM10. The upriver boundary is intended to encompass the seasonal variation in the upriver range of the salt front while recognizing the limitations in the available data. The Brackish and Freshwater River Sections are then defined as occurring between RM0 and RM6 and between RM10 and RM17.4, respectively.

3.3 DESCRIPTION OF RIVER SECTIONS

The following section provides a preliminary qualitative definition for the Freshwater River Section, Transitional River Section, and the Brackish River Section (Figure 2-2).

Freshwater River Section (RM10 to RM17.4) represents the portion of the Lower Passaic River where the water conditions are defined as "almost always" fresh, or where salinity values are less than 0.5 ‰. At high tide, the salt front rarely penetrates this section; however, the water elevations in this section are tidally influenced. Water and solids are preferentially transported from the Freshwater Section to the Transitional Section, except perhaps during dry periods when the base flow of the river declines or during extreme tidal events. Additional water and solids delivery occurs at the confluence of the Saddle River (RM15.6). Sediments in this river section tend to be characterized by coarse-grained material. Fine-grained sediment beds are scarce (refer to sediment texture maps provided in Attachment A) and are relatively thin due to low sedimentation rates. The Freshwater River Section supports a freshwater ecosystem (Aqua Survey, Inc., 2005; Germano & Associates, Inc., 2005; Earth Tech, Inc. and Malcolm Pirnie, Inc., 2005a; Earth Tech, Inc. and Malcolm Pirnie, Inc., 2005b). For example, the 2005 benthic invertebrate community survey[9] showed that a mixture of organisms that typically reside in oligohaline and freshwater environments was observed from RM7 to RM15.5 (Germano & Associates, Inc., 2005). This freshwater ecosystem provides habitat for freshwater aquatic plants (vascular and algae), macroinvertebrates, fish, and wildlife species that forage on these prey types.

<u>Transitional River Section</u> (RM6 to RM 10) represents the portion of the Lower Passaic River between the Freshwater River Section and the Brackish River Section, where the salt front ranges under typical flow and tidal conditions. Here, water conditions vary continuously from oligohaline to mesohaline due to the salt front migration. This river section is continuously influenced by saltwater intrusion and mixing, resulting in rapidly fluctuating water chemistry as well as flocculation and settling of dissolved organic matter and particulates. Water and solids are transported between the Transitional Section and Brackish Section primarily due to tidal exchange. Additional water and solids delivery occurs at the confluences of Second River (RM8.1) and Third River (RM11.3). Sediment characteristics in this section transition from relatively thin, coarse-grained sediment beds (approximately 4 feet thick) observed near the boundary with the Freshwater River Section to relatively thick, fine-grained sediment beds observed (approximately 14 feet thick) near the boundary with the Brackish River Section (Aqua Survey, Inc., 2006). A distinct boundary in sediment texture is apparent in this section

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[9] The benthic invertebrate community survey was conducted in June 2005 from RM0 to RM15.5. Salinity data indicate that oligohaline conditions existed at RM10.

near RM8 (Figure 3-2; refer to Attachment A for the complete sediment texture maps). Based on side-scan sonar images (Aqua Survey, Inc., 2006), the fine-grained surficial sediments, which are dominant between RM0 and RM8, appear to end at this point. The habitat in the Transitional Section supports a mixture of freshwater and salt-tolerant species (Aqua Survey, Inc., 2005; Germano & Associates, Inc., 2005; Earth Tech, Inc. and Malcolm Pirnie, Inc., 2005a; Earth Tech, Inc. and Malcolm Pirnie, Inc., 2005b).

<u>Brackish River Section</u> (RM0 to RM6) represents the portion of the Lower Passaic River closest to its confluence with Newark Bay, where water conditions are defined as "almost always" mesohaline or polyhaline. The salt front is rarely found in the Brackish River Section, except under high freshwater flows or abnormally low tides (due to local storms). Water and solids are transported between the Transitional River Section, Brackish River Section, and Newark Bay primarily as a result of tidal exchange. Historical dredging of the Lower Passaic River has created deep channels in this river section (authorized depth of 20 to 30 feet relative to MLW), and the lack of recent maintenance dredging has resulted in the accumulation of thick sediment beds in these channels, which are dominated by fine-grained material. The Brackish River Section supports a salt-tolerant ecosystem (Aqua Survey, Inc., 2005; Germano & Associates, Inc., 2005; Earth Tech, Inc. and Malcolm Pirnie, Inc., 2005a; Earth Tech, Inc. and Malcolm Pirnie, Inc., 2005b). For example, the 2005 benthic invertebrate community survey showed that salt-tolerant benthic organisms, which typically reside in polyhaline environments, were predominantly located from RM0 to RM1, and a mixture of organisms that typically reside in mesohaline and oligohaline environments was observed from RM1 to RM7 (Germano & Associates, Inc., 2005). This environment provides habitat for estuarine aquatic plants (vascular and algae), macroinvertebrates, fish, and wildlife species that forage on these prey types.

3.4 SHORELINE CHARACTERIZATION OF THE RIVER SECTIONS

The river sections were then described in terms of their shoreline conditions and surrounding habitats. This description supplements the shoreline characterization provided in the *Work Plan* (Malcolm Pirnie, Inc., 2005a), which provides information on the navigational channel, bridge structures, industrial facilities located along the river, and other features. The shoreline characterization provided here was accomplished using photographs collected during field reconnaissance activities [refer to the *Restoration Opportunities Report* (Earth Tech, Inc. and Malcolm Pirnie, Inc., 2006)]. Selected photographs from the reconnaissance are presented in Figures 3-3a through 3-3e.

The shoreline and land use conditions vary considerably among the Brackish, Transitional, and Freshwater River Sections. The Brackish River Section is characterized by industrial and urban lands, typically with hardened shorelines comprised of bulkheads or riprap (Figure 3-3a and Figure 3-3b). The Transitional River Section is largely surrounded by residential communities; accordingly, the river shoreline in this area more commonly features natural riverine vegetation (Figure 3-3c). The Freshwater River Section is the least industrialized of the three river sections and features the lowest density of development. The Freshwater River Section is also characterized by shorelines with natural vegetation communities, often with overhanging tree canopies (Figure 3-3d). Traveling upriver in the Freshwater River Section, the river gradually transitions from a wide, slowly-flowing river to a narrower and more swiftly-flowing stream above RM15 with a substrate composed of rock and coarse gravel (Figure 3-3e).

Further discussion on the available biological and ecological data for the Lower Passaic River is provided in Section 3.0 “Field Task Status” of the *Field Sampling Plan, Volume 2* (Malcolm Pirnie, Inc., 2006c).

3.5 UPRIVER EXTENT OF THE SALT FRONT

Based on the available salinity data (Figure 3-1d and Figure 3-1g), the salt front appears to extend seasonally upriver of RM10. An evaluation of bathymetric data, sedimentation rates, and sediment texture data was completed in an attempt to estimate the furthest upriver extent of the salt front and to examine other physical features of the Lower Passaic River. Note that the boundaries of the Transitional River Sections are roughly defined by salinity, and the following discussion is presented only to provide some insight on the farthest upriver extent of the salt front.

3.5.1 EVALUATION OF CROSS-SECTIONAL AREA AND SEDIMENT TEXTURE DATA

For most rivers, the cross-sectional area increases downriver. As the river channel widens, river velocities will decrease and cause the river bed sediments to grade from coarser to finer in the downriver direction. [For this discussion, the cross-sectional area refers to the water-filled area of the river channel when water level is equal to zero feet elevation at National Geodetic Vertical Datum of 1929 (NGVD29).] As expected, the cross-sectional area of the Lower Passaic River increases downriver from RM16.5 (closest data to the Dundee Dam) to RM0.5 (near the mouth of the river).[10] A plot of cross-sectional area versus river mile shows a 40 fold increase moving downriver (Figure 3-4). Consequently, for this evaluation, cross-sectional area is considered an adequate surrogate for long-term average velocities.

Like most estuarine rivers, fine-grained sediments are expected to dominate the lower stretches of a river where water velocities are the slowest and tides continuously cause the resuspension and redeposition of fine-grained sediments. To illustrate this phenomenon in the Lower Passaic River, the cross-sectional areas presented in Figure 3-4 were compared to sediment texture characterization to categorize the grain size distribution at the sediment surface.[11] For each half-mile stretch of the Lower Passaic River, the river bottom area was characterized by the percent spatial coverage of fine-grained sediments (classified as silt and silt/fine sand from interpretation of side-scan sonar images) and coarse-grained sediments (classified as gravel/coarse sand and rock/coarse gravel). Figure 3-5 exhibits the percentage of fine-grained sediment and percentage of coarse-grained sediment per half-mile stretch versus the corresponding

[10] Cross-sectional areas (unit of square feet) were calculated using the 2004 bathymetry surveyed by Rogers Surveying, Inc. for the USACE. While the dataset extends from RM0 to RM17.4, cross-sectional areas above RM16.5 were not examined since no accompanying sediment texture data were available for comparison.

[11] Sediment texture data were interpreted from side-scan sonar data (Aqua Survey, Inc., 2006), which provide a broad overview of surficial sediment texture. This survey did not resolve local sediment texture variations. Sediment texture data extend from RM0 to RM16.5; the survey was conducted from April to June 2005 (refer to Attachment A for sediment texture maps).

cross-sectional area calculated in the middle of that half-mile stretch (*e.g.*, sediment texture from RM1.75 to RM2.25 versus cross-sectional area at RM2.0).

A striking feature in this plot is the distinct transition from coarse-grained to fine-grained sediments between RM14 and RM8 as the cross-sectional area increases from 2,500 to 3,500 square feet (Figure 3-5). Downriver of RM8, the surficial sediment is dominated by fine-grained sediments with silt and fine sand covering more than 80 percent of the surveyed area. Upriver of RM14, the surficial sediment is dominated by coarse-grained sediment with 100 percent coverage between RM15 and RM16. This coarse-grained surficial sediment extends to the Dundee Dam (RM17.4) based on field observations of the river (Earth Tech, Inc. and Malcolm Pirnie, Inc., 2005b). This analysis suggests that for cross-sectional areas greater than about 3,500 square feet (marked as a dotted line in Figure 3-4 and Figure 3-5), the river bottom is greater than 80 percent fine-grained sediments. For cross-sectional areas less than this value, the river bottom can vary but tends to be primarily coarse-grained. Notably, cross-sectional areas below RM8 are nearly always greater than 3,500 square feet, correlating with the high percentage of fine-grained sediment in this region. Above RM8, cross-sectional areas tend to be less than 3,500 square feet and correspondingly high in coarse-grained sediment areas.

3.5.2 EVALUATION OF SEDIMENTATION RATES AND SEDIMENT TEXTURE DATA

As part of the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a), sedimentation rates were calculated by comparing the June 1989 Topo Metric, Inc. bathymetric survey to the November 2004 Rogers Surveying, Inc. bathymetric survey. To further investigate the deposition of fine-grained sediments in the Transitional and Freshwater River Sections, these sedimentation rates were compared to sediment texture. Two significant, net non-depositional areas[12] containing fine-grained sediments were

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[12] For the purposes of this evaluation, the term “non-depositional” applies to areas where the sedimentation rate is equal to or less than 0 inch/year. Since this evaluation is limited to a single bathymetric comparison (1989 to 2004), it is unclear whether these net non-depositional areas experience continual loss of sediments over time (hence classifying them as net erosional) or if they experience both a loss and gain of solids over time, yielding a bathymetrically neutral area.

identified by this process. These fine-grained, net non-depositional areas mainly occur between RM6 and RM8 and between RM13 and RM14 (Figure 3-6). The presence of fine-grained, net non-depositional areas between RM6 and RM8 is consistent with previously identified net non-depositional areas located throughout the Brackish River Section (refer to Section 5.3 "Depositional Environment in the Lower Passaic River").

The presence of fine-grained, net non-depositional areas between RM13 and RM14 may represent the extreme upriver reach of the salt front. In this stretch of the river, freshwater is flowing downriver with additional freshwater contributions from the Saddle River, approximately one-tenth the Upper Passaic River flow over Dundee Dam. The river is relatively shallow between Dundee Dam and RM15; the river bottom elevation drops about 10 feet at RM15 and drops another 5 feet at RM13 (Figure 3-7). These changes in river bottom elevation most likely represent the results of historical dredging since the authorized federal navigation channel extends to RM15.

An additional feature of the river is a tight, S-shaped meander that occurs between RM15 and RM14. The high energy of the river as it flows between the Dundee Dam and RM14 results in coarse-grained sediment dominating the river bottom. Sand and silt occur downriver of RM14. Limited observations suggest that they occur in thin beds of fine-grained sediments. Salinity data indicate that the salt front seasonally extends beyond RM10. It is likely that tidal mixing extends at least occasionally to RM13 based on sediment core evidence collected at RM12.6 and elsewhere in the river (refer to Section 6.2 "Sediment: Potential Source Area and Contaminated Medium" for further discussion on this sediment core). Based on the physical features of the river and geochemical observations, tidal mixing of surface sediments likely extends at least from RM0 to RM14.

4.0 BOUNDARY CONDITIONS

For purposes of the Study, the CSM has two primary boundaries: the Dundee Dam, where freshwater and solids flow into the Freshwater River Section, and Newark Bay, where the brackish bay water enters the Brackish and Transitional River Sections during each tidal cycle (Figure 2-2). Other boundaries such as tributaries, combined sewer overflows (CSOs), and storm water outfalls also contribute water, solids load, and contaminant mass.

4.1 DUNDEE DAM BOUNDARY CONDITION

The Dundee Dam represents the upper boundary of the Lower Passaic River. The Upper Passaic River watershed represents a point source with solids and water crossing over the dam into the Study Area. The dam, which was built in 1845, is located at RM17.4 between Garfield and Clifton, New Jersey. The Dundee Dam is the effective upriver limit of the tide for the Lower Passaic River under all known conditions, and the water flowing over the dam is made up entirely of freshwater from the Upper Passaic River.

4.1.1 RIVER FLOW AT DUNDEE DAM

Flow over Dundee Dam is estimated at 1,160 cubic feet per second (cfs). This flow is derived from the USGS gauging station located 12 miles upriver of the dam at Little Falls, New Jersey where the flow over the last 50 years averages to 1,050 cfs. The flow from the Little Falls gauge must be adjusted by approximately 10 percent to account for the additional watershed area between Little Falls and the Dundee Dam.[13]

River flow within the Lower Passaic River can be further characterized by examining the variation in flow, such as high and low flow events, and by observing whether the range

[13] River flow at Dundee Dam is based on a July 18, 2005 electronic message from Emad Sidhom (Senior Project Engineer at United Water and the New Jersey District Water Supply Commission) to F. Chris Purkiss (Malcolm Pirnie, Inc.). Mr. Sidhom indicated that the flow measurements at Dundee Dam were approximately 10 percent greater than the flows measured at the Little Falls gauging station.

in flow has changed over time. River flow statistics for the Little Falls gauging station are presented in Table 4-1, which provides flow data for an 11-year time period from 1995 to 2005 along with data for the past 50 years.

Table 4-1: Flow Statistics for the Little Falls USGS Gauging Station

Year [a]	Annual Average River Flow (cfs) [b]	Annual Peak River Flow (cfs) [b]
1995	483	2,850
1996	1,420	9,270
1997	1,400	8,090
1998	1,180	8,840
1999	679	11,300
2000	950	3,140
2001	822	4,450
2002	199	2,020
2003	1,530	6,840
2004	1,510	7,210
2005	1,210	11,700
Average from 1995 to 2005	1,030	6,880
Average from 1956 to 2005	1,050	7,180
Minimum from 1956 to 2005	199	2,020
Maximum from 1956 to 2005	2,010	18,000

a: "Year" is defined as a "water year," which extends from October 1 through September 30. For example, the 1995 water year extends from October 1, 1994 through September 30, 1995.
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).

Between 1995 and 2005, the annual average river flow and annual peak river flow varied by a factor of 7 and 6, respectively, indicating that the Lower Passaic River experiences significant variations in flow (and thus velocity), which will result in variations in sediment mobilization and deposition. However, the average annual river flow and annual peak flow between 1995 and 2005 are comparable to the average flow and peak flow over the past 50 years (Table 4-1). During the time period of 1995 to 2005, the Lower Passaic River experienced both relatively wet and dry years. For example, the water year 1995 (*i.e.*, October 1, 1994 through September 30, 1995) was relatively dry, receiving approximately half the average annual river flow observed over the past 50 years. Meanwhile, the lowest river flow for the past 50 year was recorded during the water year 2002. Conversely, 2003 was a relatively wet water year compared to the average annual flow for the 50-year record, but not as wet as the recorded maximum average river flow for the past 50 years. The water year 1999 experienced less than average annual flow but had above average peak river flow (11,300 cfs), which is likely associated with Tropical Storm Floyd. However, this peak flow event was not as large as the maximum peak flow event of 18,000 cfs that occurred in April 1984 during the Passaic River flood. Hence, during the time period of 1995 to 2005, flows recorded on the Lower Passaic River were similar to those flows experienced on the river over the past 50 years.

4.1.2 SURFICIAL SEDIMENT CHEMISTRY ABOVE DUNDEE DAM

Three historical studies are available to characterize the surficial sediment chemistry above Dundee Dam.[14] Bopp *et al*. (1991a, 1991b, and 2006) collected a high resolution sediment core[15] in 1986. Surficial sediments from this datable core represent solids deposited during the time period of 1985-1986. Among the available historical data, this Bopp *et al*. core represents the most temporally constrained sediment sample above the Dundee Dam and provides information on contaminant loads over the Dundee Dam in 1985-1986. These sediments were analyzed for four metals (lead, copper, cadmium, and mercury) and three organic compounds [Total PCB, 2,3,7,8-TCDD, and DDD (a metabolite of DDT)].

In 1990, sediment grab samples (0 to 6 inches) above the Dundee Dam were collected during a USEPA-sponsored investigation; among these samples, three were collected within 1.5 miles upriver of the Dundee Dam. Since grab samples are not temporally constrained, the time period represented by these samples is unknown. As discussed in Section 2.2.1 "Relationship of the Lower Passaic River with the Estuary," a sediment core was collected 0.3 miles above Dundee Dam during a USEPA-sponsored investigation in 1991. However, the core was not datable, so temporal constraints on the

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[14] Data are available from the articles referenced and www.ourpassaic.org.

[15] A high resolution sediment core is a finely-segmented core collected from a depositional area in the river. If continuously depositional, the core segments can be dated through comparison of radioisotope measurements to known radiochemical events and trends. When analyzed for specific contaminants, the individual dated segments can be used to infer contaminant loads historically borne by the river.

surficial sediments (0 to 2 inches as defined in this study) were not available. Because this sample contains the only available data for calculating the 2,3,7,8-TCDD/Total TCDD ratio, an alternative method to estimate the date of the core top was necessary. The core top sediments were cesium-137 bearing, indicating that the sediments were deposited post-1954. The Total PCB concentration of 3,900 μg/kg measured in the USEPA 1991 sediment core top lies between the concentrations of 480 μg/kg and 15,000 μg/kg reported for the Bopp *et al*. core for sediments that were deposited in 1985-1986 and 1963, respectively (Bopp *et al*., 1991a). This observation suggests that the 1991 core top represents sediments from the 1960s or 1970s.

Sediment chemistry results for these historical samples are provided in Table 4-2. While the USEPA cores were analyzed for a suite of analytes, only contaminants corresponding to those contaminants reported by Bopp *et al*. plus Total PAH are listed for comparison. (The ratio of 2,3,7,8-TCDD/Total TCDD was calculated when detectable concentrations of both analytes were available.)

Table 4-2: Available Historical Surficial Sediment Data Above Dundee Dam

Analytes (units) [a]	Bopp *et al*. Sediment Core Top (1985-1986 time horizon)[b]	USEPA 1990 Sediment Grabs [c]	USEPA 1991 Sediment Core Top (not datable)
Cadmium (mg/kg)	4.2	3.4 ±1.8 (N = 3)	3.9
Copper (mg/kg)	120	49 ±31 (N = 3)	110
Lead (mg/kg)	307	360 ±480 (N = 3)	230
Mercury (mg/kg)	1.8	0.34 ±0.16 (N = 3)	1.4
Total PCB (μg/kg)	480	350 ±370 (N = 3)	3,900
DDD (μg/kg) [d]	58	19 ±15 (N = 3)	8.3
Total PAH (mg/kg)	Not analyzed	13 ±4.7 (N = 2)	24
2,3,7,8-TCDD (ng/kg)	20	10 ±15 (N = 3)	27
Ratio of 2,3,7,8-TCDD/Total TCDD	Not analyzed	Not calculated [e]	0.1

a: Whenever possible, Total PCB represents the sum of Aroclors, and Total PAH represents the sum of 16 PAH compounds. Nondetected concentrations were incorporated into the summation as zero.
b: Reported literature values (Bopp *et al*., 2006; Bopp *et al*., 1991a; Bopp *et al*., 1991b), representing 1985-1986 surficial sediment concentraitons.
c: Arithmetic average and standard deviation (± 1 sigma) based on a normal distribution of sample size; nondetected values are incorporated into the average as half the reported detection limit. Results rounded to two significant figures, whenever possible.
d: DDD concentrations represent the 4,4'-DDD isomer only.
e: Since Total TCDD concentrations were reported as non-detected due to a high detection limits in the samples, no 2,3,7,8-TCDD/Total TCDD ratio could be calculated for these sediments.

Based on the available historical data, the surficial sediments above Dundee Dam are contaminated relative to the NJDEP sediment guidelines (NJDEP, 1998). Consequently, solids that are transported over the Dundee Dam to the Lower Passaic River are also contaminated, and the Upper Passaic River represents a source to the Lower Passaic River for certain contaminants. As discussed in the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a), the metals concentrations and mass fractions that were observed above the Dundee Dam in 1985-1986 are comparable to the corresponding metals concentrations and mass fractions observed below the dam in 1995 (RM0.9 to RM7).[16] These data suggest that the Upper Passaic River has recently contributed a significant load of lead, mercury, and cadmium to the Lower Passaic River. Once introduced to the Lower Passaic River, these contaminated solids become re-worked in the surface sediments through tidal resuspension and redeposition.

With respect to organic contaminants, the concentrations detected in the Bopp *et al*. core are generally less than the corresponding concentrations reported in surface sediment from depositional areas below the dam in 1995. The concentrations for DDT-derived compounds and Total PCB in the 1985-1986 core top above the Dundee Dam were one-fourth to one-third, respectively, of the concentrations observed in the 1995 surface sediments in the Lower Passaic River. Hence, it can be inferred that the loads are similarly proportioned. It is also unlikely that the source of 2,3,7,8-TCDD contamination to the Lower Passaic River originated above the Dundee Dam. This observation is based on the low 2,3,7,8-TCDD concentrations from the various Upper Passaic River sediments and the low 2,3,7,8-TCDD/Total TCDD ratio observed in the 1991 USEPA core top.

These conclusions, however, must be regarded with some caution since the core top sediments in the Bopp *et al*. core above the dam predate the 14 datable cores from the Lower Passaic River (1995 TSI dataset). Consequently, some additional changes in contaminant load over the Dundee Dam may have occurred in the 9-year period between

[16] The 1995 Tierra Solution, Inc. (TSI) dataset defines surficial sediment as 0-6 inches in the Lower Passaic River.

sampling events. Note that this caveat largely applies to those compounds where the upriver and downriver concentrations are comparable. For compounds with downriver concentrations substantively greater than the upriver concentrations, interim upriver changes are unlikely to be important.

4.2 NEWARK BAY BOUNDARY CONDITION

Newark Bay represents the lower boundary of the Lower Passaic River. Newark Bay is located at the confluence of the Lower Passaic River and the Hackensack River. The bay is linked to Upper New York Bay by the Kill van Kull and Raritan Bay by the Arthur Kill (refer to Figure 2-1 and Section 2.1 "The Hudson-Raritan Estuary" for further discussion). Like the rest of the Hudson-Raritan 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. Consequently, contaminated solids from Newark Bay become distributed throughout the Hudson-Raritan Estuary. However, 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 those solids are removed from Newark Bay during maintenance dredging. Refer to Section 7.4 "Initial Mass Balance for the Lower Passaic River and Newark Bay" for discussion on solids mass balance and the accumulation of solids in Newark Bay.

Newark Bay and its tributaries have been subjected to expanding urban and industrial development, resulting in a dramatic ecological degradation of the Newark Bay area. Surficial sediment chemistry in Newark Bay was characterized in 2005 during a low resolution coring program,[17] which was developed to support the Phase 1 Remedial Investigation of Newark Bay (TSI, 2006).[18] As part of this program, cores were collected from 69 sampling locations. Among these locations, 35 were identified as beryllium-7 bearing and were considered to represent net depositional areas (these areas include

[17] A low resolution sediment core is a coarsely-segmented core that records the general chemistry of the river sediment. In some cases, the cores may provide data to approximate historic contaminant load (time-scale of decades).

[18] Data are available at www.ournewarkbay.org.

locations within the federal navigational and port channels).[19] Table 4-3 characterizes the surficial sediment (defined as 0 to 6 inches in this study) in net depositional areas located in the federal navigational channel, accounting for 13 to15 sampling locations. These values are compared to the Lower Passaic River, represented by the surface layer of high resolution cores collected in 2005. In general, average surface concentrations in Newark Bay are less than concentrations in the Lower Passaic River, confirming that Newark Bay does not export contamination to the Lower Passaic River in most cases. These concentration gradients and the change in the 2,3,7,8-TCDD/Total TCDD ratio indicate that both contamination and solids are transferred from the Lower Passaic River to Newark Bay. (Refer to Section 6.0 "Source Area Analyses" for further discussion on the interactions between the Lower Passaic River and Newark Bay.)

Table 4-3: Summary of Contaminant Concentrations in Newark Bay and in the Lower Passaic River

Analyte (units)	Lower Passaic River Sediment Core Top (2005-2003 time horizon) [a]	Newark Bay Sediment Core Top (not datable) [a,b]
Cadmium (mg/kg)	3.5 ± 0.68 (N = 5)	1.3 ±2.3 (N = 15)
Copper (mg/kg)	150 ± 29 (N = 5)	120 ±110 (N = 13)
Lead (mg/kg)	209 ± 39 (N = 5)	110 ±75 (N =15)
Mercury (mg/kg)	1.7 ± 0.55 (N = 5)	1.5 ±0.9 (N = 15)
Total PCB (µg/kg) [c]	280 ± 61 (N = 5)	360 ± 170 (N = 13) [d]
2,3,7,8-TCDD (ng/kg)	480 ± 430 (N = 5)	52 +61 (N = 15)
Ratio of 2,3,7,8-TCDD/Total TCDD	0.7 ± 0.1 (N = 5)	0.4 ± 0.1 (N = 15)

a: Arithmetic average and standard deviation (± 1 sigma) based on a normal distribution of sample size; nondetected values are incorporated into the average as half the reported detection limit. Results rounded to two significant figures, whenever possible.
b: Newark Bay sediment core tops represent 0 to 6 inches.
c: Total PCB for the Newark Bay samples represents the sum of 209 congeners while Total PCB for the Lower Passaic River samples represents the sum of 159 congeners.
d: Average Total PCB for Newark Bay excludes the elevated value of 3,700 µg/kg.

While this analysis precludes substantive contaminant transport from Newark Bay to the Lower Passaic River, it does not entirely rule out the transport of *some* Newark Bay solids to the Lower Passaic River. A mass balance suggests that current solids transport from the bay to the river is relatively minor based on the general homogeneity of contaminant concentrations in surficial sediments in depositional areas of the Lower

[19] A depositional environment is defined as a location where sediments (0-1 inch) have detectable beryllium-7 concentrations that are greater than 0.5 pCi/g.

Passaic River and the estimated mass of the Passaic-derived contamination that must reach Newark Bay (refer to Section 7.4 "Initial Mass Balance for the Lower Passaic River and Newark Bay"). However, this relationship between the Lower Passaic River and Newark Bay was probably not the case historically given the following scenario.

As discussed in the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a), approximately 5 to 6.5 million cubic yards of 2,3,7,8-TCDD-contaminated sediments are located between RM0.9 and RM7. This estimated volume should probably be expanded by roughly one-third to account for deposition in the areas between RM7 and RM8 as well as between RM0 and RM0.9. Given the historical period of 2,3,7,8-TCDD production and the sediment core records, these 2,3,7,8-TCDD-contaminated sediments were deposited between 1940 and 1995, the latter year being the coring basis for the volume estimate. Thus, roughly 55 years were available to have deposited at least 5 to 6.5 million cubic yards and probably another 2 million cubic yards more in RM7 to RM8 and RM0 to RM0.9.

Meanwhile, the Upper Passaic River and the other tributaries to the Lower Passaic River are estimated to deliver an annual solids load of approximately 77,000 cubic yards. Over 55 years, conservatively assuming no losses to Newark Bay, this delivery would represent approximately 4.2 million cubic yards, leaving approximately 0.8 to 2.3 million cubic yards to be made up from other sources to total the estimated contaminated sediment volume between RM0.9 and RM7. These volumes do not include the additional material from RM7 to RM8 and RM0 to RM0.9 mentioned above, which would add to these volume estimates. There are two main potential sources for these sediments: (1) the Upper Passaic River solids load – given the relatively poor dataset used to construct the estimated Upper Passaic River's solids load, a real possibility exists that this load may be underestimated; and (2) Newark Bay – the enhanced channel depth created for navigational purposes could have permitted additional solids transport upriver. The contribution from Newark Bay has probably declined over time, with its greatest contribution occurring soon after the construction of the federal navigational channel in the Lower Passaic River and gradually decreasing as the channel filled with sediment and limited the volume of the salt intrusion and its associated Newark Bay solids.

4.3 OTHER BOUNDARY CONDITIONS

While Dundee Dam and Newark Bay are the two primary boundaries, other boundaries continue to impact water and sediment quality in the Lower Passaic River. These boundaries include major tributaries (Saddle River, Second River, and Third River), minor tributaries (Frank's Creek, Lawyer's Creek, Harrison Creek, and Plum Creek), storm water outfalls, CSO sites, known New Jersey Pollutant Discharge Elimination System (NJPDES) sites, and groundwater seepage. [Refer to the *Work Plan* (Malcolm Pirnie, Inc., 2005a) for location maps of storm water outfalls and CSO sites in the Study Area.] Each of these boundaries may contribute or exchange water, solids load, contaminant mass, or a combination of these elements to the Lower Passaic River.

While the chemical contributions of these inputs to the system boundaries have not been fully quantified at the time of this writing, the solids load and volume of surface water for each boundary condition were estimated, where data were available (Table 4-4). These estimated values indicate that the surface water flow and solids load over the Dundee Dam are an order of magnitude greater than contributions from the tributaries and other sites. For example, the surface water flows and solids loads from the tributaries (Saddle River, Third River, and Second River) are approximately 13 percent of the freshwater and solids entering the Lower Passaic River at Dundee Dam. Consequently, tributary contaminant loads in the water and on the solids would have to be greater than 8 times the contaminant load from Dundee Dam to impact the contaminant mass received by the Lower Passaic River from the dam.

Table 4-4: Estimated Surface Water Flow and Estimated Solids Load on the Lower Passaic River

Gauged Boundary Condition	Estimate Surface Water Flow (cfs)	Estimated Solids Load [a] (cubic yards/year)
Dundee Dam	1,160 [b]	69,000
Saddle River	108 [b]	3,700
Third River	19 [b]	920
Second River	22 [b]	790
Additional ungauged watershed area	67 [c]	2,400 [d]
NJPDES sites	27 [a]	NA
CSO sites	NA	2,500 [d,e]

a: Solids loads derived from information provided in Lowe *et al*., 2005.
b: Refer to Attachment B for calculations and references therein.
c: Additional ungauged watershed area is based on USGS watershed values for the Lower Passaic River. Flow value based on drainage area with Saddle River water yield.
d: Some proportion of the ungauged watershed area is also incorporated within the CSO "sewershed." This results in some unknown overlap of the estimated solids load.
e: For lack of supporting data, this value is based on the assumption that half of the annual CSO solids deposited in Newark Bay (Lowe *et al*., 2005) originated from the Lower Passaic River.

It is unlikely that atmospheric deposition and solids from CSOs are a significant source of metals contamination to the Lower Passaic River. Atmospheric deposition (based on the data available at the New Jersey Atmospheric Deposition Network) cannot yield the observed metals concentrations in the Upper Passaic River and Lower Passaic River (Reinfelder *et al.*, 2004). Furthermore, it is unlikely that CSO inputs could dominate metals loadings to the Lower Passaic River given their relative magnitude. The annual CSO solids load is approximately 2,500 cubic yards, which is approximately 4 percent of the solids load from Dundee Dam.[20] Consequently, for CSO solids to have comparable impact on metals contamination relative to solids transported over the dam, the metals concentrations on CSO solids would have to be 30 times greater than those concentrations above the dam. These concentration levels are unlikely to exist. Nevertheless, CSO sampling or evaluating existing CSO data should be completed to better quantify the importance of this source area to the Lower Passaic River.

[20] Lacking supporting data, the annual CSO solids load value for the Lower Passaic River is a conservatively high value obtained by assuming that half of the annual CSO solids delivered to Newark Bay were first discharged to the Lower Passaic River. The original CSO solids load value is based on solids load calculations provided in Lowe *et al.*, 2005.

Given their magnitude in both solids load and contaminant concentration, it is likely that the major boundary conditions at Dundee Dam and Newark Bay have the greatest impact on the Lower Passaic River. Consequently, they are the main focus of this CSM along with the main stem of the river. However, future sampling and evaluation of existing tributary and CSO data are necessary to fully assess the impact of these discharges on the Lower Passaic River.

5.0 SEDIMENT TRANSPORT

As previously reported, the Lower Passaic River is a dynamic environment, experiencing both periods of net erosion and net deposition [refer to Section 3.0 "Sediment Transport" in the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a) for further discussion]. Solids are introduced to the Lower Passaic River from above the Dundee Dam, tributaries, and discharge points. They are homogenized and re-worked through tidal mixing and erosional/depositional events. Eventually, some of these solids are transported through the river sections and deposited in Newark Bay. The following discussion describes sediment transport in the Lower Passaic River by analyzing solids accumulation and erosion/deposition activity. Throughout this discussion, it should be kept in mind that tidal mixing continuously causes surface sediments to resuspend and redeposit in response to the tidal currents. These currents also cause the salt front to advance twice-daily through the Brackish River Section and Transitional River Section, adding to the complexity of sediment transport in the Lower Passaic River.

Since historical investigations of the Lower Passaic River focused on the region between RM0.9 and RM7, multiple bathymetric surveys were conducted in this portion of the river, which roughly coincides with the Brackish River Section (RM0 to RM6). Only two bathymetric surveys are available to characterize the remainder of the river, covering the Transitional River Section (RM6 to RM10) and portions of the Freshwater Section (RM10 to RM17.4; refer to Table 5-1).

Table 5-1: Summary of Available Bathymetric Surveys

Date	Survey Company	Survey Extent (RM) [a]
November 1989	Topo-Metrics, Inc. for USACE	0 to 15
March/April 1995	Ocean Surveys, Inc. for TSI	0.5 to 8.2
November 1996	Ocean Surveys, Inc. for TSI	0.5 to 6.94
April 1997	Ocean Surveys, Inc. for TSI	0.5 to 6.94
June 1999	Ocean Surveys, Inc. for TSI	0.9 to 6.94
August 2001	Ocean Surveys, Inc. for TSI	0.9 to 6.94
July 2002	TVGA Consultants for USACE	0 to 8.0
November 2004	Rogers Surveying, Inc. for USACE	0 to 17.4

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.

5.1 SOLIDS ACCUMULATION

To evaluate the net annual solids accumulation in the Lower Passaic River (RM0.9 to RM7), difference among historical bathymetric surveys were evaluated. Available historical surveys from 1989 through 2004 were considered in a series of 10 comparisons [refer to Section 2.1 “Sedimentation Rates and Annual Accumulation” in the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a) for description of methodology]. Net annual solids accumulation ranged from a loss of 166,000 cubic yards (representing a net erosional period between surveys) to a gain of 200,000 cubic yards (representing a net depositional period between surveys; Table 5-2). These results indicate that the Lower Passaic River is a dynamic system, experiencing periods of both net deposition and net erosion superimposed on the gross cycling of solids caused by the twice-daily tidal exchange.

Table 5-2: Net Solids Accumulation and Loss Based on Bathymetric Surveys (1989 to 2004)

Survey Comparison Interval [a]	Net Accumulation and Loss Between Surveys (cubic yards) [b, c]
1989-1995	101,000
1995-1996	144,000
1996-1997	-23,100
1997-1999	94,400
1999-2001	121,000
2001-2002	-166,000 [d]
2002-2004	200,000 [d]

a: Based on evaluations provided in the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a). Each year listed corresponds to a bathymetric survey that covered at least RM0.9 to RM7. The time between surveys varies from less than 1 year to 6 years.

Table 5-2 footnotes (continued)

b: The actual uncertainty in these estimates of annual accumulation is unknown. However, in the absence of any actual change, a 1-inch offset in the vertical reference plane between any two surveys would represent a volume equivalent to about 36,000 cubic yards.
c: Positive values represent net accumulation of solids while negative values represent a net loss of solids. The volumetric difference between surveys reported here does not necessarily represent an annual net gain or annual net loss of solids since the periods separating the surveys vary significantly from 12 months.
d: The large difference from 2001 to 2002, and again from 2002 to 2004, may be the result of a change in surveying companies in 2002. Refer to the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a).

The variations in sediment volume between bathymetric surveys give testament to the dynamic nature of the river bed of the Lower Passaic River. While the river tends to accumulate sediments in most cases, two of the seven intervals examined had large sediment losses. Notably, the largest loss and one of the largest gains of solids occurred when the bathymetric surveys used in the comparison was conducted by different surveying companies. Nonetheless, the differences in surveys still suggest major solids deposition and erosion events. To place this difference in context, a net change of 36,000 cubic yards represents an average gain of 1 inch over the entire area between RM1 to RM7 of the Lower Passaic River. Solids gains during at least one interval (*i.e*., the 19-month period from April 1995 to November 1996) would represent a net deposition of approximately 4 inches of sediment over the entire area.

The relationship between net erosional events, net depositional events, and river flow is not well known currently. It is unclear whether net deposition occurs most rapidly during short periods of high flow or long periods of low flow. Similarly, it is not known what type of flow conditions yield periods of net erosion. The volume estimates provided in Table 5-2 suggest that the river is generally depositional over time but is still subject to fairly frequent major erosional events. An evaluation of the interplay between river flow, net erosion, and net deposition is recommended to further this understanding and to provide a basis for the prediction of erosion and deposition as river flow varies.

5.2 SOLIDS MASS BALANCE

Recent work by Lowe *et al*. (2005) provides additional information used to derive the external solids load to the Lower Passaic River. The solids load to the Lower Passaic

River at the head-of-tide, including the flow over the Dundee Dam as well as the tributaries of the Lower Passaic River, is roughly 77,000 cubic yards/year. The Lowe *et al*. study, however, did not examine solids deposition in the Lower Passaic River. In an effort to complete this calculation and to estimate the solids load at the mouth of the Passaic River, the 1989 and 2004 bathymetric surveys were compared from RM0 to RM15. These surveys were compared because both surveys extend to RM15 and because the 15-year time span between surveying events serves to average out any extreme depositional or erosional events. This comparison yielded average annual net solids accumulation of 67,000 cubic yards for RM0 to RM15, which is roughly equivalent to 1 inch of sediment accumulation over the Lower Passaic River bottom (RM0 to RM17) or 1.5 inches over the lower 7 miles. Approximately 90 percent of this accumulation occurs from RM0 to RM7. However, since the head-of-tide solids load to the Lower Passaic River is likely greater than the annual net solids accumulation, the remaining solids load must be transported out of the river into Newark Bay. A combined solids and 2,3,7,8-TCDD mass balance suggests that an even larger solids volume (approximately 36,000 cubic yards) is transported out of the Lower Passaic River and into Newark Bay (refer to Section 7.4 "Initial Mass Balance for the Lower Passaic River and Newark Bay"). Based on these estimates, a solids load equivalent to 20 to 50 percent of the solids entering the Lower Passaic River over the Dundee Dam is eventually transported to Newark Bay each year (Malcolm Pirnie, Inc. 2006a).

The surficial sediment texture in the Lower Passaic River is consistent with the bathymetric observations of deposition, with coarse-grained sediment present above RM14 transitioning to predominantly fine-grained sediments below RM8 (Figure 3-5). The fine-grained sediments are considered characteristically depositional for the Lower Passaic River while the coarse-grained sediments are characteristic of areas where flow velocities are too great to permit substantive rates of fine-grained deposition. While the Lower Passaic River has experienced, on average, net deposition of sediment (for the period examined), tidal velocities continuously cause surface sediments to resuspend and redeposit. It is likely that the layer of sediments resuspended and redeposited by tidal currents (*i.e.*, gross sediment cycling) represents a greater thickness than the net annual accumulation of sediments in most areas.

5.3 DEPOSITIONAL ENVIRONMENT IN THE LOWER PASSAIC RIVER

As noted in the introduction (Section 1.1 "Objective of the Conceptual Site Model"), one objective of a CSM is to assist remedial decision-making. As a preliminary approach to delineate possible remedial targets, it was decided to identify areas of the sediment beds undergoing net erosion, potentially re-releasing older, highly contaminated sediments. The previous section examined the evidence for solids transport, net erosion, and net deposition in the Lower Passaic River as a whole. In addition, a detailed examination of sediment deposition rates on a local scale indicates a high degree of spatial heterogeneity in the Lower Passaic River [refer to Section 3.0 "Sediment Transport" in the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a) for further discussion]. Given the large, fine-grained sediment inventory between RM0.9 and RM7, the heterogeneous nature of sediment deposition, and the particle-reactive nature of most of the contaminants of potential concern, the following analysis focuses on this stretch of the river.

To identify consistently net erosional and depositional areas in RM0.9 to RM7, the evaluation focused on the historical TSI bathymetric surveys performed by Ocean Surveys, Inc. in 1995, 1996, 1997, 1999, and 2001. These surveys were selected because the bathymetric surveying tracks are well aligned, reducing the uncertainty in year-to-year comparisons. The close alignment of the survey tracks meant that differences in river bottom elevation between surveys were largely the result of measured differences and not interpolated ones. While much of the bottom surface elevations were still interpolated values, the relative uncertainty at a given location remains the same across surveys since the distance to measured values remains constant. This level of uncertainty is in contrast to the level of uncertainty associated with the 1989-2004 bathymetric comparison where surveying tracks were not aligned. Thus, TSI-surveyed locations compared year-to-year do not have varying uncertainties depending on survey alignment.

Uncertainty can be minimized with this approach, but it can still be substantial at locations between survey tracks.

The interpreted bathymetric surveys cover a time period (1995 to 2001) when the Lower Passaic River experienced both relatively "wet" years and relatively "dry" years (Table 4-1). Since the period from 1995 to 2001 includes conditions reasonably representative of high flow events and low flow events on the Lower Passaic River, an evaluation of bathymetric surveys from this period should be sufficient to characterize the general behavior of the river. An important note concerning the original goals of this evaluation is warranted here. The original purpose of this evaluation was to identify areas that might be suitable as remedial targets and not to attempt a fine resolution of the net depositional and erosional environments. The identification process was done on a semi-quantitative basis, recognizing the uncertainties in individual bathymetric survey measurements and the inherent uncertainty in the interpolation schemes despite our efforts to minimize it by survey selection. Such an approach permits the identification of those portions of the Lower Passaic River where the main net erosional areas are concentrated without developing a rigorous statistical basis in an attempt to sharply define these areas. Since net erosion and contaminated sediment volume were important to the selection of remedial targets, this analysis attempted to identify river segments on the scale of one-quarter mile or more (which is the approximate spacing of the 1995 coring transects). The analysis did not attempt to develop the statistics to delineate sharper boundaries.

To accomplish the analysis, individual locations were paired across surveys to assign a value for an indicator variable. Values of -1, 0, and 1 are assigned respectively to indicate areas that were net erosional, bathymetrically neutral, or net depositional to create a map of -1's, 0's, and 1's. These maps were simply summed to identify areas where net erosion was occurring most frequently. Essentially, the more negative the summed value was, the more often that survey comparisons showed net erosion for a location. Both short-term (2 years or less) and longer-term (greater than 2 years) comparisons were made. The short-term comparisons and longer-term comparisons were combined into separate maps and compared to each other to identify the consistently erosional areas. (Refer to Attachment C for details on methodology.)

Delineated net erosional and depositional areas based on these comparisons are presented in Figure 5-1. Red or orange colors represent areas of the river that have frequently experienced net erosion. Conversely, green or blue colors represent areas that have frequently experienced net deposition. Grey indicates “bathymetrically neutral” areas, that is, areas that have experienced both erosion and deposition and, therefore, cannot be classified as net erosional or net depositional. The term “bathymetrically neutral” does not in any way discount the short-term gross resuspension and settling that is the result of tidal flows or hydrologic events. Both of these latter phenomena, however, have only a transient effect on the sediment bed elevation compared to the longer-term net changes documented by the various investigations.

One striking feature of Figure 5-1 is the complexity of the Lower Passaic River as denoted by the intertwining of net depositional and net erosional areas, not only along the river but also across the river from bank-to-bank. Net erosional areas are relatively smaller and less densely spaced. They often occur most densely on the outer bank of a meander. For example, this situation occurs downriver of RM7 as the river makes a slight bend to the southwest (RM6.7 to RM6.0). Sporadic net erosional areas then appear downriver of RM6 near a series of bridges. Net erosional areas become prominent again between RM5.1 and RM3.3 as the river bends in an S-shape and the channel shifts from the right-bank descending toward the left-bank descending at RM3.7. Net erosional areas also occur between RM2.4 and RM1.8 as the river makes its final bend in Kearny, New Jersey. Another feature is the frequent occurrence of the bathymetrically neutral areas throughout the river, covering approximately 35 percent of the surveyed area between RM0.9 and RM7.

The semi-quantitative approach described above permitted the identification of some stretches of the river as having a higher density of net erosional areas by examining the fraction of the river bottom that is classified as net depositional, net erosional, or bathymetrically neutral within quarter-mile (bank-to-bank) units. Figure 5-2, which distills the information presented on the map in Figure 5-1, shows the relationship between river mile and the percentage of the river bottom that falls into each of these categories. In this line plot, net depositional areas are shown to account for more than 80 percent of the area near RM0.9 and in parts of the area between RM2.5 and RM3.5. While net depositional areas are still common farther upriver, between RM3.5 and RM5, net erosional areas account for more than 20 percent of the river bottom in much of this stretch. Upriver of RM5, net depositional and bathymetrically neutral areas again become prevalent.

The analysis presented here is appropriate for the purposes of preliminarily identifying remedial targets. More detailed information on long-term net deposition and erosion rates and associated areas can be obtained from the data but only after more rigorous analyses. Such analyses would also be very useful constraints on the numerical simulations of sediment transport and long-term recovery of the river bottom.

6.0 SOURCE AREA ANALYSES

Each of the three river sections as defined in Section 3.0 "River Sections" has been further subdivided into three media: sediment, water, and air (Figure 6-1). These media interact through various natural processes and are impacted by various contamination source areas in the Lower Passaic River. The following section examines these potentially contaminated media, source areas, and potential migration pathways. Source areas are defined as locations from which contamination originates and becomes available for transfer to other media and other areas. For example, a source area may be an area of sediment scour, where older, highly contaminated sediments are being re-released into the water column, contaminating both the water column and the sediment surface in other areas. Alternatively, a source area can be the point of discharge of a CSO or other discharge conduit into the water column, assuming the discharge is contaminated. The water of the Lower Passaic River and its biota are not considered to be source areas, but rather as the ultimate recipients of contamination. Sediments of the river may be both a recipient of contamination and a source area, as noted above.

6.1 IDENTIFICATION OF SOURCE AREAS

A schematic flow diagram is presented in Figure 6-1 to describe how the different contaminated media and source areas interact on the Lower Passaic River. In Figure 6-1, the different media are marked with different colors (*e.g.*, sediment is marked as brown, water is marked as dark blue, and air is marked as light blue), source areas or inventories are denoted in boxes, and release mechanisms or fluxes are marked on the arrows connecting associated inventories.[21] Since limited data are available to assess all sources in each river section, the same potential source areas are listed for each river section (Figure 6-2). However, some source areas will be absent or less significant within a given river section.

[21] In Figure 6-1, the arrow length does *not* reflect the flux magnitude.

Various datasets are available to identify contaminant input and source areas and to understand the mechanisms impacting the fate and transport of those contaminants. These datasets include available historical data, field data collected in 2005 and 2006 as part of the USEPA field sampling program, field data collected as part of the Phase 1 Remedial Investigation of Newark Bay (TSI, 2006), as well as the dataset and evaluations incorporated in the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a). Table 6-1 and Table 6-2 summarize the available datasets used and evaluations conducted to characterize the source areas on the Lower Passaic River. The source areas listed in these tables correspond to the source areas presented in the schematic diagrams of Figure 6-1 and Figure 6-2. (Refer to Section 8.0 "Uncertainties and Future Updates" for a list of potential actions that are anticipated to occur to address data gaps.)

Table 6-1: Currently Available Data and Identified Data Gaps for the Sediment Beds

Potential Source Area to Sediment Beds	Currently Available Data and Identified Data Gaps
Transport of solids originating above Dundee Dam	• Limited data on solids transport over dam; refer to Section 5.1 on solids load. • Data gap in sediment chemistry above Dundee Dam (refer to Table 4-2); to be addressed by results of USEPA coring event in January 2007. • Refer to Section 7.4 on Dundee Dam contribution to mass balance.
Resuspension and erosion/deposition of solids due to tides	• Limited data on suspended solids collected during dredge pilot study (December 2005). • Data on suspended solids collected by Malcolm Pirnie, Inc. for USEPA and Rutgers University for the New Jersey Department of Transportation (NJDOT) in 2004 and 2005. • Data gap for magnitude of this process - to be addressed by model simulation.
Transport of solids from Newark Bay	• Data on sediment concentrations in both the Lower Passaic River and Newark Bay suggest minimal upriver transport of contaminants from Newark Bay at the current time. • Data on concentrations from historical and recent sediment coring programs (TSI Phase 1 dataset and Bopp *et al*. cores). Refer to Section 4.2. • Refer to Section 7.4 on Newark Bay mass balance. • Data gap for magnitude of this process - to be addressed by subsequent dated sediment core data analysis and model simulation.

Table 6-1 (continued)	
Resuspension and erosion/deposition of solids from tributaries	• Very limited data on suspended solids collected on tributaries in 2005 by Malcolm Pirnie, Inc. for USEPA. • Data gap in suspended solids and sediment chemistry from tributaries. • Data gap not expected to be substantial for most contaminants due to limited watershed area associated with the tributaries.
Discharge of solids from non-point sources	• Data gap in solids from non-point sources. • Estimates by Lowe *et al*., 2005. • Data gap not expected to be substantial for most contaminants due to limited water volume through this pathway.
Discharge of solids from point sources	• Data gap in solids from point sources. • Estimates by Lowe *et al*., 2005. • Data gap not expected to be substantial for most contaminants due to limited water volume through this pathway and evidence collected on other point sources (such as CSOs) throughout the New York-New Jersey harbor area (Chaky, 2003).
Burial of surficial sediment to deep sediment beds	• Refer to Section 5.0 on sediment transport. • Bathymetry data from RM0 to RM17.4 limited to 1989 and 2004 surveys.
Resuspension and erosion/deposition on mudflats	• Limited sediment chemistry data on shoals (refer to Section 6.3). • Data gap in deposition rates and sediment chemistry on mudflats. • Data gap not expected to be substantial for most contaminants since mudflats are typically non-depositional (<< 1 inch/year) and do not accumulate large temporary sediment volumes.
Resuspension and erosion/deposition on floodplains	• Data gap in sediment chemistry from floodplains. • Data gap not expected to be substantial for most contaminants due to extensive armoring of shoreline areas along much of the Brackish and Transitional River Sections, which limits flood plain deposition and transfer.
Interactions between sediment, groundwater, and porewater	• Refer to Section 6.5 on groundwater discussion. • Data gap for porewater and groundwater conditions.
Remobilization of sediment due to floods	• Suggestive evidence from historical bathymetric surveys; more rigorous analysis of the bathymetric data in concert with hydrographic data would be appropriate. • Modeling analysis by HydroQual, Inc. is ongoing.

Table 6-2: Currently Available Data and Identified Data Gaps for the Water Column

Potential Source Area to Water Column	Currently Available Data and Identified Data Gaps
Main-stem flow originating above the Dundee Dam	• Refer to Section 4.1 for Dundee Dam flow. • Data gap in water chemistry - to be addressed by results of anticipated sampling event in spring 2007 by Malcolm Pirnie, Inc. for USEPA. • Data gap in suspended solids chemistry - to be addressed by results of coring event in January 2007 and water column sampling event in spring 2007 by Malcolm Pirnie, Inc. for USEPA. • Data gap in suspended solids load above dam.
Tidal exchange with adjacent river sections and Newark Bay	• Refer to Section 3.2 for river section definition. • Data gap in magnitude of transfer process to be addressed by computer simulation of salinity distribution data collected by Malcolm Pirnie, Inc. for USEPA and Rutgers University for NJDOT. • Large and small volume water samples collected in 2005 by Malcolm Pirnie, Inc. for USEPA on the Lower Passaic River. • Semi-permeable membrane devices deployed in 2005 by Malcolm Pirnie, Inc. for USEPA on the Lower Passaic River. • Limited data available on tidal exchange volume through measurements of salinity in 2004 and 2005. • Data gap in water chemistry in Newark Bay.
Discharge of water from tributaries	• Refer to Section 4.3 for estimates of tributary flow. • Tributary water collected in 2005 by Malcolm Pirnie, Inc. for USEPA (limited in temporal extent). • Semi-permeable membrane devices deployed in 2005 by Malcolm Pirnie, Inc. for USEPA on the Lower Passaic River. • Data gap in measurements of magnitude of flow due to lack of gauging stations - not expected to be substantial for most contaminants due to limited watershed area and relatively small flows associated with the tributaries.
Discharge and runoff of water from non-point sources	• Data gap in water chemistry and volume from non-point sources – not expected to be substantial for most contaminants due to limited water volume through this pathway.
Discharge of water from point sources	• Refer to Attachment B for known point source flow discharges. • Data gap in water chemistry from point sources – believed to be addressed by Contaminant Assessment and Reduction Program (CARP); not expected to be substantial for most contaminants due to limited water volume through this pathway.
Exchange between porewater and water column	• Refer to Section 6.5 on groundwater discharges. • Data gap for porewater and groundwater conditions.
Exchange between groundwater and water column	• Refer to Section 6.5 on groundwater discharges. • Data gap for porewater and groundwater conditions.

Table 6-2 (continued)	
Atmospheric dry and wet deposition and volatilization	• Limited atmospheric data available for some contaminants in the region. • Limited data on dissolved-phase concentration needed to estimate loss by gas exchange. • Data gap not expected to be substantial for most contaminants due to relatively low concentrations associated with atmospheric particles as compared to Lower Passaic River solids concentrations. Gas exchange losses limited to those organics with significant solubilities and vapor pressures (*e.g.*, low molecular weight PAH and PCB compounds and methyl mercury).

As noted in Table 6-1 and Table 6-2, a number of data gaps exist that limit the precision on the estimates of the magnitude of potential source areas in each river section (refer to Section 8.0 "Uncertainties and Future Updates"). With the available data, the following evaluations and discussions are presented on potential source areas and contaminated media, including sediment, water column, and groundwater.

6.2 SEDIMENT: POTENTIAL SOURCE AREA AND CONTAMINATED MEDIUM

6.2.1 SURFACE SEDIMENT CONCENTRATIONS AND GRADIENTS

Surface sediment concentrations were evaluated and discussed in Section 4.4 "Surface Sediment Concentration" and Section 4.5 "Source Analysis" of the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a). The results of these evaluations are summarized below:

- Metals concentrations in surficial sediments reveal a consistent mass fraction pattern between RM0.9 and RM7. A similar mass fraction pattern was generated for sediment collected from the Bopp *et al*. 1985-1986 core that was collected above the Dundee Dam. These observations suggest one potential source area of metals contamination is upriver of RM7 and is likely to originate upriver of the Dundee Dam.

- Ratio analysis of metals concentrations (RM0.9 to RM7) showed little variation. Analysis of metals concentrations in surface sediments also showed relatively little trend longitudinally. This evidence demonstrates the homogeneity of contaminant concentrations in surficial sediments in depositional areas of the Lower Passaic River and suggests that tidal mixing is able to homogenize local metals loads over long distances, prior to the deposition of the contaminants on the river bottom. Hence, the presence or absence of an interval of high concentration within the sediments at a given location is a function of the depositional history and is not controlled by proximity to source. To a significant degree, this efficient mixing process limits the ability to identify source areas in this region.
- The Upper Passaic River has been and is likely to be a source area of cadmium, lead, mercury, and Total PCB to the Lower Passaic River. Historical loads of Total DDT were unimportant but may have become more important recently (within the last 10 to 15 years). However, additional sources of these contaminants are likely present on the Lower Passaic River as well. Concentrations of 2,3,7,8-TCDD in sediments just upriver of the Dundee Dam are approximately 40 times less than concentrations below the dam; therefore, the Upper Passaic River is likely *not* the source of this contaminant to the Lower Passaic River.

The surface sediment concentrations were further examined by constructing scatter plots that included the 1995 TSI dataset and the 2005 high resolution sediment cores for the Lower Passaic River as well as the 2005 low resolution sediment cores collected in Newark Bay.[22] These plots were supplemented with concentrations from the literature, when available. Figure 6-3 presents the combined datasets of surface sediment concentrations for cadmium, copper, lead, mercury, Total PCB, and 2,3,7,8-TCDD. Table 6-3 provides statistics on these concentrations. Because the various studies were designed to fulfill different DQOs, the results plotted in Figure 6-3 (and summarized in Table 6-3) reflect various depositional environments in the Lower Passaic River. For

[22] The Malcolm Pirnie, Inc. 2006 low resolution cores collected for USEPA on the Lower Passaic River were not incorporated into Table 6-3 because the tops of the cores were not finely sliced, resulting in a lack of temporal resolution.

example, the 2005 high resolution cores and the Bopp *et al*. cores were collected in consistently net depositional environments and have datable core top segments. The 1995 and 2005 TSI samples were collected from both net depositional and non-depositional locations along a grid pattern; hence, most of the 0-6 inch depth sediment samples are not temporally well-constrained. Samples from the various depositional environments are plotted on one figure to illustrate the range of surface sediment concentrations over the past 2 decades in the Lower Passaic River (from 1985-1986 to 1995 to 2005) and to discuss surface sediment gradients from the Lower Passaic River to Newark Bay in 2005.

Table 6-3: Summary of Surficial Sediment Concentrations from Dundee Dam to Newark Bay

Analyte	Newark Bay 2005 [a,b]	Lower Passaic River 1995 [a,c]	Lower Passaic River 2005 [a,d]	Dundee Dam Sediment Core Top (1985-1986 time horizon) [a,e]
Cadmium (mg/kg)	2.3 ±3.4 (N = 67)	5.1 ±3.1 (N = 95)	3.5 ±0.68 (N = 5)	4.2
Copper (mg/kg)	150 ±130 (N = 67)	230 ±250 (N = 95)	150 ±29 (N = 5)	120
Lead (mg/kg)	160 ±160 (N = 67)	330 ±150 (N = 90)	209 ±39 (N = 5)	307
Mercury (mg/kg)[f]	3.4 ±9.5 (N = 67)	3.3 ±1.9 (N = 92)	1.7 ±0.55 (N = 5)	1.8
Total PCB (μg/kg)[g]	750 ±1,100 (N = 67)	1,300 ±1,800 (N = 90)	280 ±61 (N = 5)	480
2,3,7,8-TCDD (ng/kg)	64 ±80 (N = 67)	830 ±2,000 (N = 95)	480 ±430 (N = 5)	20
Ratio of 2,3,7,8-TCDD/Total TCDD	0.4 ±0.1 (N = 67)	0.7 ±0.1 (N = 95)	0.7 ±0.1 (N = 5)	NA

a: Arithmetic average and standard deviation (± 1 sigma) based on a normal distribution of sample size; nondetected values are incorporated into the average as half the reported detection limit. Results rounded to two significant figures, whenever possible.
b: The 2005 TSI Newark Bay dataset represents surficial sediment (0 to 6 inches) collected from net depositional and net non-depositional sampling locations.
c: The 1995 TSI Lower Passaic River dataset represents surficial sediment (0 to 6 inches) collected from net depositional and net non-depositional sampling locations.
d: The 2005 Malcolm Pirnie, Inc. dataset represents surficial sediment dating from 2003-2005 based on the estimated age of the surface layers used.
e: Literature data
f: This average excludes the one elevated value in Port Newark of 77 mg/kg.
g: Total PCB for the 2005 Newark Bay data and the 2005 Lower Passaic River data were calculated as the sum of congeners, (209 congeners and 159 congeners, respectively). The 1995 Lower Passaic River data and the Dundee Dam data represent the sum of Aroclors.

The 2005 field data provide further insight into the processes occurring within the Lower Passaic River since data are available at RM11 and RM12.6 and in Newark Bay. For the metals and Total PCB, the 2005 surficial sediment concentrations at RM11 and RM12.6 are comparable to those at RM1.4 and RM2.2. The close agreement among all the high resolution core surface samples can be observed in the small standard deviation relative to the mean values. The close agreement among the sediment core tops has important implications for tidal mixing.

In addition, the average 2005 surface concentrations for metals and Total PCB are also comparable to solids collected above the Dundee Dam from 1985-1986, implying that the Upper Passaic River may still be contributing a significant portion of the load for these contaminants to the Lower Passaic River (assuming that the contaminant load has not changed over time).[23] Local sources on the Lower Passaic River may also contribute to the contaminant load, resulting in higher surface concentrations in the Lower Passaic River relative to those above the Dundee Dam.

A distinct concentration gradient is shown to extend out of the mouth of the Lower Passaic River and into Newark Bay for several contaminants (based on the data collected in 2005), suggesting that Newark Bay is not contributing a contaminant load to the Lower Passaic River in these cases. Further analysis of the newly available data for the Lower Passaic River and Newark Bay is warranted since some contaminants exhibit a sharp decline to Newark Bay (*e.g.*, 2,3,7,8-TCDD) while others do not (*e.g.*, Total PCB and mercury). Analysis of this information will provide a rigorous constraint on the volume of suspended matter that Newark Bay currently contributes to the Lower Passaic River. This analysis will serve as an important constraint on the numerical simulation of transport between the two water bodies.

6.2.2 TIDAL MIXING OF SEDIMENTS

The 2,3,7,8-TCDD concentration and the ratio of 2,3,7,8-TCDD/Total TCDD are fairly uniform along the Lower Passaic River (Figure 6-3e and Figure 6-3f); however, as discussed in Section 2.2.1 "Relationship of the Lower Passaic River with the Estuary,"

[23] At the time of this writing, high resolution cores have been collected above the Dundee Dam and are being analyzed to assess potential changes in contaminant load over the past two decades.

2,3,7,8-TCDD does not have an upriver source. The uniform surface concentrations suggest that tidal mixing is impacting sediment quality along the length of the Lower Passaic River, even as far upriver as RM11 and RM12.6. The similarity in sediment concentrations of 2,3,7,8-TCDD as well as other contaminants among core tops considered to represent 2003-2005 deposition shows that sediments are homogenized over at least a distance of 11 miles (RM1.4 to RM12.6) prior to deposition. This also indicates that contaminant releases downriver are transported upriver at least as far as RM12.6.

Salinity data presented in Section 3.2 "Salinity Data Available to Define the River Sections" define the Transitional River Section between RM6 and RM10; however, the salinity data also indicate that the salt front seasonally extends beyond RM10. Apparently the upriver excursion is sufficiently frequent or the tidal velocities are sufficiently strong so as to transport and homogenize the sediments at least as far as RM12.6, the location of the upriver-most core. The geochronological profiles of 2,3,7,8-TCDD and other contaminants over the past 60 years are very similar in absolute concentration and in historical trends for the three high resolution sediment cores (collected at RM1.4, RM2.2, and RM11; Figure 6-4). For 2,3,7,8-TCDD, for example, each core documents the low levels present prior to the 1950s (<1 ng/kg), with levels increasing to peak concentrations in the late 1950s and early 1960s (10,000 ng/kg), and then declining to the 2005 concentration (400 ng/kg). The recent concentration decline likely reflects the cessation of major external loads to the Lower Passaic River while showing the ongoing re-release of previously contaminated and deposited sediments.

A related plot showing the ratio of 2,3,7,8-TCDD/Total TCDD is provided in Figure 6-5. Here, the diagnostic ratio of the Lower Passaic River (0.7 ±0.1; Malcolm Pirnie, Inc., 2006a and Chaky, 2003) is observed in the three cores from the 1950s to 2005. The cores also provide a consistent picture prior to 1950 as the 2,3,7,8-TCDD/Total TCDD ratio and the 2,3,7,8-TCDD concentration in each core declines to levels more typical of atmospheric deposition and sewage discharge (Chaky, 2003). The rigorous mixing of sediments in the Lower Passaic River prevents a simple identification of the source area by eliminating local concentration gradients. While the number of samples above the dam from which to draw conclusions are limited, the region upriver of the Dundee Dam does not contribute substantially to the concentrations of 2,3,7,8-TCDD in sediments of the Lower Passaic River, as noted above in Section 6.2.1 "Surface Sediment Concentrations and Gradients." The absence of substantial upriver contributions and the data presented in Figures 6-4 and 6-5 suggest that a single source (or at least a single source type) has generated the 2,3,7,8-TCDD contamination to the Lower Passaic River for the past 55 years.

6.2.3 SHOAL CONTAMINATION

The "shoals" are defined as areas located outside the footprint of the authorized dimensions of the federal navigation channel but below MLW. As a result of tidal currents and hydrologic events, solids are exchanged between shoal and channel, upriver and downriver, through resuspension and deposition processes. The shoals, like the channel, have been subject to extensive deposition as a result of dredging. As part of the construction of the channel itself, the channel walls were either purposefully sloped or the slopes formed as a result of material slumping into the channel. In either case, areas outside the authorized channel footprint were made deeper by the creation of the channel. Additionally, ship traffic needed berths along the river in order to deliver or accept goods from local facilities. To satisfy this, berths would likely have been dug out to the river's edge, locally deepening the shoal. Consequently, various dredging activities would have deepened the shoals in a more haphazard fashion than the channel. With the ensuing lack of channel maintenance, the shoals, like the channel, have filled in with river sediment. Like sediments in the channel, these sediments are extensively contaminated. This scenario is supported by the depth of contamination observed in numerous cores outside the authorized channel boundary.

As further discussed in Section 7.3 "Estimates of the Volume of Contaminated Sediment and the Associated Mass of Contaminants" in this document and in Section 5.2 "MPA Approach" of the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a), the average measured depth of contamination in the sediments (which was estimated using historical mercury data) is approximately 9 feet. This average depth incorporates sediment cores collected in the channel and on the shoals of the Lower Passaic River but does not correct for historical cores that showed incomplete concentration profiles.[24] In fact, the average depth of contamination is actually deeper than 9 feet since 48 percent of the historical mercury cores were incomplete with a rising concentration gradient at the bottom of the core. The need to extrapolate these cores to greater depths, either by sampling or by estimation, in order to characterize the complete thickness of contamination virtually guarantees that the actual average depth is greater than 9 feet. The average depth of contamination based on mercury, and accounting for incomplete cores, was estimated to be 13 feet as of 1995, the time of the largest sediment survey.

To investigate the potential depth of contamination in the shoals, historical low resolution cores located outside the authorized federal navigation channel were identified based on their geographical coordinates. Downcore profiles of mercury were then constructed for these selected shoal cores.[25] Of the 59 shoal cores identified, approximately half showed complete mercury concentration profiles (the same percentage observed for the entire river). For these complete cores, the average depth of contamination in the shoals is known, approximately 7 feet (minimum depth of 0.1 foot and maximum depth of 19 feet). Conversely, the other half of the cores showed incomplete mercury concentration profiles; therefore, the depth of contamination is unknown but is greater than the depth of the core bottom. For these incomplete cores, the bottom of the collected core was 7 feet on average, suggesting that the depth of contamination is greater than 7 feet at these incomplete coring locations. This value (7 feet) is slightly shallower than the depth of contamination in the river as a whole (9 feet), but given the uncertainty in both estimates

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[24] An incomplete sediment core profile is defined as a core in which the concentration in the bottom segment is not equal to background concentrations, or post-industrial conditions. Hence, the contaminant inventory at that sampling location is uncertain. Incomplete sediment cores result from the presence of dredge horizons or cores that do not penetrate deep enough into the sediment bed.

[25] Mercury was selected as a surrogate to identify depth of contamination because mercury contamination occurs deeper in the sediment bed relative to 2,3,7,8-TCDD and Total PCB (Malcolm Pirnie, Inc., 2006a).

due to the large percentages of incomplete cores, the difference between shoal contamination depth and that of the entire river may not be significant.

6.3 WATER COLUMN: CONTAMINATED MEDIUM

The water column serves as a means for the transport and dispersal of contaminants throughout the Lower Passaic River. Consequently, the water column is not a potential source area but rather a medium whose inventory is transient and regularly replaced and replenished. The water column inventory at any moment represents a dynamic balance of the various loads and sinks connected to the water column.

The current understanding of typical water column conditions and loads is particularly limited by the lack of available water chemistry data. In 2005, Malcolm Pirnie, Inc. deployed semi-permeable membrane devices and collected small-volume and large-volume water column samples along the main stem of the Lower Passaic River and at the confluences of the major tributaries. (An evaluation of these data has not been completed.) Historical water chemistry data were discussed in the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a) and are summarized below. [Refer to Section 4.7 "Water Column and Biota Evaluations," Appendix C, and Appendix D of the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a) for more information.]

- For mercury, lead, Total PAH, Total PCB, and Total DDT, the suspended-phase concentrations approximate the surficial sediment concentrations, demonstrating the close link between the two media, presumably as the result of tidally driven resuspension and settling.
- In general, contaminants in the water column were primarily borne by the suspended solids as opposed to the dissolved-phase.
- The suspended solids and dissolved-phase both have a 2,3,7,8-TCDD/Total TCDD ratio of approximately 0.5 to 0.8, similar to that observed in the surface sediments of the Lower Passaic River, as would be expected given the close link between the two media.

6.4 GROUNDWATER: CONTAMINATED MEDIUM

Groundwater represents another potential contaminant source area to the Lower Passaic River. Groundwater may impact surface water quality in two ways: (1) by carrying chemicals from nearby groundwater contamination sites to the surface water body; and (2) by displacing contaminated porewater contained within the sediments. Some studies have also shown that low molecular weight organic chemicals (such as solvents) dissolved in groundwater can mobilize heavier compounds having high soil-water partition coefficients (Huling, 1989).

The potential for groundwater that is discharging to the Lower Passaic River to be contaminated with lighter, organic compounds has not been evaluated. Several documented groundwater contamination sites are located adjacent to the river, so a strong likelihood exists that contaminated groundwater is discharged to the river. There is also anecdotal support for the existence of such contamination, such as observations of solvent odors by the Malcolm Pirnie, Inc. field team staff when processing the low resolution sediment cores (January 2006). The effect of these solvents on the mobilization of heavier hydrophobic compounds cannot be evaluated without knowledge of their distribution and concentration. Moreover, analyses of groundwater contaminant sources and transport mechanisms need to be conducted to assess groundwater's contribution to the river's contaminant load.

To begin to understand the impacts of contaminated groundwater to the Lower Passaic River, an evaluation was done to quantify the volume of water in the Lower Passaic River that originates as groundwater. The groundwater contribution to a river's flow is termed "base flow." When precipitation falls within a river's drainage area (or watershed), the majority of the water evaporates, flows overland to the river, or is removed by plants in transpiration. However, some water infiltrates to the groundwater table and flows underground until the water enters the river through the sediment bed. Because the underground flow encounters greater resistance than the overland flow, groundwater flows more slowly. Consequently, any groundwater surges from storm events are usually 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.

The base flow to the Lower Passaic River was calculated using a water budget and subtracting out other additions to the river flow (refer to Attachment B for calculation). Because no gauging station exists on the Lower Passaic River, three nearby gauges (located in similar watersheds) were used as surrogates to estimate the base flow. The observed flow rates from these gauging stations were divided by their respective drainage areas to calculate the amount of the annual precipitation within the watershed that may enter the river as groundwater, resulting in a groundwater recharge value per unit area. Because the climate, soil type, land use and geologic setting for these watersheds are comparable, the calculated recharge values are similar to one another. The recharge values were averaged and then applied to the Lower Passaic River. When the recharge value was multiplied by the drainage area of the Lower Passaic River, the groundwater contribution was calculated to be about 20 cfs, which is more than 50 times less than the average river flow of 1,150 cfs over the Dundee Dam. The base flow is roughly equivalent to the flow from the Second River or Third River, small tributaries to the Lower Passaic River.

Given the high organic content of Lower Passaic River sediments and the potential for suspension and remobilization of large quantities of hydrophobic compound-laden sediments by erosion as a riverine process, it is unlikely that groundwater contaminant flux, even with enhanced transport potential from dissolved organic compounds, will approach the magnitude of the hydrophobic contaminant contribution presented by sediment resuspension and transport. However, the groundwater transport mechanisms are not quantified by field data, so their relative importance cannot be confirmed.

7.0 CONTAMINANT FATE AND TRANSPORT

7.1 FATE AND TRANSPORT MODEL

A preliminary fate and transport model for the Lower Passaic River is presented in Figures 7-1 and 7-2. This model will be refined when the results of the problem-formulation phase of the BERA are available. The preliminary model presented in Figures 7-1 and 7-2 depicts the movement of chemicals between the sediment, water column, and air through a series of reactions and pathways to achieve equilibrium. Certain bioavailable, hydrophobic chemicals will also partition from either the sediment or water column into biological tissue. Depending on the chemical nature of these bioavailable chemicals, they may bioaccumulate in the food web, resulting in higher tissue concentrations in higher trophic level receptors.

The abiotic reactions and pathways are presented in Figure 7-1 as black arrows; biological pathways are added to this underlying graphic as green arrows and are presented in Figure 7-2. [For a discussion of biological exposure pathways and receptors, refer to the *Pathways Analysis Report* (Battelle, 2005) and the revised figures presented in Attachment D.] The chemical state (*i.e.*, sorbed chemical, dissolved chemical, or vapor) is denoted in the boxes, which represent inventory, while mechanisms are represented by arrows connecting associated boxes, as appropriate. Identification of complete exposure pathways, ecosystems potentially at risk, assessment endpoints, risk hypotheses, risk questions, and measurement endpoints as well as the refined list of COPECs, their effects, fate, and transport will be provided at the end of the problem-formulation phase of the BERA.

Figure 7-1 and Figure 7-2 portray general reactions and pathways that may occur in the Transitional River Section; however, some reactions and pathways may be absent or less significant for certain chemicals and for certain river sections. Potential mechanisms influencing fate and transport of a given chemical in the water and air include advection, flocculation (aggregation) or disaggregation, sorption or desorption, degradation, volatilization, and/or deposition. In the sediment, the potential mechanisms include sorption or desorption, resuspension, degradation, potential burial or bioturbation, and transformations. In biota, the potential mechanisms are bioconcentration and bioaccumulation.

7.2 NATURE AND EXTENT OF CONTAMINATION

The main contaminant transport mechanism for most contaminants in the Lower Passaic River is resuspension and settling of contaminated solids. As these solids move through the Study Area, they become incorporated into the sediment beds throughout the river and into Newark Bay. Geochemical and geochronological analyses of sediment chemistry data can then describe the nature and extent of contamination in the Study Area. The *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a) discusses the nature and extent of contamination for several contaminants in the Lower Passaic River. General geochemical observations include:

- The Lower Passaic River is a dynamic system with areas of net erosion intertwined and adjacent to areas of net deposition. Sediment transport is primarily driven by the twice-daily tidal mixing that causes surface sediments to resuspend and redeposit.
- The high degree of spatial heterogeneity exhibited in the coring data (RM0.9 to RM7) with respect to contaminant inventory suggests that localized areas of relatively higher concentrations typically described as “hot spots” do not exist in the Lower Passaic River. That is, local variation is so great that local deposits of significant inventory (as identified by several adjacent cores) are not apparent. Instead, “hot regions” of the river typically exist on the scale of a mile or more, nearly bank to bank in lateral extent. However, this conclusion does not diminish the significance of potential historic and/or current point sources as the origin of contaminant inventory in the Lower Passaic River. Estuarine mechanisms are believed to quickly render contaminant concentration gradients indistinct on the scales examined here. Nonetheless, it is possible that environmental sampling on a finer scale (on the order of less than a quarter mile) would identify localized

gradients near prominent historical and/or current source areas. For example, evidence of a local source is suggested by two sediment cores (TSI cores 285 and 286; 1995 TSI dataset) on the southern shore of RM3.1.

- Dated sediment cores from the Upper Passaic River and Lower Passaic River were used to differentiate the source area for several major contaminants. These cores suggest that the major historical loads of cadmium, lead, mercury, and Total PCB originated in the Upper Passaic River above the Dundee Dam. A substantial load of copper was shown to have originated above the Dundee Dam, but an additional load was also shown to have been present below the dam in 1995. Smaller contaminant source areas, particularly for mercury, may also have existed in the Lower Passaic River (RM0.9 to RM7).
- Surface sediment data in the RM3.5 to RM4 region had a relatively high density of elevated values, occurring for several contaminants, although this observation was not statistically significant. Bathymetric data show that this region has a higher density of locations undergoing net erosion, re-mobilizing sediment, and exposing older, more-contaminated sediments. The consistent occurrence of these elevated values for several contaminant types tends to rule out the possibility of an ongoing external source since it would need to include all the major contaminants.

In the following sections, chemical-specific (mercury, lead, 2,3,7,8-TCDD, Total PCB, Total DDT, and Total PAH) discussions on the nature and extent of contamination are presented. The sediment bed schematic presented in Figure 7-3 accompanies this discussion. Mercury, lead, 2,3,7,8-TCDD, Total PCB, Total DDT, and Total PAH were selected for illustrative purposes only to describe the nature and extent of contamination and represent examples of the general contaminant classes present in the Study Area. These chemicals were originally presented in the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a). The CSM will be updated with site-specific COPCs and COPECs after the problem-formulation phase of the BERA is completed.

7.2.1 MERCURY CONTAMINATION

Dated sediment cores from the Upper Passaic River and Lower Passaic River and an examination of metals ratios suggest that the major historical mercury loads primarily originated in the Upper Passaic River above the Dundee Dam. An examination of the 1995 surface sediments in the Lower Passaic River suggests that at least two mercury source areas were present in 1995: one at or below RM1 and one at or above RM7 (which may be the same as the source area above Dundee Dam). Dated sediment cores show a similar condition for mercury in 1963. Peak mercury concentrations appear to have occurred in the 1960s or earlier. Dated sediment cores from the TSI 1995 dataset were insufficient to establish the depth of contamination for mercury; however, analysis of the 2006 low resolution sediment cores indicated that the sand layer underneath the fine-grained sediment beds was contaminated with mercury as well as other metals and Total PAH. The presence of mercury and the other contaminants at this depth suggests that they may have been present in the Lower Passaic River since the time of the original construction of the navigational channel.

7.2.2 LEAD CONTAMINATION

Like mercury, major lead contamination in the Lower Passaic River occurred in the 1960s or earlier. Elevated concentrations of lead (approximately 700 mg/kg) occur at depth in dated sediment cores from the TSI 1995 dataset, usually reaching a maximum at the core bottom. This evidence indicates that the vertical extent of lead (as well as other metals, such as arsenic, chromium, copper, cadmium, and mercury) is undefined for nearly all of the 1995 TSI cores. The 2006 low resolution sediment cores indicated that the sand layer underneath the fine-grained sediment beds was contaminated with lead as well as mercury, other metals, and Total PAH. Major inventories of lead and other metals most likely lie below the documented depth of 2,3,7,8-TCDD contamination. An examination of metals ratios in dated sediment cores and surface sediment samples further supports the origin of the Lower Passaic River lead contamination above the Dundee Dam (Malcolm Pirnie, Inc., 2006a). Further information on metal contaminants (including cadmium and copper) in the Lower Passaic River can be found in the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a).

7.2.3 2,3,7,8-TCDD Contamination

Consistent with the observations by Bopp *et al*. (1991a) and Chaky (2003) for Newark Bay, dated sediment cores from the 1995 TSI dataset (RM0.9 to RM7) show that the major releases of 2,3,7,8-TCDD began in the late 1940s to early 1950s and peaked in the late 1950s to early 1960s. Dated sediment cores from the Upper Passaic River and Lower Passaic River further indicate that much less than 1 percent of the 2,3,7,8-TCDD contamination in the Lower Passaic River originated above the Dundee Dam historically. The Upper Passaic River remains a trivial source of 2,3,7,8-TCDD to the Lower Passaic River despite the passage of time.

The diagnostic ratio of 2,3,7,8-TCDD/Total TCDD of 0.7 can be used to trace Lower Passaic River 2,3,7,8-TCDD throughout the Newark Bay complex and over the last 60 years. Based on dated sediment cores, this diagnostic ratio is observed throughout the sediments of the Lower Passaic River as far back as the 1950s. Prior to 1950, however, the 2,3,7,8-TCDD/Total TCDD ratio declines to a value of 0.1, approaching the value of 0.06, which is characteristic of sewage and atmospheric fallout (Chaky, 2003). The 2006 low resolution sediment cores indicated that the sand layer underlying the fine-grained sediment beds is not contaminated with 2,3,7,8-TCDD.

7.2.4 Total DDT Contamination

Dated sediment cores reveal that Total DDT contamination in the Lower Passaic River began in the 1930s, peaking in the late 1940s or early 1950s, consistent with the observations of Bopp *et al.* (1991a). Results consistently show measurable Total DDT concentrations occurring deeper in the sediment core than measurable 2,3,7,8-TCDD concentrations. Dated sediment cores from the Upper Passaic River and Lower Passaic River further indicate that, *circa* 1995, a small proportion, perhaps one quarter of the input of the Total DDT contamination in the Lower Passaic River, originated above the Dundee Dam. The observation relating the Upper Passaic River to the Lower Passaic River is tempered by the fact that measurements of Total DDT above the Dundee Dam were limited to only one form of DDT, specifically DDD. Thus, the total amount of DDT and its derivatives was not measured.

7.2.5 TOTAL PCB CONTAMINATION

Total PCB contamination is distributed throughout the Lower Passaic River with peak concentrations (4 to 18 mg/kg) occurring in the sediments dating to the 1960s or later. Hence, the extent of Total PCB contamination in the sediment beds is shallow when compared to mercury, lead, 2,3,7,8-TCDD, and Total DDT. Aroclor 1248 is the most commonly reported PCB mixture, typically comprising 60 percent or more of the Total PCB burden. Dated sediment cores from the Upper Passaic River and Lower Passaic River suggest that the major historical loads of Total PCB primarily originated in the Upper Passaic River above the Dundee Dam. In 1963, the Total PCB input upriver of the Dundee Dam accounted for the majority of the Total PCB load in the Lower Passaic River. However, evidence suggests that recently (*circa* 1995), the Upper Passaic River Total PCB input has become less important relative to Lower Passaic River Total PCB load. Nevertheless, the Upper Passaic River source area may still comprise one-third of the Total PCB loading in the Lower Passaic River. Evidence also suggests that in 1995 at least one source area existed in the Lower Passaic River for Total PCB (Malcolm Pirnie, Inc., 2006a).

7.2.6 TOTAL PAH CONTAMINATION

Total PAH contamination is unique in its temporal distribution, with the highest concentrations observed in the deepest core layers, gradually declining to the most recent deposition. The presence of Total PAH contamination in the sand layer underneath the thick silt deposits may represent historic deposition or alternatively a contaminated groundwater source.

Ratio analysis of Total PAH shows that the majority of PAH contamination in the sediments is derived from combustion-related processes (Malcolm Pirnie, Inc., 2006a). The ratio “fingerprint” suggests that Total PAH originates from two sources: coal tar residue (a by-product of manufactured gas plants) and urban background combustion. Of these sources, coal tar wastes are the dominant source to the Lower Passaic River based on the prevalence of coal tar-like PAH ratios in more-contaminated sediments. The same analysis essentially rules out creosote-derived contamination and suggests that only minor portions of the sediment PAH contamination are derived from a petrogenic source (*e.g.*, oils spills).

7.3 ESTIMATES OF THE VOLUME OF CONTAMINATED SEDIMENT AND THE ASSOCIATED MASS OF CONTAMINANTS

7.3.1 ESTIMATES OF THE VOLUME OF CONTAMINATION

The combination of the navigational dredging activities and the long and extensive history of contaminant discharges to the Lower Passaic River have served to create a uniquely large inventory of highly contaminated sediments contained within a relatively small area. Other major Superfund sites may have similar volumes of contaminated sediments [*e.g.*, Hudson River PCB site at 2.6 million cubic yards (USEPA, 2002) and Fox River PCB site at 8 million cubic yards (USEPA, 2003a)], but these inventories are spread over much greater distances than the 17 miles of the Lower Passaic River. While data are not sufficient to assess the volume of contaminated sediment for the entire Lower Passaic River, the volume is estimated at 5 to 8 million cubic yards for RM0.9 to RM7, with an average depth of contamination ranging from 7 to 13 feet. The evidence from the side-scan sonar and bathymetric surveys suggests that the conditions observed in RM0.9 to RM7 probably also apply over the area of RM0 to RM8, suggesting that the actual inventory of contaminated sediments is at least one-third greater than the values obtained in the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a). The volume of 2,3,7,8-TCDD-contaminated sediments is somewhat smaller than the overall contaminated sediment volume, since several contaminants are present at greater depths than 2,3,7,8-TCDD. The estimate of 2,3,7,8-TCDD-contaminated sediment volume ranges from 5 to 6.5 million cubic yards for RM0.9 to RM7.

The mass of contaminants contained within the sediments is also quite large (Table 7-1). Moreover, the mass of 2,3,7,8-TCDD represents one of the largest site inventories in the United States.

Table 7-1: Summary of Contaminant Inventory Estimates for RM0.9 to RM7

Inventory Estimate [a]	Total DDT (metric tons)	2,3,7,8-TCDD (kilograms)	Mercury (metric tons)	Total PCB (metric tons)
Based on measured core intervals only	6.4	20	24	6
Based on measured and extrapolated core profiles	11	29	37	8
Percent Increase [b]	72 percent	45 percent	54 percent	33 percent

a: Based on information provided in *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a).
b: Percent increase is relative to the interpolated mass estimate.

Uncertainties are associated with these estimates, which arise from the lack of horizontal coverage and lack of "completeness" in the vertical direction. As mentioned above, the physical survey data suggest that at least two additional miles (RM7 to RM8 and RM0 to RM0.9) of the Lower Passaic River may contain substantive inventories (extrapolation uncertainty). Additionally, large distances exist between many of the cores located within RM0.9 to RM7, adding some uncertainty to the estimated volumes; however, the direction of any correction is not known (interpolation uncertainty). Finally, many of the cores used in the estimates were not "complete," or they did not penetrate and capture the entire sequence of contaminated sediments (vertical extrapolation uncertainty). These cores were extrapolated based on profiles observed in other cores. The range in volume estimates given above (5 to 8 million cubic yards) reflects the uncertainty related to horizontal interpolation and vertical extrapolation, with the lower value based only on the measured core intervals, and the larger value incorporating the vertically extrapolated mass estimates. This range does not include the volume related to horizontal extrapolation from RM7 to RM8 and from RM0 to RM0.9.

To estimate the sediment volume from RM7 to RM8 and from RM0 to RM0.9, the conditions in the one-mile lengths of river adjacent to these stretches were extrapolated. Extrapolation was performed on the basis of surface area of the river. Thus, the average depth of sediment and the average MPA in these adjacent one-mile lengths were applied to the surface area of these stretches. These calculations were performed for mercury to obtain the total volume of contaminated sediment as well as the entire mass of mercury, because mercury is one of the oldest (deepest) contaminants (Table 7-2). They were also performed for 2,3,7,8-TCDD to obtain an estimate of the 2,3,7,8-TCDD inventory for the lower 8 miles in total (Table 7-3).

Table 7-2: Estimated Mass and Estimated Volume of Mercury-Contaminated Sediments

Analyte	Average Extrapolated MPA (g/m^2)	Extrapolated Mercury Mass (kilograms)	Average Extrapolated Depth (feet)	Extrapolated Volume of Sediment (cubic yards)
RM0 to RM0.9	23	7,400	14	1,800,000
RM0.9 to RM7	19	37,000	13	6,500,000
RM7 toRM8	22	5,500	12	1,200,000
Total RM0 to RM8	**20**	**50,000**	**13**	**9,500,000**
RM8 to RM15 [a]	14	4,900	11	1,500,000
RM8 to RM15 [b]	5.2	1,800	4	550,000

a: Values were calculated for the fine-grained sediments only by assuming the average extrapolated mass per unit area and depth of contamination from RM6 to RM7. The inventory in the coarse-grained sediment was not calculated.
b: Values were calculated assuming average depth of contamination of approximately 4 feet based on the geotechnical and high resolution cores collected above RM8.

Table 7-3: Estimated Mass and Estimated Volume of 2,3,7,8-TCDD-Contaminated Sediments

Analyte	Average Extrapolated MPA (mg/m^2)	Extrapolated 2,3,7,8-TCDD Mass (kilograms)	Average Extrapolated Depth (feet)	Extrapolated Volume of Sediment (cubic yards)
RM0 to RM0.9	6.5	2	12	1,500,000
RM0.9 to RM7	19	29	11	6,500,000
RM7 toRM8	11	2.4	7.8	660,000
Total RM0 to RM8	**16**	**33**	**11**	**8,700,000**
RM8 to RM15 [a]	8.5	2.9	11	1,200,000
RM8 to RM15 [b]	3.1	1.1	4	550,000

a: Values were calculated for the fine-grained sediments only by assuming the average extrapolated mass per unit area and depth of contamination from RM6 to RM7. The inventory in the coarse-grained sediment was not calculated.
b: Values were calculated assuming average depth of contamination of approximately 4 feet based on the geotechnical and high resolution cores collected above RM8.

The inventory for RM0 to RM0.9 was estimated using the average MPA, the depth of contamination, and the actual surface area from RM0.9 to RM1.9. The surface area of RM0.9 to RM1.9 was used as a basis to limit the horizontal spread of the estimate where the river widens at its mouth into shallow, non-channel areas, which are unlikely to be contaminated at depth. The inventory for RM7 to RM8 was estimated using the average MPA and the depth of contamination for RM6 to RM7, but using the actual surface area between RM7 and RM8. Based on the inventories estimated from RM0 to RM0.9, RM0.9 to RM7 (Table 7-2 and Table 7-3), and RM7 to RM8, the estimated volume of contaminated sediment from RM0 to RM8 thus calculated approaches 10 million cubic yards. This estimate represents an increase of 25 to 50 percent over the original estimates of contaminated sediments in RM0.9 to RM7. The inventory of mercury in the sediments between RM0 to RM8 is estimated at 50,000 kilograms, and the inventory of 2,3,7,8-TCDD is estimated at 33 kilograms.

A separate inventory estimate was created for the region above RM8, based solely on the extent of fine-grained sediments as estimated from interpreted side-scan sonar images (Aqua Survey, Inc., 2006) and the depth penetrated by geotechnical cores collected in June 2005. In this region of the river, fine-grained sediments represent only about a third of the river bottom, as compared to more than 80 percent below RM8. Estimates of the MPA and the depth of contamination were obtained by using the mean values for these parameters based solely on the fine-grained areas in RM6 to RM7. The higher values given in Tables 7-2 and 7-3 use these mean values directly. The lower volume and mass estimates are obtained by multiplying the average MPA for RM6 to RM7 times the nominal thickness of fine-grained sediment determined from the geotechnical cores (*i.e.*, 4 feet). This estimate suggests that the fine-grained sediments outside of RM0 to RM8 represent only about 6 percent of the volume of contaminated sediment below RM8. No estimate of the inventory in coarse-grained areas was created due to lack of appropriate data.

7.3.2 DISTRIBUTION OF INVENTORY WITH RIVER MILE

The contaminant inventories are not evenly distributed and vary along the length of the Lower Passaic River, with maximum values occurring near the areas encompassing RM1 to RM2, RM3 to RM4, and RM6 to RM7. However, the coring data, which form the basis for these inventories, indicate a high degree of local spatial heterogeneity, suggesting that localized areas of relatively higher concentrations typically described as "hot spots" do not exist. Instead, "hot regions" of the river typically exist on the scale of a mile or more, nearly bank to bank in lateral extent. This conclusion does not, however, diminish the significance of potential historic and/or current point sources as the origin of contaminant inventory in the Lower Passaic River. Estuarine mechanisms are believed to quickly render contaminant concentration gradients indistinct on the scales examined here. It is possible that environmental sampling on a finer scale (on the order of less than a quarter mile) would identify localized gradients near prominent historical and/or current source areas. For example, evidence of a local source is suggested by two sediment cores (TSI cores 285 and 286; 1995 TSI dataset) on the southern shore of RM3.1.

Despite the observations of local spatial heterogeneity, the inventories of the four examined contaminants (mercury, 2,3,7,8-TCDD, Total PCB, and Total DDT) were shown to correlate, indicating that their inventories coincide in space and are consistent with the anticipated geochemical behavior of the compounds (Figure 7-4). Essentially, when a location has a locally high inventory of any one of these four contaminants, the other contaminants will also be concentrated at that location. It is anticipated that similar behavior will be exhibited by any hydrophobic compound in the Lower Passaic River. As noted previously, the variations in inventory are not believed to represent proximity to external point sources. Rather, variations in inventory may represent variations in the rate of deposition, with sites having higher rates of deposition generating larger contaminant inventories. Both the coring data and the bathymetric survey analyses performed for the Lower Passaic River suggest a high degree of spatial heterogeneity in inventory and deposition rate, supporting this premise.

7.4 INITIAL MASS BALANCE FOR THE LOWER PASSAIC RIVER AND NEWARK BAY

An initial mass balance for the Lower Passaic River and Newark Bay was documented in the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a). In this initial mass balance, contributions from non-point sources and floodplains were not considered because data gaps exist for the solids load and contamination from each of these source areas, and because they were not deemed likely to represent substantive contaminant sources. The mass balance estimates for Newark Bay involve the simultaneous balancing of solids, 2,3,7,8-TCDD, and Total TCDD, thereby forcing the mass balance parameters to reasonably predict all three constituents. The mass balance calculations used the work by Lowe, *et al.* (2005) as a starting point, and then adjusted various factors in order to achieve a mass balance for all three constituents. The premise of the mass balance is to equate the annual loads to Newark Bay with the average annual removal of solids and contaminants from Newark Bay by maintenance dredging activities. The results of the 2,3,7,8-TCDD mass balance calculations are discussed below. A mass balance analysis was also attempted for mercury based on the solids loads developed from the simultaneous 2,3,7,8-TCDD and solids balances (refer to Section 7.4.2 "Mercury Mass Balance").

7.4.1 2,3,7,8-TCDD Mass Balance

The ratio of 2,3,7,8-TCDD/Total TCDD is a conservative tracer of solids in the Study Area and Newark Bay. Fitting a mass balance to them provides a powerful constraint on the mass balance calculations since loads of both contaminants must be matched with the same set of solids inputs.

The mass balance results for 2,3,7,8-TCDD and Total TCDD are presented in Table 7-4 [excerpted from the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a)]. The total mass of 2,3,7,8-TCDD entering Newark Bay is approximately 14 grams/year, resulting in a calculated Newark Bay sediment concentration of 0.083 μg/kg. Since this calculated concentration approximates the measured 2,3,7,8-TCDD concentration, other major sources of 2,3,7,8-TCDD are unlikely, and the chemical mass balance is considered closed. Similarly for Total TCDD, the mass balance appears closed since the estimated surface concentration matches the measured concentration in Newark Bay. The balance is further verified by the estimated ratio of 2,3,7,8-TCDD/Total TCDD, which also matches the measured data. Based on the concurrent mass balances, the Lower Passaic River comprises approximately 10 percent of the total amount of solids accumulating in the Newark Bay and more than 80 percent of the 2,3,7,8-TCDD accumulating in the bay. No other single source delivers more than 10 percent of the total 2,3,7,8-TCDD load.

Table 7-4: 2,3,7,8-TCDD Mass Balance for Newark Bay

Source Area [a]	Solids Mass Balance [b]		2,3,7,8-TCDD Concentration	2,3,7,8-TCDD Annual Load	Total TCDD Concentration	Total TCDD Annual Load	Ratio of 2,3,7,8-TCDD to Total TCDD
	cubic yards/year	metric-tons/year	µg/kg [c]	grams/year	µg/kg [c]	grams/year	unitless
Passaic River (RM0.9 to RM7)	35,600	21,200	0.54	12	0.68	14	0.8
Mouth of Hackensack River	6,460	3,870	0.093	0.36	0.14	0.54	0.67
CSO/WWTP [d]	10,500	6,300	Unk [e]	Unk	Unk	Unk	Unk
Atmospheric Deposition	285	170	Unk	Unk	Unk	Unk	Unk
Kill van Kull	241,000	116,000	0.01 [f]	1.16	0.07	7.7	0.15
Arthur Kill	49,300	23,700	0.05	1.19	0.18	4.2	0.28
Total	343,000	171,000		14		26	
Newark Bay Calculated			**0.083**		**0.15**		**0.53**
Newark Bay Measured			**0.076**		**0.16**		**0.56**
Total Annual Load	**343,000 cubic yards/year**			**14 grams/year**		**26 grams/year**	

a: Excerpt from *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a).
b: Solids mass balance based on Lowe, *et al*. (2005) with several adjustments made to satisfy the chemical mass balance. Conversion of sediment volume to sediment mass as given by Lowe, *et al* (2005).
c: Concentrations represent average surface sediment concentrations for 1991 to 1995 sediments, unless otherwise noted.
d: WWTP = Wastewater treatment plant
e: Unk = unknown value. Mass fluxes for source areas within unknown values were set to zero for the chemical mass balance.
f. Concentration represents mean New York Bay sediments at the entry to Kill van Kull, 1994 to 1998 (Chaky, 2003).

7.4.2 MERCURY MASS BALANCE

Unlike the 2,3,7,8-TCDD and Total TCDD mass balances, the mercury mass balance required an additional, substantive mercury input to complete the balance [Table 7-5; excerpted from the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a)]. The total mass of mercury entering Newark Bay from known source areas is 259 kg/year. This annual load yields a calculated average Newark Bay sediment concentration for mercury of 1.5 mg/kg. The calculated average concentration is much less than the measured average mercury concentration of 2.4 mg/kg, indicating another mercury input. To complete the mercury mass balance, additional source(s) producing 150 kilograms per year (kg/year) are required to meet the measured Newark Bay sediment concentration of 2.4 mg/kg. Atmospheric deposition alone cannot account for the missing mercury load. Annual mercury precipitation fluxes in the State of New Jersey range from 11 to 14 micrograms/square meter/year (μg/m^2/yr; Reinfelder *et al.*, 2004). Using the highest flux, the amount of mercury delivered by the atmosphere to Newark Bay is approximately 250 grams/year, which is significantly less than the missing mercury load of 150 kg/year. Therefore, a significant, but currently unknown, source of mercury must exist on Newark Bay. This mercury source may be related to the exchange of particles from the Hackensack River, which is not accounted in the "net" solids mass balance of Table 7-5, alternatively it may be a local source.

Table 7-5: Mercury Mass Balance for Newark Bay

Source Area [a]	Solids Mass Balance [b]		Mercury Concentration	Mercury Annual Load
	cubic yards/year	metric-tons/year	mg/kg [c]	grams/year
Passaic River (RM0.9 to RM7)	35,600	21,200	3.4	73,000
Mouth of Hackensack River	6,460	3,870	4.0	16,000
CSO/WWTP	10,500	6,300	Unk [d]	Unk
Atmospheric Deposition	285	170	Unk	Unk
Kill van Kull	241,000	116,000	1.1	132,000
Arthur Kill	49,300	23,700	1.6	38,000
Total	343,000	171,000		259,000
Newark Bay Calculated			**1.5**	
Missing Mercury Input				**150,000**
New Newark Bay Calculated			**2.4**	
Newark Bay Measured			**2.4**	
Net Annual Load				**409,000 grams/year**

a: Excerpt from *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006a).
b: Solids mass balance based on Lowe, *et al*. (2005) with several adjustments made to satisfy the chemical mass balance. Conversion of sediment volume to sediment mass as given by Lowe, *et al.*, 2005.
c: Mercury concentrations represent average surface sediment concentrations for 1991 to 1995 sediments.
d: Mass fluxes for source areas within unknown values were set to zero for the chemical mass balance.

8.0 UNCERTAINTIES AND FUTURE UPDATES

The CSM presented in this document is based on geochemical, geophysical, and geotechnical data. Together, these data describe the fate and transport of contaminants in the river and the nature and extent of contamination. The quality and amount of data are sufficient to identify the processes occurring within the river, to advance the CSM considerably, and to support the ongoing project needs. However, data gaps do exist in the datasets, which consequently result in uncertainties within the CSM. For example, very limited field data exist for areas upriver of RM7 and between RM0 and RM1. Water column and hydrodynamic data are also incomplete for the Lower Passaic River. Other uncertainties involve the appropriate linkage of the human health and ecological exposure pathways and receptors (Battelle, 2005) to construct a comprehensive CSM.

Tables 8-1 and 8-2 summarize the known data gaps in the CSM and potential action that may occur to address these data gaps (based on source areas originally presented in Tables 6-1 and 6-2).

Table 8-1: Known Data Gaps and Uncertainties in the CSM for the Sediment Beds

Potential Source Area to Sediment Beds	Known Data Gaps	Potential Action to Address Data Gap
Transport of solids originating above Dundee Dam	• Limited data on solids transport over dam. • Data gap in current sediment chemistry above Dundee Dam.	• Evaluate November 2005 (Malcolm Pirnie, Inc.) small volume water column data. • Analyze and evaluate January 2007 (Malcolm Pirnie, Inc.) Dundee Lake high resolution cores.
Resuspension and erosion/deposition of solids due to tides	• Limited data on suspended solids in the river. • Data gap for magnitude of the process.	• Evaluate November 2005 (Malcolm Pirnie, Inc.) small volume water column data. • Evaluate available suspended solids data collected during the dredge pilot study (December 2005). • Evaluate 2005 (Malcolm Pirnie, Inc.) high resolution sediment cores. • Estimate gross resuspension and settling processes via model simulation.

Table 8-1 (continued)		
Transport of solids from Newark Bay	• Data gap for magnitude of solids exchange • Data gap between RM0 and RM1	• Evaluate data from the anticipated Phase 2 remedial investigation field work. • Additional sediment and water column sampling is expected to be implemented in the near future between RM0 and RM1. • Modeling analysis by HydroQual, Inc. is ongoing.
Resuspension and erosion/deposition of solids from tributaries	• Limited data on suspended solids in the tributaries. • Data gap in suspended solids and sediment chemistry from the tributaries	• Evaluate tributary suspended solids and chemistry data within November 2005 (Malcolm Pirnie, Inc.) small volume water column dataset.
Discharge of solids from non-point sources	• Data gap on solids from non-point sources.	• Evaluate data available under the CARP.
Discharge of solids from point sources	• Data gap on solids from point sources.	• Evaluate data available under the CARP. • A sampling program designed to collect water samples from CSOs and other outfalls to the Lower Passaic River is expected to be implemented in the near future.
Burial of surficial sediment to deep sediment beds	• Data limited to the 1989 and 2004 bathymetric surveys for upriver areas.	• Evaluation of sediment chronologies in high and low resolution sediment cores.
Resuspension and erosion/deposition on mudflats	• Limited sediment chemistry data on the mudflats. • Limited data on sediment transport on the mudflats.	• A mudflat sampling program is outlined in *Field Sampling Plan Volume 1* (Malcolm, Pirnie, Inc., 2006d).
Resuspension and erosion/deposition on floodplains	• Data gap on sediment chemistry and sediment transport on the floodplain.	• Modeling analysis by HydroQual, Inc. is ongoing.
Interactions between sediment, groundwater, and porewater	• Data gap on porewater and groundwater conditions	• This data gap necessitates field investigations of porewater contaminant transport. It is anticipated that the next round of field investigations will begin in the middle of 2007.
Remobilization of sediment due to floods		• Modeling analysis by HydroQual, Inc. is ongoing. • More rigorous analysis of bathymetric data in concert with hydrographic data is needed. • Storm-event suspended solids sampling is necessary.

Table 8-2: Known Data Gaps and Uncertainties in the CSM for the Water Column

Potential Source Area to the Water Column	Known Data Gaps	Potential Action to Address Data Gap
Main-stem flow originating above the Dundee Dam	• Data gap in water chemistry, suspended solids chemistry, and suspended solids load above dam.	• Evaluate November 2005 (Malcolm Pirnie, Inc.) small volume water column data. • Evaluate January 2007 Dundee Lake high resolution cores.
Tidal exchange with adjacent river sections	• Limited data available on tidal exchange volume and sediment load. • Data gap in water chemistry in Newark Bay.	• Evaluate November 2005 (Malcolm Pirnie, Inc.) small and large volume water column data. • Evaluate data from semi-permeable membrane devices deployed in 2005. • A regular, ongoing water column monitoring program for the Lower Passaic River is required. • Tidal exchange volume to be estimated via computer simulation of salinity data.
Discharge of water from tributaries	• Limited data available on tributary contribution of flow and chemistry.	• Evaluate November 2005 (Malcolm Pirnie, Inc.) small and large volume water column data. • Evaluate data from semi-permeable membrane devices deployed in 2005. • A regular, ongoing water column monitoring program for the Lower Passaic River tributaries is required.
Discharge and runoff of water from non-point sources	• Data gap in water chemistry and volume from non-point sources.	• Evaluate data available under the CARP.
Discharge of water from point sources	• Data gap in water chemistry from point sources.	• Evaluate data available under the CARP. • A sampling program designed to collect and analyze water samples from CSOs and other outfalls to the Lower Passaic River is expected to be implemented in the near future.
Exchange between porewater and water column	• Data gap for porewater conditions.	• Conduct field investigations of porewater contaminant transport.
Exchange between groundwater and water column	• Data gap for groundwater conditions.	• Conduct literature review of vicinity sites with known groundwater contamination; assess need for field investigations of groundwater discharge to the Lower Passaic River.
Atmospheric dry and wet deposition and volatilization	• Limited atmospheric data available for the region.	• Continue to evaluate data available through the New Jersey Atmospheric Deposition Network.

To address the current data gaps and uncertainties within the CSM, data should continue to be collected and evaluated. Moreover, as relevant data gaps are identified during further application of the CSM and the iterative DQO process, a procedure is needed for maintaining, refining, and updating the CSM to describe site-specific conditions. To accomplish this CSM refinement, appropriate study questions, including risk hypotheses and questions aimed at evaluating risk-based remediation, should continue to be posed. Then, historical data should be evaluated and appropriate field data collected to address the Study questions and to increase the understanding of the system. Due to the complexity of the Study, future iterations of the CSM may include separate models to highlight different aspects of the project. These individual models may focus on source areas, release mechanisms, and media. The CSM should also be refined to include the site-specific exposure pathways, measurement endpoints, assessment endpoints, COPCs, and COPECs that will be identified as part of the problem-formulation phase of the BERA.

9.0 ACRONYMS

BERA	Baseline Ecological Risk Assessment
CARP	Contaminant Assessment and Reduction Program
cfs	cubic feet per second
COPCs	Chemicals of potential concern
COPECs	Chemicals of potential ecological concern
CSM	Conceptual Site Model
CSOs	Combined Sewer Overflows
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
DQO	Data Quality Objective
g/m^2	grams per squared meter
kg/year	kilograms per year
mg/kg	milligrams per kilogram of sediment
mg/m^2	milligrams per squared meter
MLW	Mean Low Water
MPA	Mass per Unit Area
N	Sample Size
NA	Not available (refer to acronym used in table)
ng/kg	nanograms per kilogram of sediment
NGVD29	National Geodetic Vertical Datum of 1929
NJDEP	New Jersey Department of Environmental Protection
NJDOT	New Jersey Department of Transportation
NJPDES	New Jersey Pollutant Discharge Elimination System
OSWER	Office of Solid Waste and Emergency Response
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
PCDD/F	Polychlorinated Dibenzodioxins/furans

pCi/g	picocuries per gram of sediment
QAPP	Quality Assurance Project Plan
RM	River Mile
SVOC	Semivolatile Organic Compounds
2,3,7,8-TCDD	2,3,7,8-Tetrachlorodibenzo-p-dioxin
Total TCDD	Total Tetrachlorodibenzodioxin
TSI	Tierra Solutions, Inc.
Unk	Unknown (refer to acronym used in table)
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WWTP	Wastewater Treatment Plant
‰	parts per thousand or “per mil”
μg/kg	micrograms per kilogram of sediment
$\mu g/m^2/yr$	microgram/square meter/year

10.0 REFERENCES

Aqua Survey, Inc., 2006. "Technical Report: Geophysical Survey Lower Passaic River Restoration Project." Lower Passaic River Restoration Project. July 2006.

Aqua Survey, Inc., 2005. "Taxonomic Identification of Benthic Invertebrates from Sediment Collected in the Lower 17 Miles of the Lower Passaic River." September 2005.

Battelle, 2005. "Pathways Analysis Report." Lower Passaic River Restoration Project. July 2005.

Bopp RF, Chillrud SN, Shuster EL, and Simpson HJ, 2006. "Contaminant Chronologies from Hudson River Sedimentary Records." In: The Hudson River Estuary. J. Levinton and J. Waldman eds., Cambridge University Press, January 2006, Chapter 26: 383-397.

Bopp RF, Chillrud SN, Shuster EL, Simpson HJ, and Estabrooks FD, 1998. "Trends in Chlorinated Hydrocarbon Levels in Hudson River Basin Sediments." Environ. Health Perspect. 106, Supplement 4, 1075-81.

Bopp RF, Gross ML, Tong H, Simpson HJ, Monson SJ, Deck BL, and Moster FC, 1991a. "Sediment sampling and radionuclide and chlorinated hydrocarbon analysis in Newark Bay and the Hackensack and Passaic Rivers." Report to New Jersey Department of Environmental Protection, Division of Science and Research Contract P24096, March 31, 1991.

Bopp RF, Gross ML, Tong H, Simpson HJ, Monson SJ, Deck BL, and Moster FC, 1991b. "A major incident of dioxin contamination: sediments of New Jersey estuaries." Environmental Science and Technology. 25(5): 951-956.

Chant RJ and Fugate D, 2006. “Response of Salt, Circulation and Sediment Transport to Variations in Tidal Forcing and River Discharge” Oral presentation at the Second Passaic River Symposium: Progress and Challenges. Montclair State University Conference Center, Montclair, New Jersey. October 13, 2006. http://pages.csam.montclair.edu/pri/symposium2006/2006abstractsandpresentations.htm. (Site last accessed on February 2, 2007).

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.

Earth Tech, Inc. and Malcolm Pirnie, Inc., 2006. “Draft Final Restoration Opportunities Report.” Lower Passaic River Restoration Project. July 2006.

Earth Tech, Inc. and Malcolm Pirnie, Inc., 2005a. “Report for October 20-22, 2004 Field Reconnaissance.” Lower Passaic River Restoration Project. January 2005.

Earth Tech, Inc. and Malcolm Pirnie, Inc., 2005b. “Report for December 14, 2004 to February 24, 2005 Field Reconnaissance.” Lower Passaic River Restoration Project. February 2005.

Germano & Associates, Inc., 2005. “Final Report: Sediment Profile Imaging Survey of Sediment and Benthic Habitat Characteristics of the Lower Passaic River.” Prepared for Aqua Survey, Inc. August 2005.

Huling SG, 1989. “Facilitated Transport: USEPA Superfund Groundwater Issue.” August 1989. http://www.epa.gov/ada/download/issue/facili.pdf. (Site last accessed on February 2, 2007).

Iannuzzi T, Ludwig DF, Kinnell JC, Wallin JM, Desvousges WH, and Dunford RW. 2002. A Common Tragedy: History of an Urban River. Amherst Scientific Publishers. (Amherst, Massachusetts).

IT Corporation, 1986. “Passaic River Sediment Study.’ Submitted to New Jersey Department of Environmental Protection. March 1986.

Lowe S, Abood K, Ko J, and Wakeman T, 2005. “A sediment budget analysis of Newark Bay.” Journal of Marine Science and Environment. C3: 37-44.

Malcolm Pirnie, Inc., 2006a. “Draft Geochemical Evaluation (Step 2).” Lower Passaic River Restoration Project. Prepared in conjunction with Battelle and HydroQual, Inc. March 2006.

Malcolm Pirnie, Inc., 2006b. “Community Involvement Plan.” Lower Passaic River Restoration Project and Newark Bay Study. June 2006.

Malcolm Pirnie, Inc., 2006c. “Draft Field Sampling Plan, Volume 2.” Lower Passaic River Restoration Project. Prepared in conjunction with Earth Tech, Inc. and Battelle. June 2006.

Malcolm Pirnie, Inc., 2006d. “Field Sampling Plan, Volume 1.” Lower Passaic River Restoration Project. Prepared in conjunction with Earth Tech, Inc. and Battelle. January 2006.

Malcolm Pirnie, Inc., 2005a. “Work Plan.” Lower Passaic River Restoration Project. Prepared in conjunction with Battelle and HydroQual, Inc. August 2005.

Malcolm Pirnie, Inc., 2005b. “Quality Assurance Project Plan.” Lower Passaic River Restoration Project. Prepared in conjunction with Battelle and HydroQual, Inc. August 2005.

Miller RM, Farley KJ, Wands JR, Santore R, and Redman AD, 2007. “Fate and Transport Modeling of Sediment Contaminants in the NY/NJ Harbor Estuary.” HydroQual, Inc., Mahawah, NJ. Presented at the Fourth International Conference on Remediation of Contaminated Sediments, January 22-25, 2007. Savannah, Georgia.

NJDEP, 1998. “Guidance for Sediment Quality Evaluation.” New Jersey Department of Environmental Protection. November 1998.

Reinfelder JR, Totten LA, and Eisenrich SJ, 2004. “Final Report to the New Jersey Department of Environmental Protection from the New Jersey Atmospheric Deposition Network.” January 2004.

TSI, 2006. “Phase 1 Remedial Investigation Dataset” In the Newark Bay Study Area Remedial Investigation Work Plan. October 2006.

United States Census Bureau, 2007. “New Jersey QuickFacts.” http://quickfacts.census.gov/qfd/states/34000.html. (Site last updated January 12, 2007. Site last accessed February 2, 2007)

USACE, USEPA, NJDOT, 2003. “Project Management Plan: Lower Passaic River, New Jersey. Investigation and Feasibility Study for Remediation and Ecosystem Restoration.” April 2003.

USACE, 2002. “Report of Channel Conditions 100 to 400 feet Wide” ER 1130-2-3165. December 2002.

USACE, 1986. “Newark Bay, Hackensack & Passaic Rivers, N.J. (Passaic River).” Map dated September 30, 1986.

USACE, 1917. “Improvement of rivers and harbors in the third New York, NY, district. Annual report of the Chief of Engineers. Part 2, Appendix G.” Washington, DC.

USACE, 1916. “Improvement of rivers and harbors in the third New York, NY, district. Annual report of the Chief of Engineers. Part 2, Appendix G.” Washington, DC.

USACE, 1915. “Improvement of rivers and harbors in the third New York, NY, district. Annual report of the Chief of Engineers. Part 2, Appendix G.” Washington, DC.

USACE, 1913. “Improvement of rivers and harbors in northeastern New Jersey. Annual report of the Chief of Engineers. Part 2, Appendix G.” Washington, DC.

USACE, 1907. “Newark Bay, and Hackensack and Passaic Rivers, NJ.” Letter from the Secretary of War, 59th Congress, 2d Session, Washington, DC. House of Representatives Document No. 441, 1907 Jan 8.

USACE, 1900. “Annual Reports of the War Department.” Report of the Chief of Engineers. Part 2, Appendix H. Washington, DC.

USACE, 1884. “Annual report of the Chief of Engineers, U.S. Army, Appendix G8, improvement of the Passaic River above Newark, New Jersey.” Washington, DC.

USACE, 1880. “Annual report of the Chief of Engineers, U.S. Army, Appendix E, improvement of rivers in northern New Jersey.” Washington, DC.

USEPA, 2007. “Fact Sheet: Diamond Alkali Co. New Jersey. USEPA #NJD980528996.” http://www.epa.gov/region02/superfund/npl/0200613c.pdf. (Site last accessed February 2, 2007).

USEPA, 2006a. “Fact Sheet: Witco Chemical Corp. (Oakland Plant) New Jersey. USEPA #NJD045653854.” http://www.epa.gov/region02/superfund/npl/0200316c.htm. (Site accessed February 2, 2007).

USEPA, 2006b. “Fact Sheet: Caldwell Trucking. New Jersey. NJD048798953.” http://www.epa.gov/region02/superfund/npl/0200340c.pdf. (Site accessed February 2, 2007).

USEPA, 2003a. “Record of Decision Operable Units 3, 4, and 5: Lower Fox River and Green Bay, Wisconsin, Record of Decision Responsiveness Summary.” USEPA Region 5, New York. http://dnr.wi.gov/org/water/wm/foxriver/reportsanddocs.html. (Site last accessed February 2, 2007).

USEPA, 2003b. “Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity, and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries.” EPA 903-R-03-002. April 2003.

USEPA, 2002. “Record of Decision, Hudson River PCBs Reassessment RI/FS.” USEPA Region 2, New York. http://www.epa.gov/hudson/rod.htm. (Site last accessed February 2, 2007).

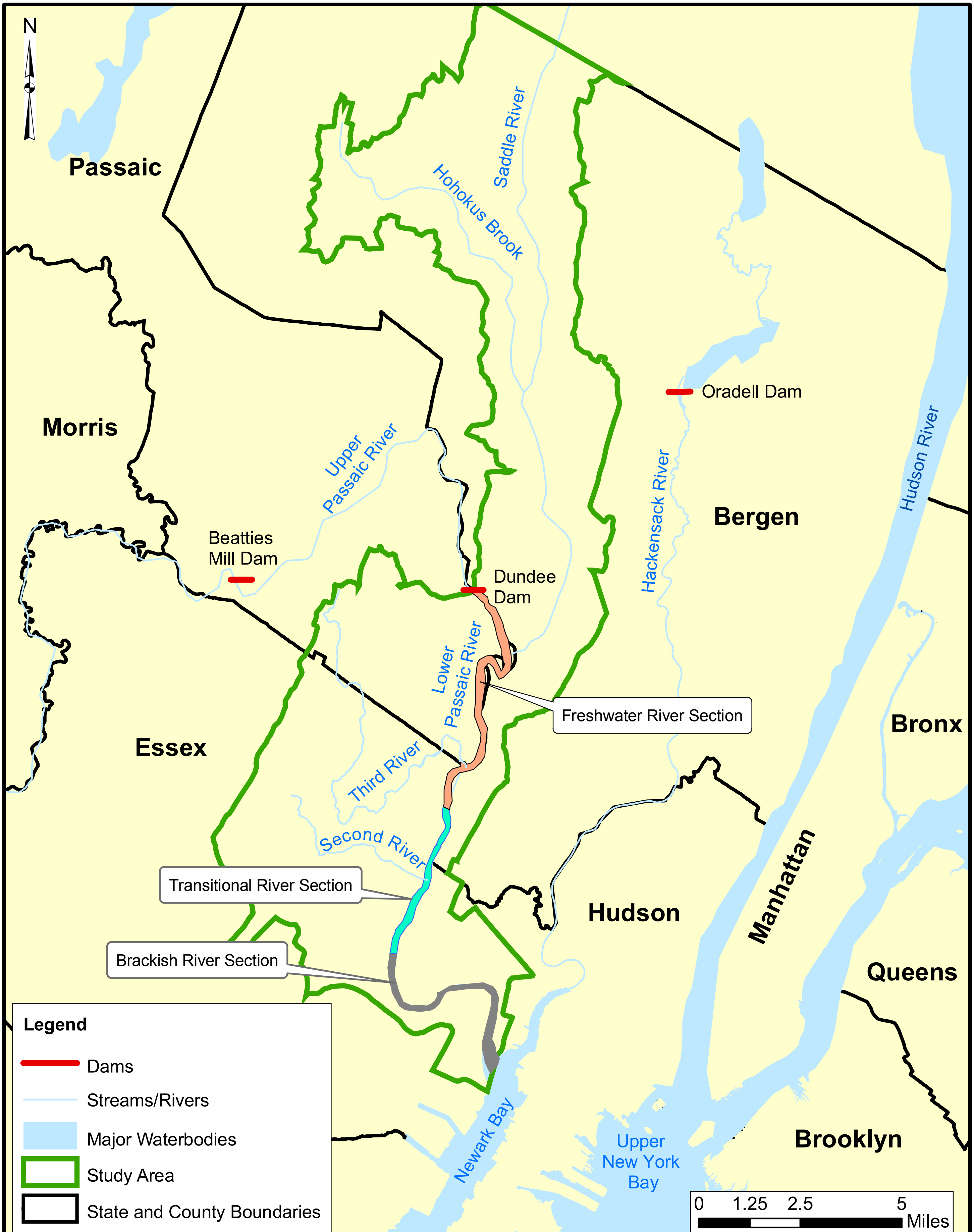
USEPA, 2000. “Data Quality Objective Process for Hazardous Waste Site Investigation.” Office of Environmental Information. EPA/600/R-00/007. January 2000.

USEPA, 1997. “Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments.” Interim Final. EPA/540/R-97/006. June 1997.

USEPA, 1995. “Passaic River Study Area. Investigation Work Plan, Feasibility Study Work Plan.” January 1995.

USEPA, 1988. "Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA." Office of Emergency and Remedial Response. OSWER Directive 9355.3-01. EPA/540/G-89/004. October 1988.

Figures



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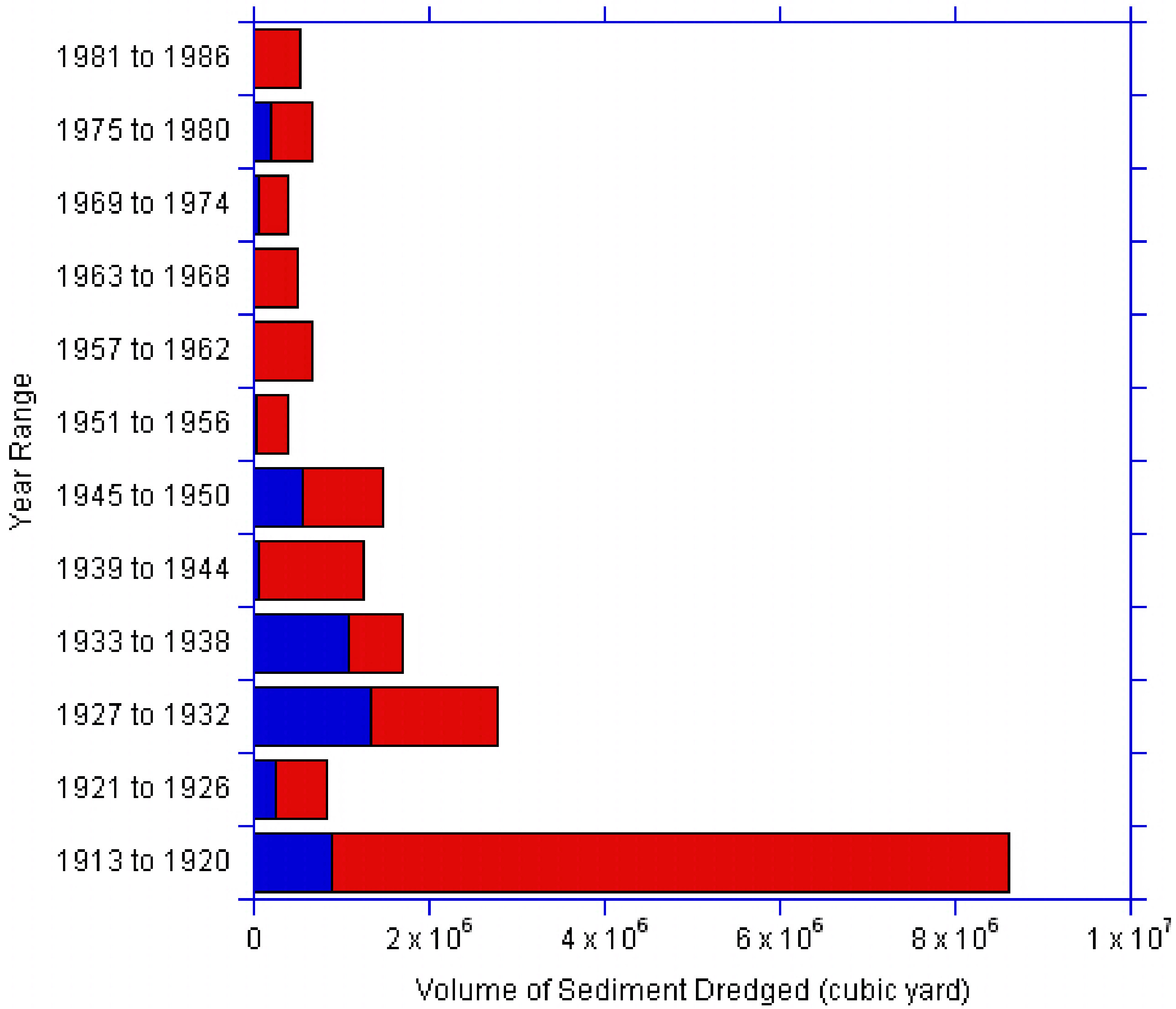
Study Area Location Map

Lower Passaic River Restoration Project

Figure 1-1

February 2007



Legend

Below RM2

Above RM2

Notes

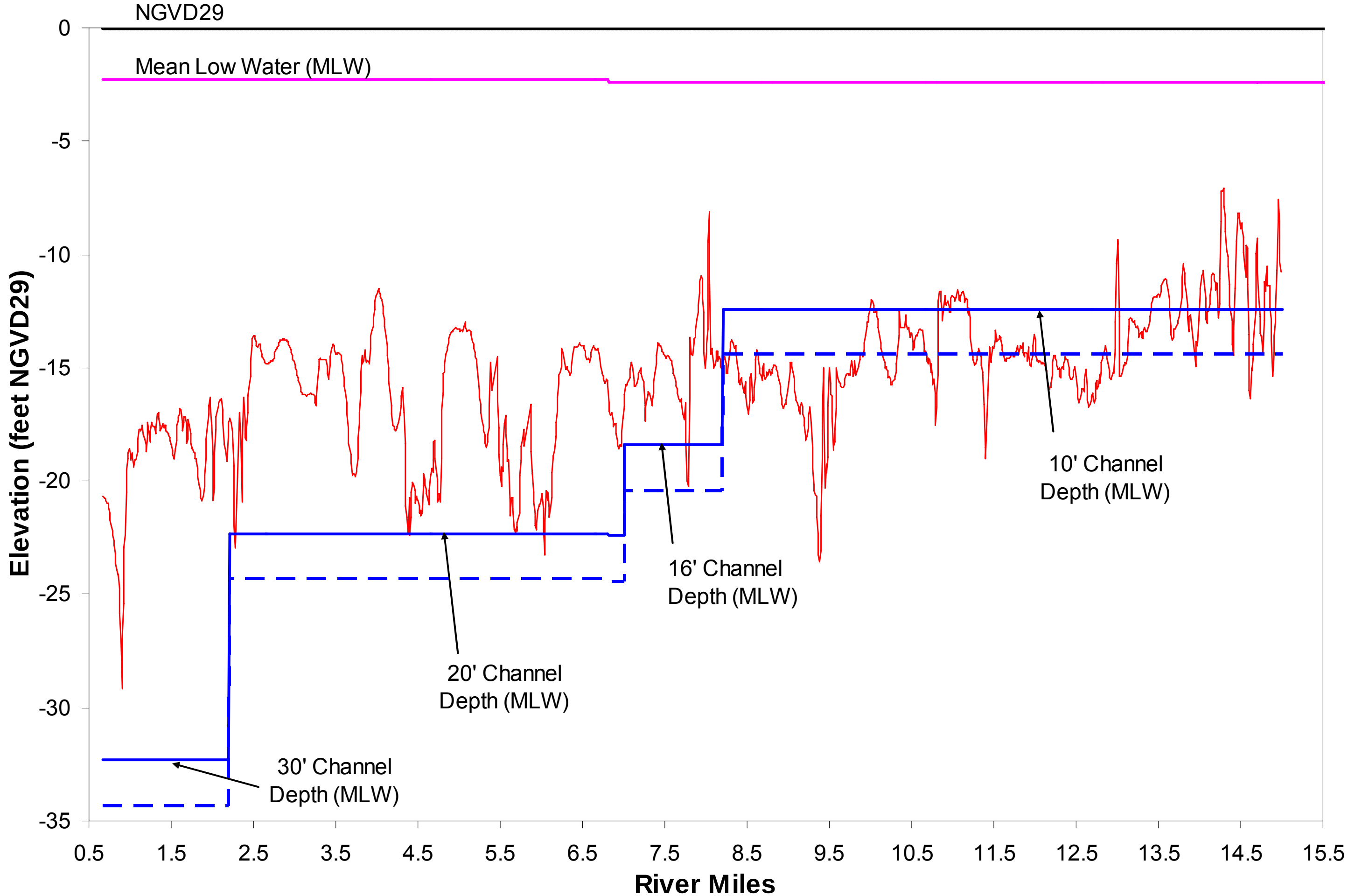
Data Sources: USACE, 1880, USACE, 1884, USACE, 1900, USACE, 1907, USACE, 1913, USACE, 1915, USACE, 1916, and USACE, 1917 as cited in Iannuzzi, *et al*., 2002 (refer to Section 10 “References” for complete citation).

The History of Dredging in the Lower Passaic River

Lower Passaic River Restoration Project

Figure 1-2

February 2007



Legend

Navigational Channel Centerline Bathymetry

Navigational Channel Depth

Navigational Channel Depth + 2 feet

Notes

Channel depths were dredged relative to mean low water (MLW). The difference between NGVD29 and MLW is approximately 2.3 feet.

Solid blue line represents federally mandated channel depth.

Dashed blue line represents the channel depth +2 feet which would have been the dredged depth in order to maintain the federally specified channel depth.

Elevation data estimated from 2004 bathymetric data surveyed by Rogers Survey,Inc. for USACE.

US Army Corp of Engineers

River Bottom Elevation and Authorized Channel Depths

Lower Passaic River Restoration Project

Figure 1-3

February 2007

Legend

- Rock and Coarse gravel
- Gravel and Sand
- Sand
- Silt and Sand
- Silt
- River Mile Post

2004 USACE Bathymetric Survey

Elevation (Feet) Relative to NGVD29

- -30 to -20
- -8 to 0
- -18 to -10
- 2 to 10

Notes

Data Sources:
Buildings: CADD drawing, 09994X01, dated January 1, 2002 received from BBL.

Roads: 2000 TIGER line data.

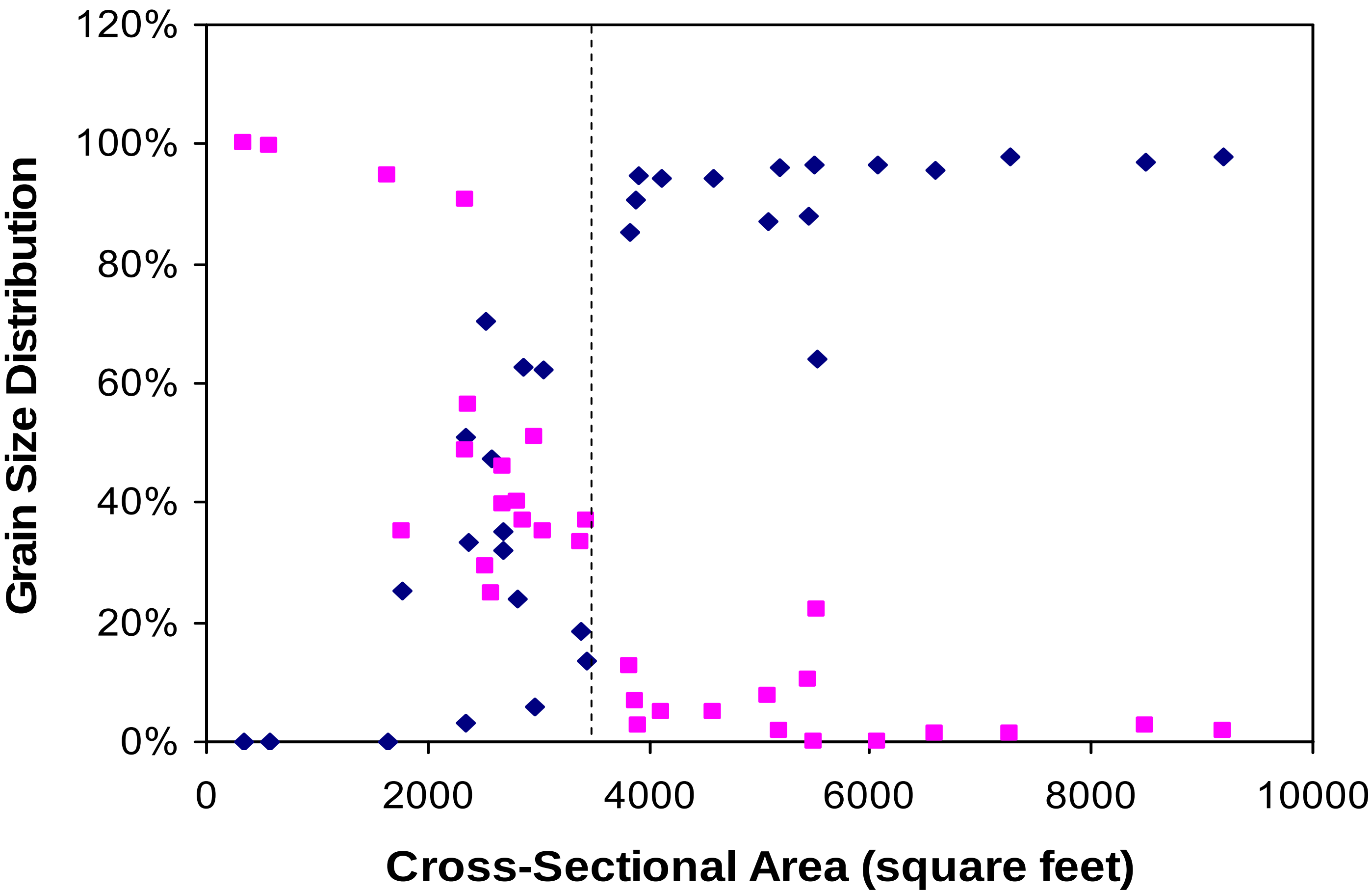
Sediment Texture: 2005 Side scan SONAR data from Aqua Survey, Inc.

Side-Scan Sonar Survey Interpretation of Lower Passaic River Bottom Sediments near RM8

Lower Passaic River Restoration Project

Figure 1-4

February 2007



Legend

Fine-grained sediment

Coarse-grained sediment

Highlights the change to a river cross sectional area of 3,500 square feet

Notes

Cross-sectional area estimated from 2004 bathymetric data surveyed by Rogers Survey, Inc. for USACE.

Sediment texture was evaluated based on data interpolated by Aqua Survey, Inc. using side-scan sonar images (Aqua Survey, Inc., 2006). Sediment texture data extends from RM0 to RM16.5.

Refer to Figure 1-6 for relationship between river mile and cross-sectional area.

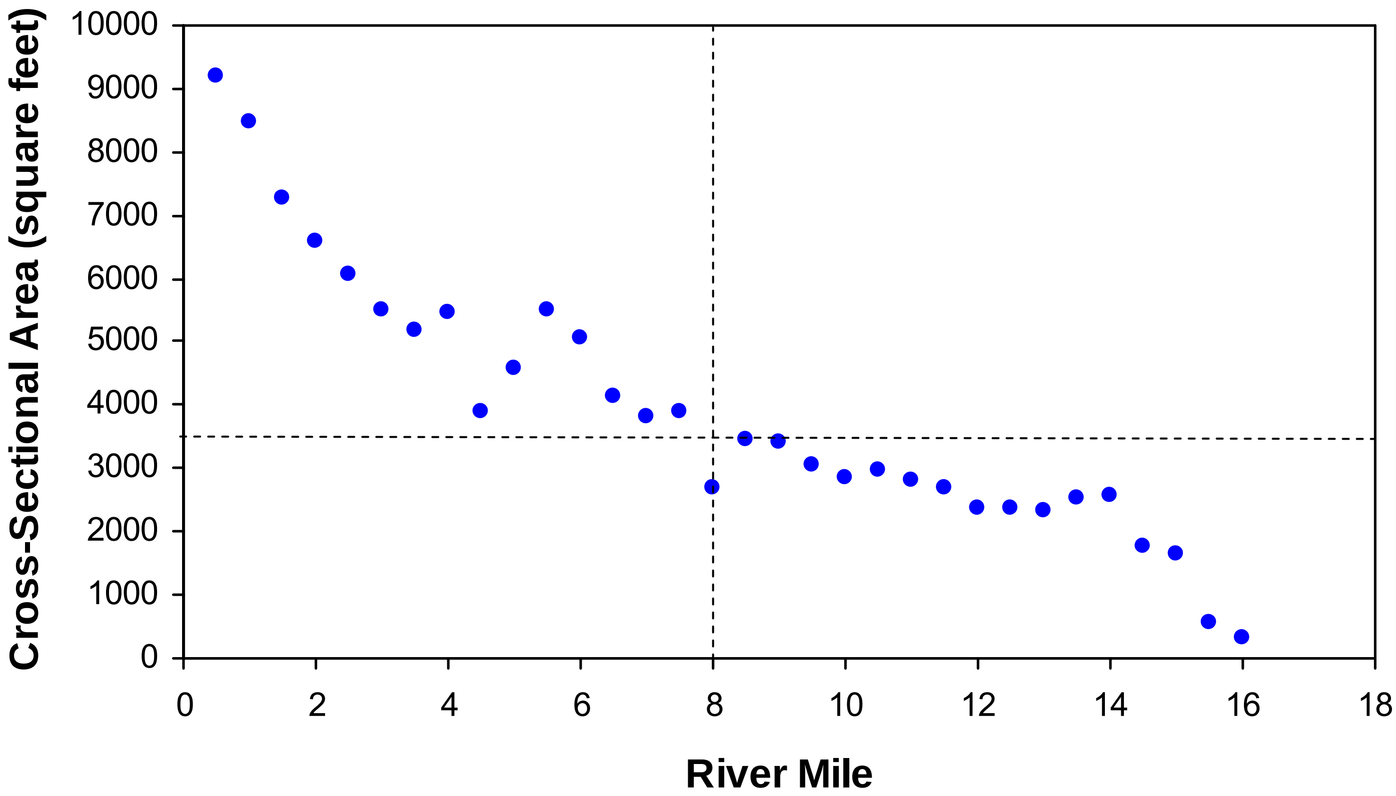
US Army Corps of Engineers

Variation of Lower Passaic River Sediment Type with River Cross-Sectional Area

Lower Passaic River Restoration Project

Figure 1-5

February 2007



Legend

Cross-Sectional Area (square feet)

Highlights the change to a river cross sectional area of 3,500 square feet at RM8

Notes

Cross-sectional area estimated from 2004 bathymetric data surveyed by Rogers Survey, Inc. for USACE.

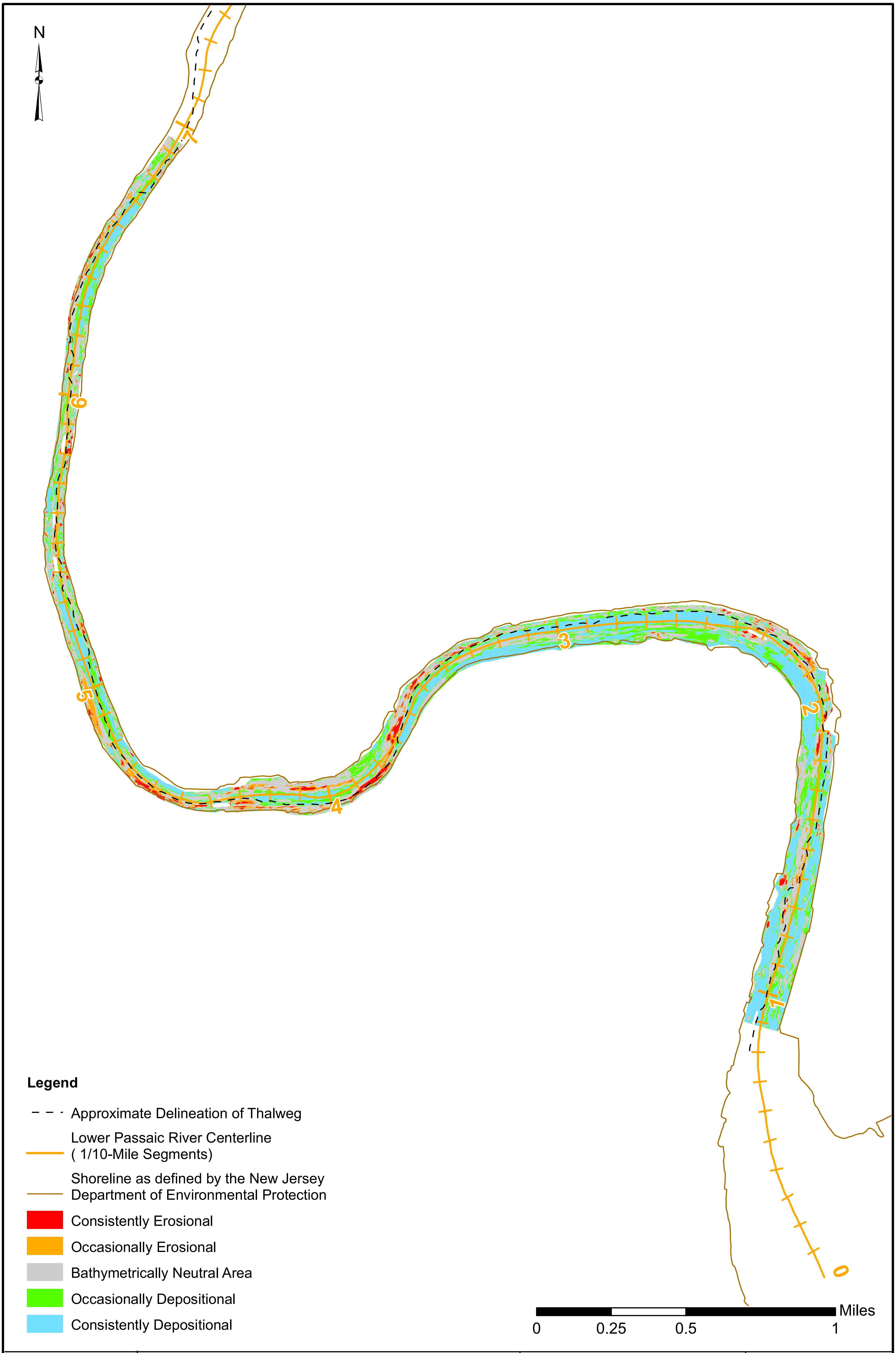
Cross-sectional area refers to the water filled area of the river channel when water level is equal to 0 feet elevation at NGVD29.

Variation of Lower Passaic River Cross-Sectional Area with River Mile

Lower Passaic River Restoration Project

Figure 1-6

February 2007



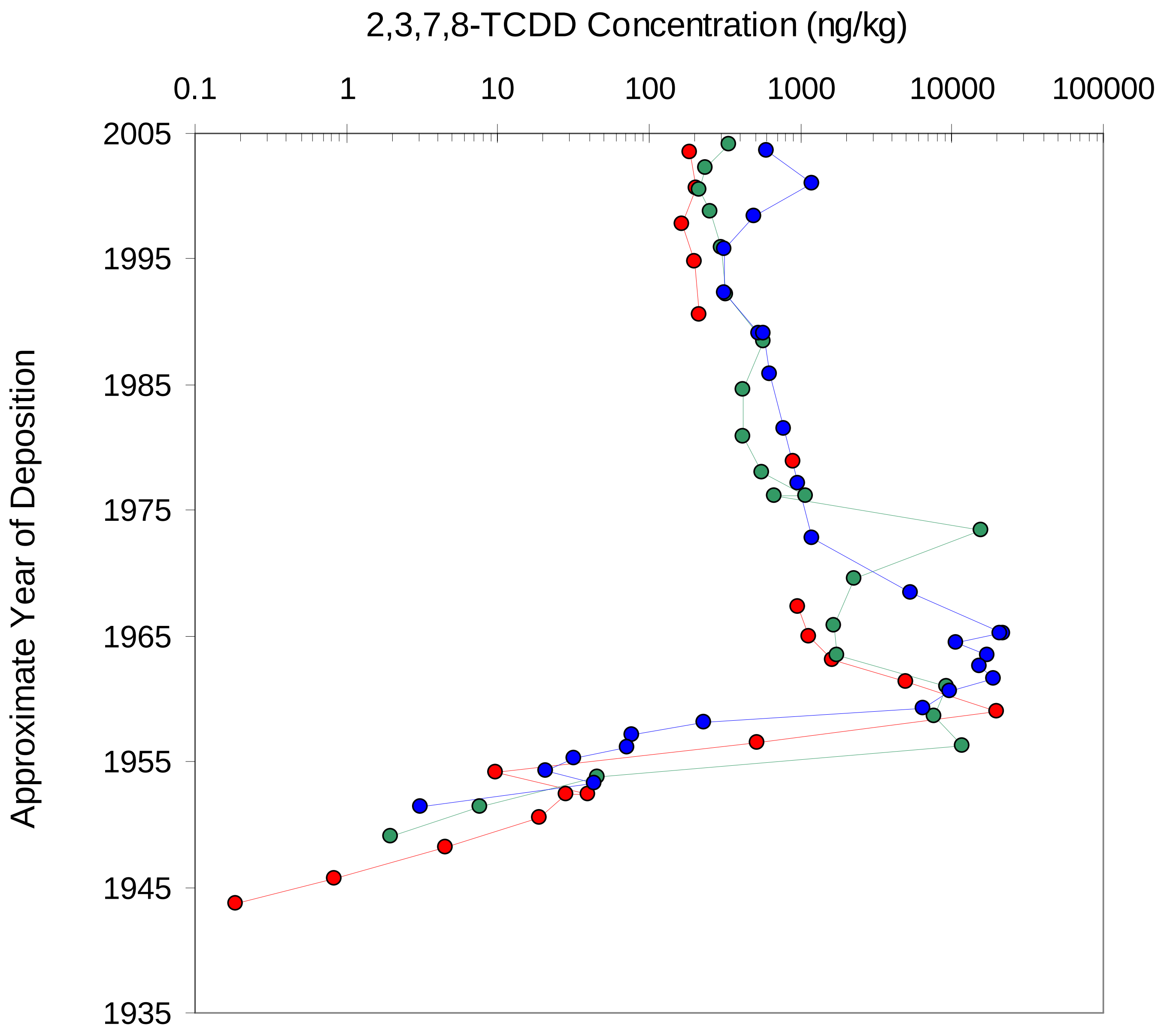
Net Erosional and Net Depositional Areas (RM0.9 to RM7)

Lower Passaic River Restoration Project

Data Sources : Tierra Solutions Inc., Bathymetric Surveys for 1995,1996,1997,1999 and 2001

Figure 1-7

February 2007



Legend

- 2,3,7,8-TCDD at RM 1.4
- 2,3,7,8-TCDD at RM 2.2
- 2,3,7,8-TCDD at RM 11

Notes

2005 Malcolm Pirnie, Inc. High Resolution Sediment Core Programs.

Depositional years calculated using cesium-137 concentrations.

Note that one criterion for a high resolution sediment core is that the location experiences continuous deposition over time.

The determination of the 1954 horizon in core at RM11 is based on the absence of cesium-137 detection below 191 centimeters. There are some uncertainties with this assignment, and the core may extend 4 years longer than is shown here.

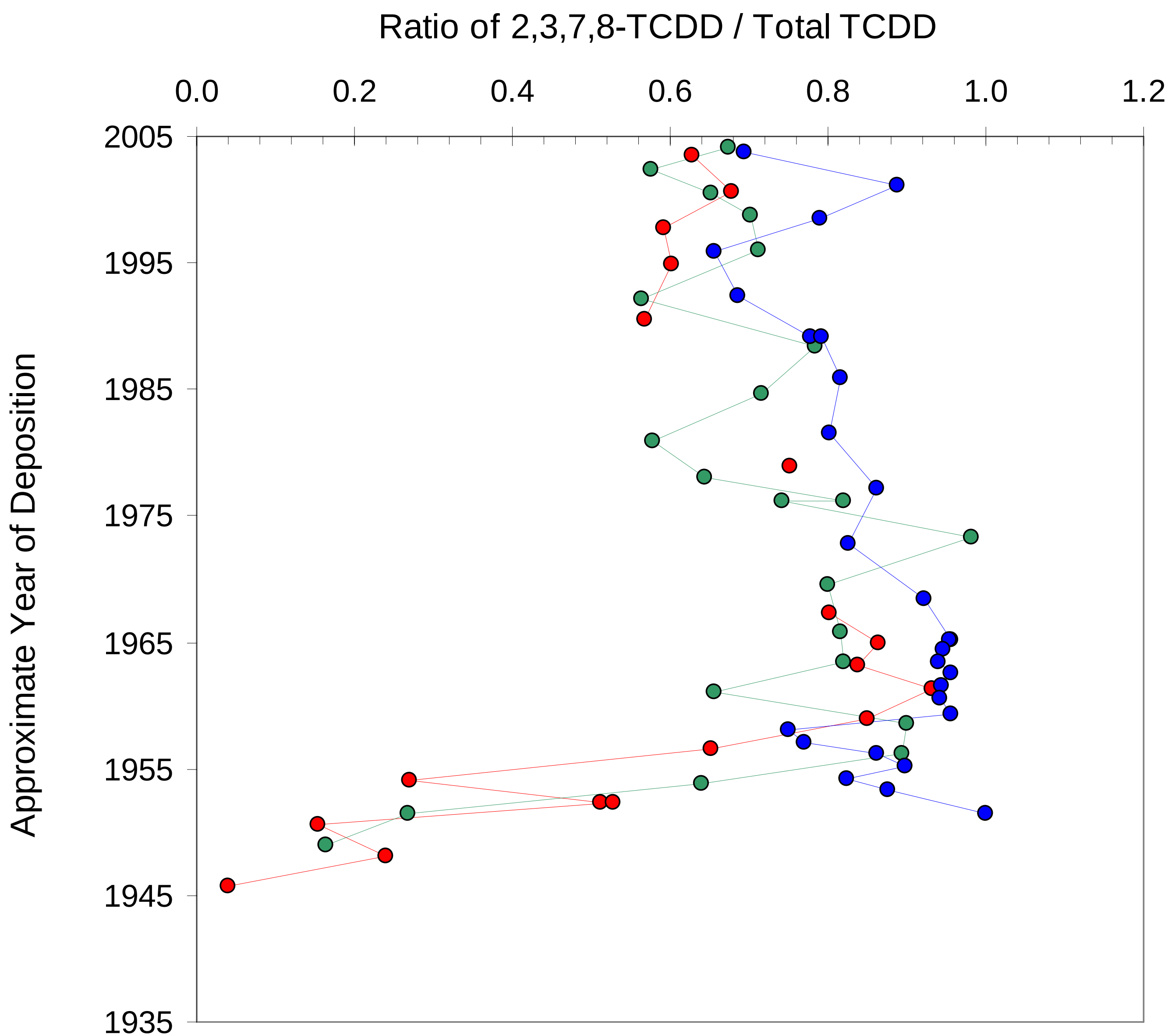
US Army Corps of Engineers

Downcore Profiles of 2,3,7,8-TCDD Concentrations at RM 1.4, RM 2.2, and RM 11

Lower Passaic River Restoration Project

Figure 1-8

February 2007



Legend

- Ratio at RM 1.4
- Ratio at RM 2.2
- Ratio at RM 11

Notes

2005 Malcolm Pirnie, Inc. High Resolution Sediment Core Programs.

Depositional years calculated using cesium-137 concentrations.

Note that one criterion for a high resolution sediment core is that the location experience continuous deposition over time.

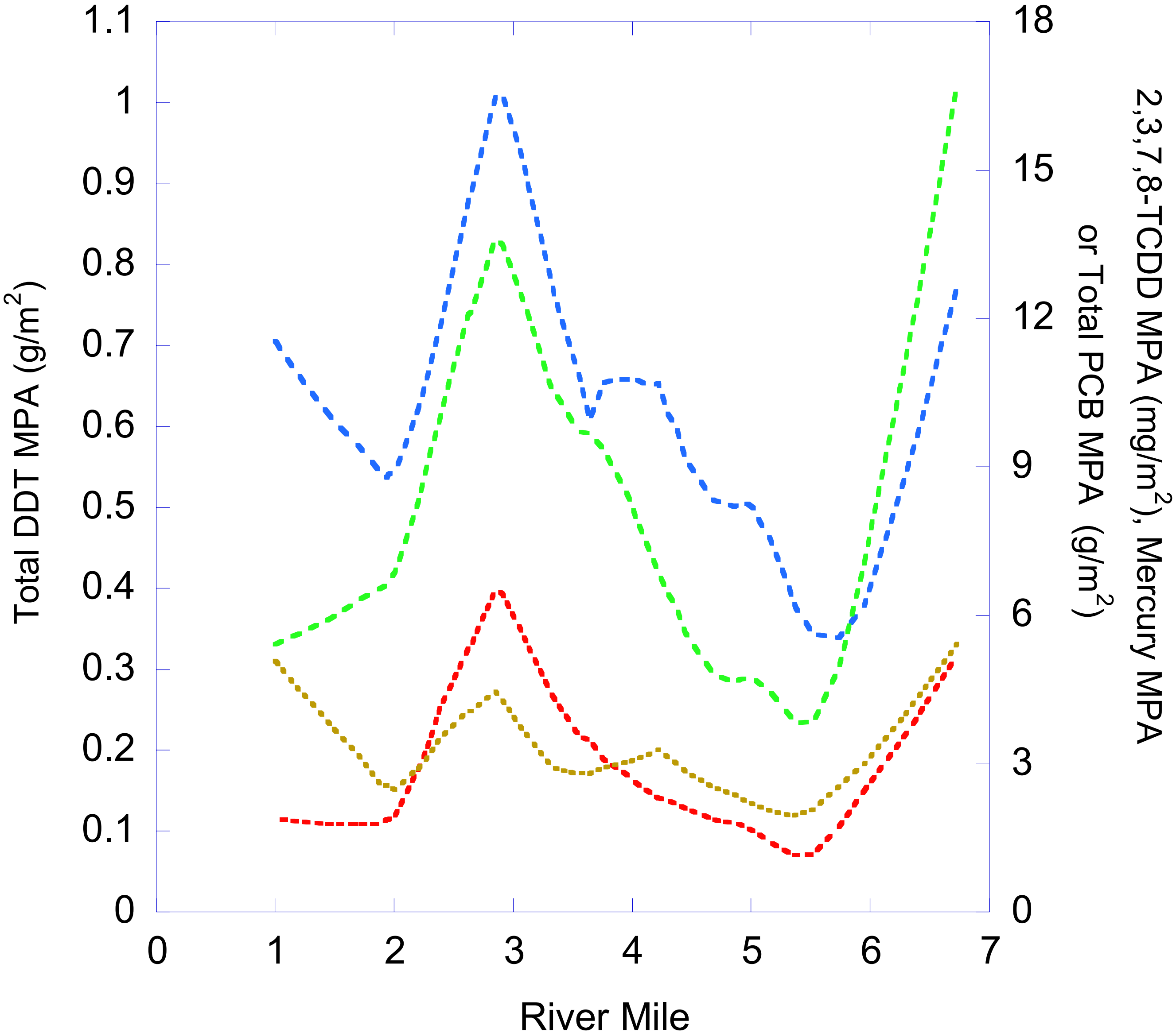
The determination of the 1954 horizon in core at RM11 is based on the absence of cesium-137 detection below 191 centimeters. There are some uncertainties with this assignment, and the core may extend 4 years longer than is shown here.

Downcore Profiles of 2,3,7,8-TCDD/Total TCDD Ratio
at RM 1.4, RM 2.2, and RM 11

Lower Passaic River Restoration Project

Figure 1-9

February 2007



Legend

- Mercury
- 2,3,7,8-TCDD
- Total PCB
- Total DDT

Notes

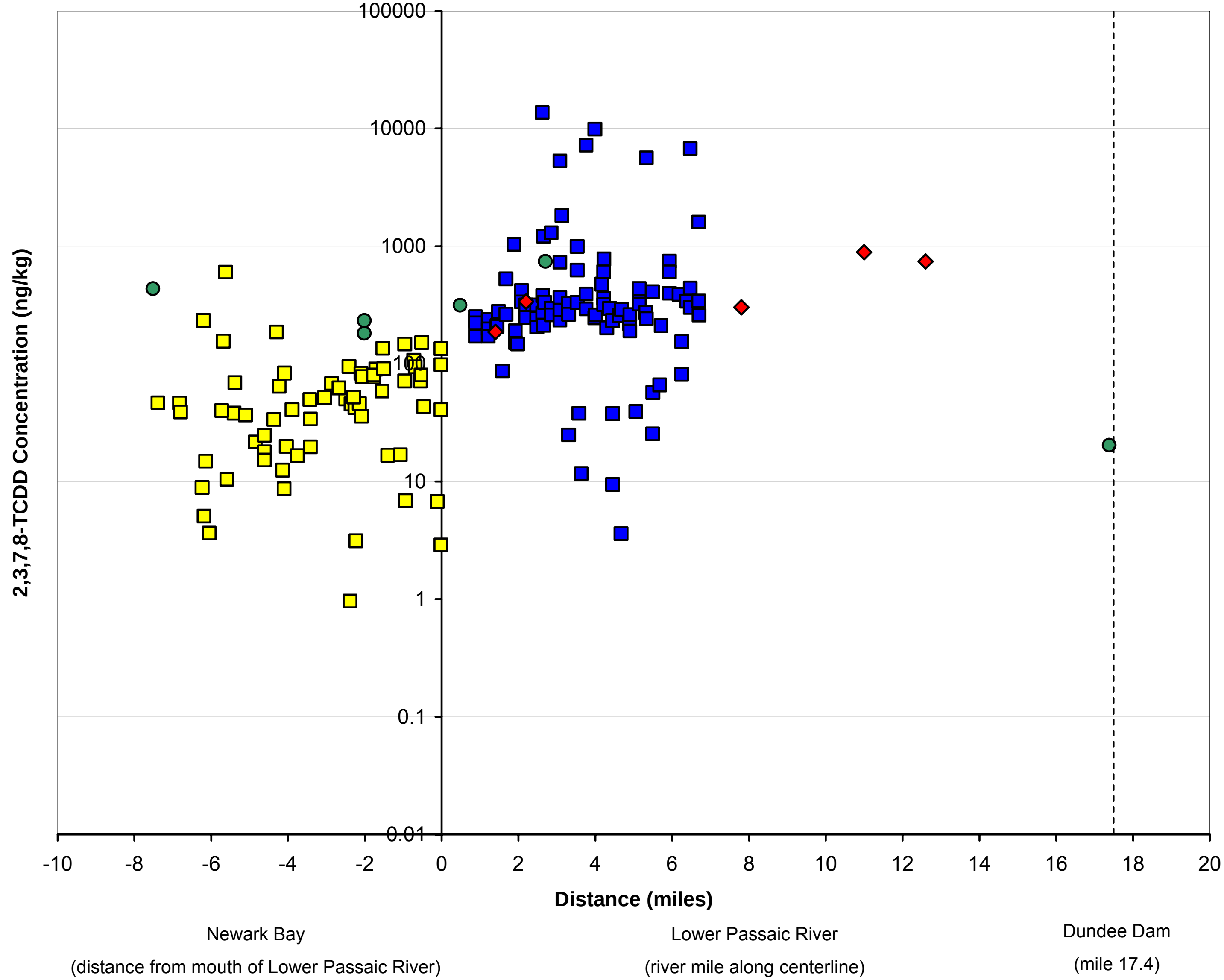
MPA is mass per unit area

Weighted Curve Sediment Inventory from RM1 to RM7

Lower Passaic River Restoration Project

Figure 1-10

February 2007



Legend

Malcolm Pirnie, Inc. (2005) (represents 2003-2005 time horizon)

TSI (2005) (represents 0-6 inches of sediment)

TSI (1995) (represents 0-6 inches of sediment)

Bopp *et al.* (2006) (represents 1985-1986 time horizon)

Notes

Malcolm Pirnie, Inc. Data Source: USEPA 2005-2006 Sampling Program.

TSI Data Source: 2005 Newark Bay Phase I Investigation and 1995 TSI Dataset.

Bopp Data Source: "Contaminant Chronologies from Hudson River Sedimentary Records," Bopp *et al.* (2006).

Nondetect (lab qualifier containing a U) plotted as half the reported value.

Surface concentrations represent a depth of 0 to <1 foot.

Comparison of Surface 2,3,7,8-TCDD Concentrations in 1985-1986, 1995, and 2005

Lower Passaic River Restoration Project

Figure 1-11

February 2007

Hudson-Raritan Estuary

Lower Passaic River Restoration Project

Figure 2-1

February 2007

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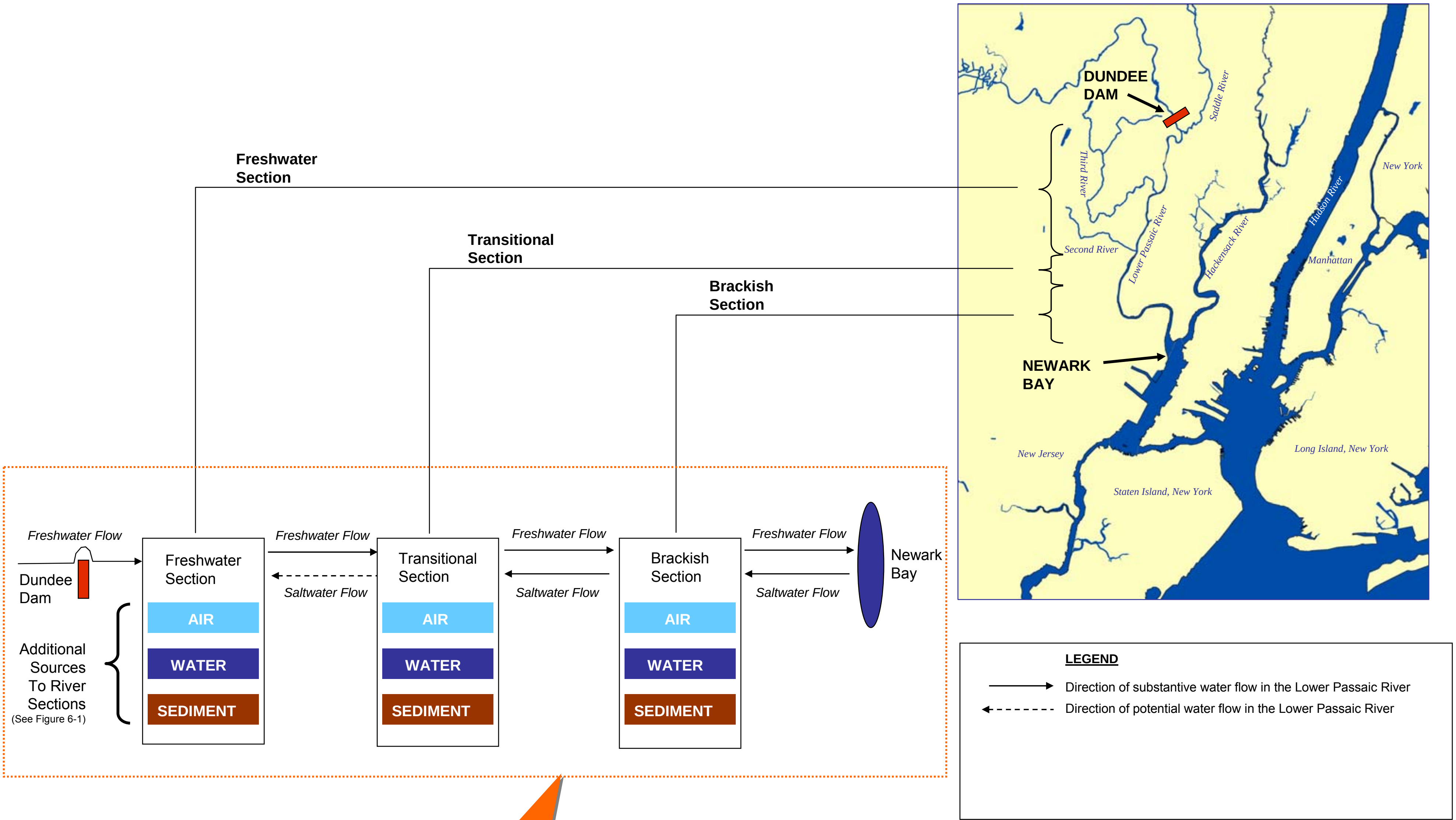


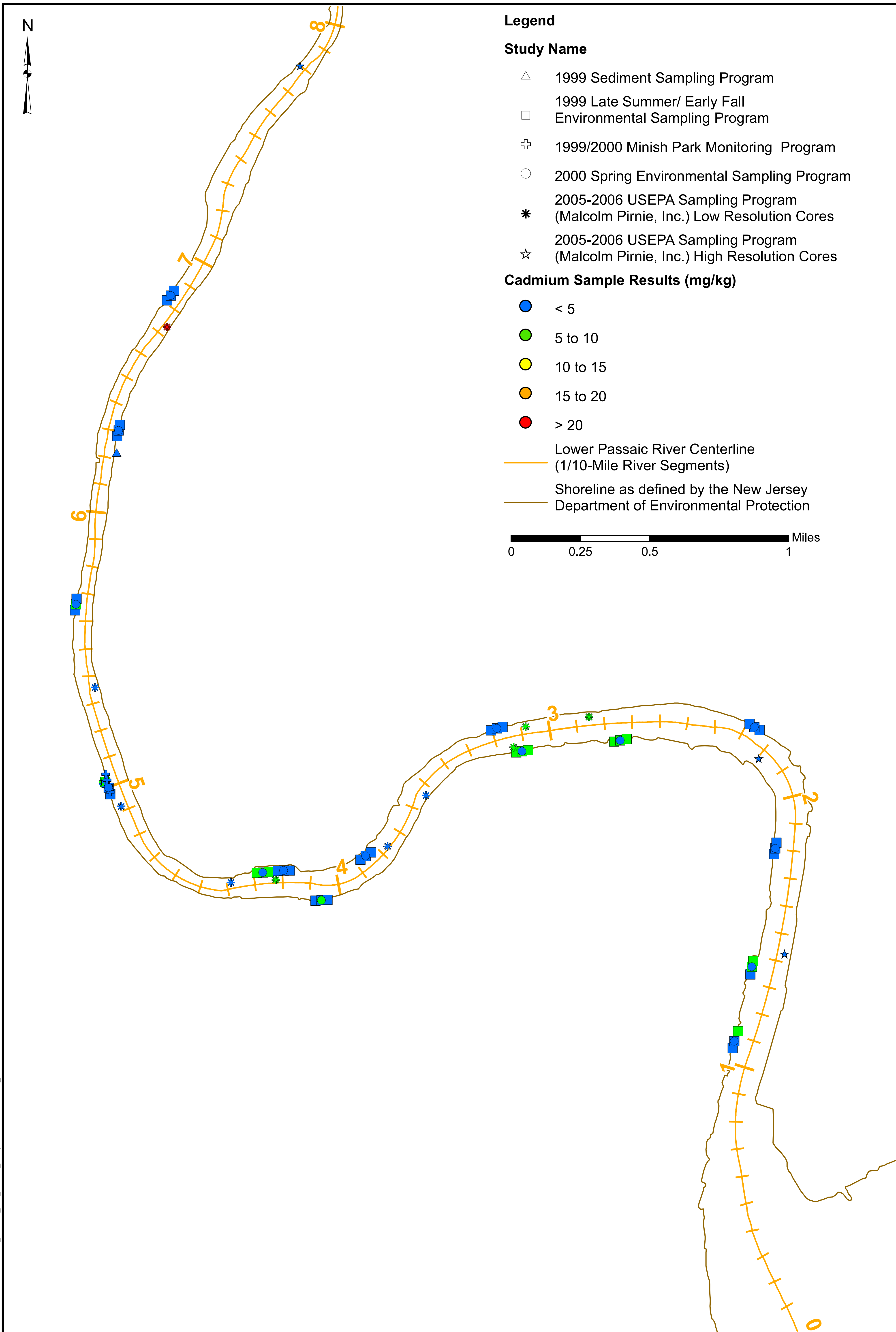
US Army Corp of Engineers

River Sections for the Lower Passaic River

Lower Passaic River Restoration Project

Figure 2-2

February 2007



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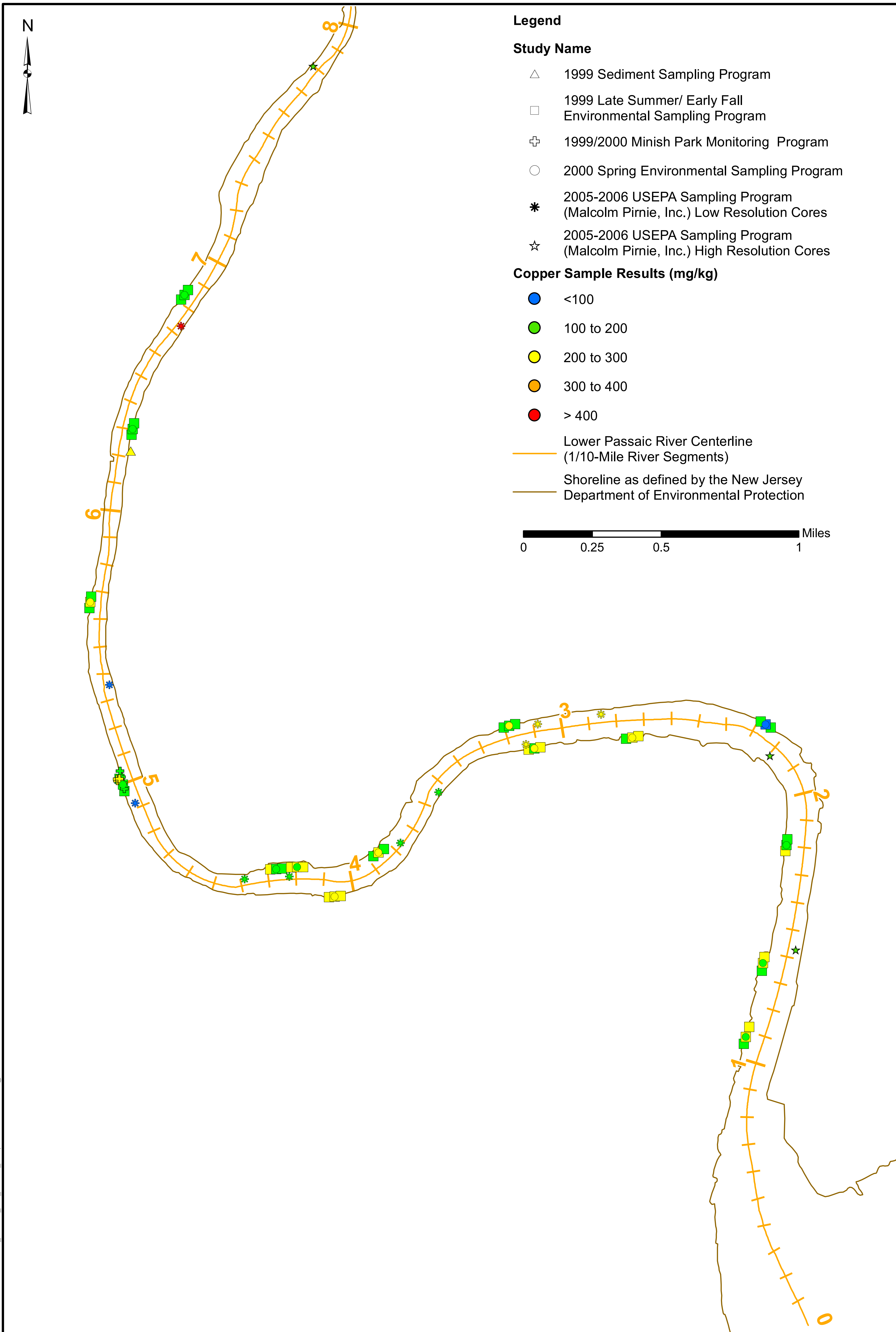
Available Cadmium Surface Sediment Samples from 1997 to 2006

Lower Passaic River Restoration Project

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. However, low resolution cores represent sediments from a depth of 0 to 2.3 feet. 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 2-3a

February 2007



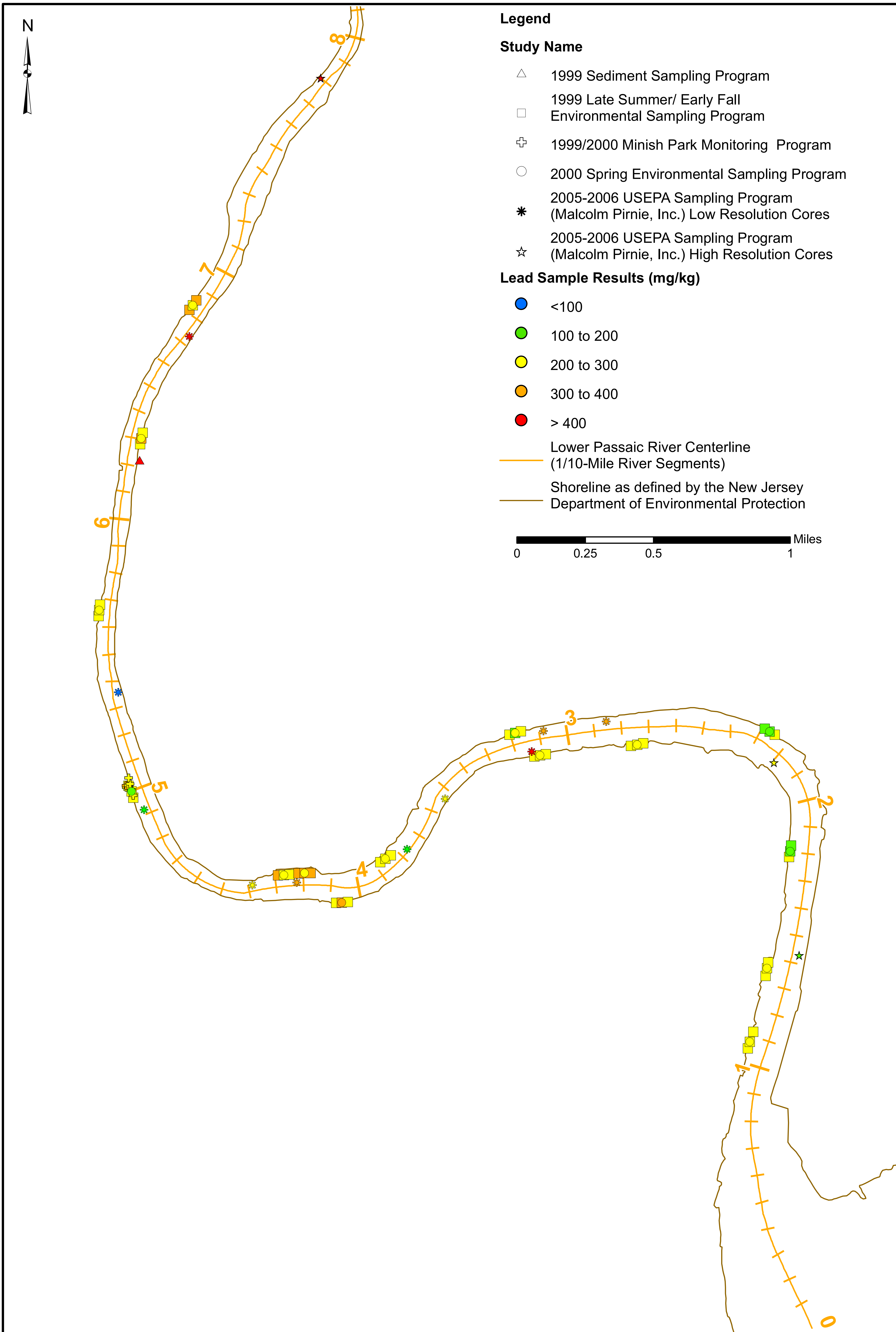
Available Copper Surface Sediment Samples from 1997 to 2006

Lower Passaic River Restoration Project

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. However, low resolution cores represent sediments from a depth of 0 to 2.3 feet. 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 2-3b

February 2007



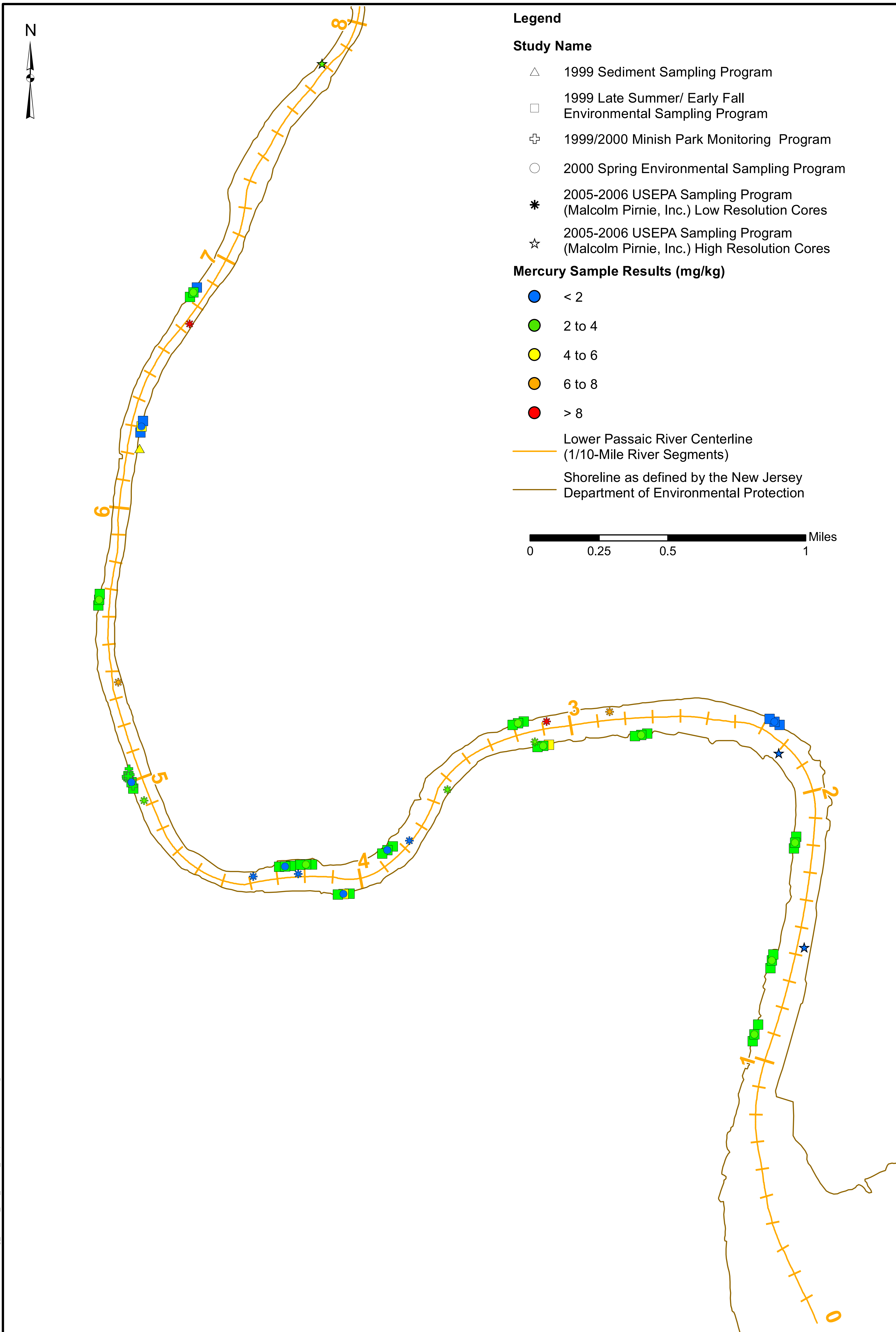
Available Lead Surface Sediment Samples from 1997 to 2006

Lower Passaic River Restoration Project

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. However, low resolution cores represent sediments from a depth of 0 to 2.3 feet. 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 2-3c

February 2007



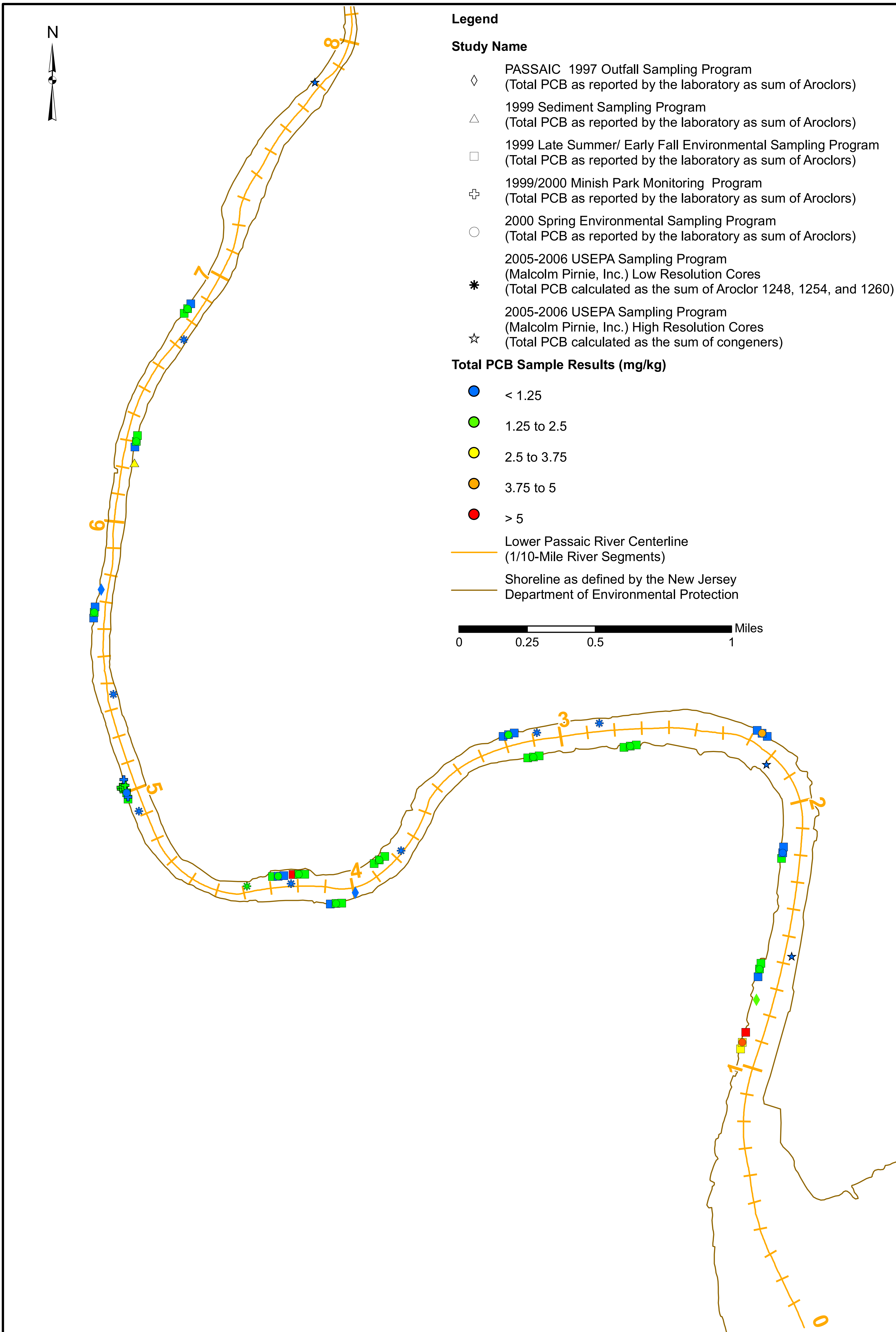
Available Mercury Surface Sediment Samples from 1997 to 2006

Lower Passaic River Restoration Project

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. However, low resolution cores represent sediments from a depth of 0 to 2.3 feet. 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 2-3d

February 2007



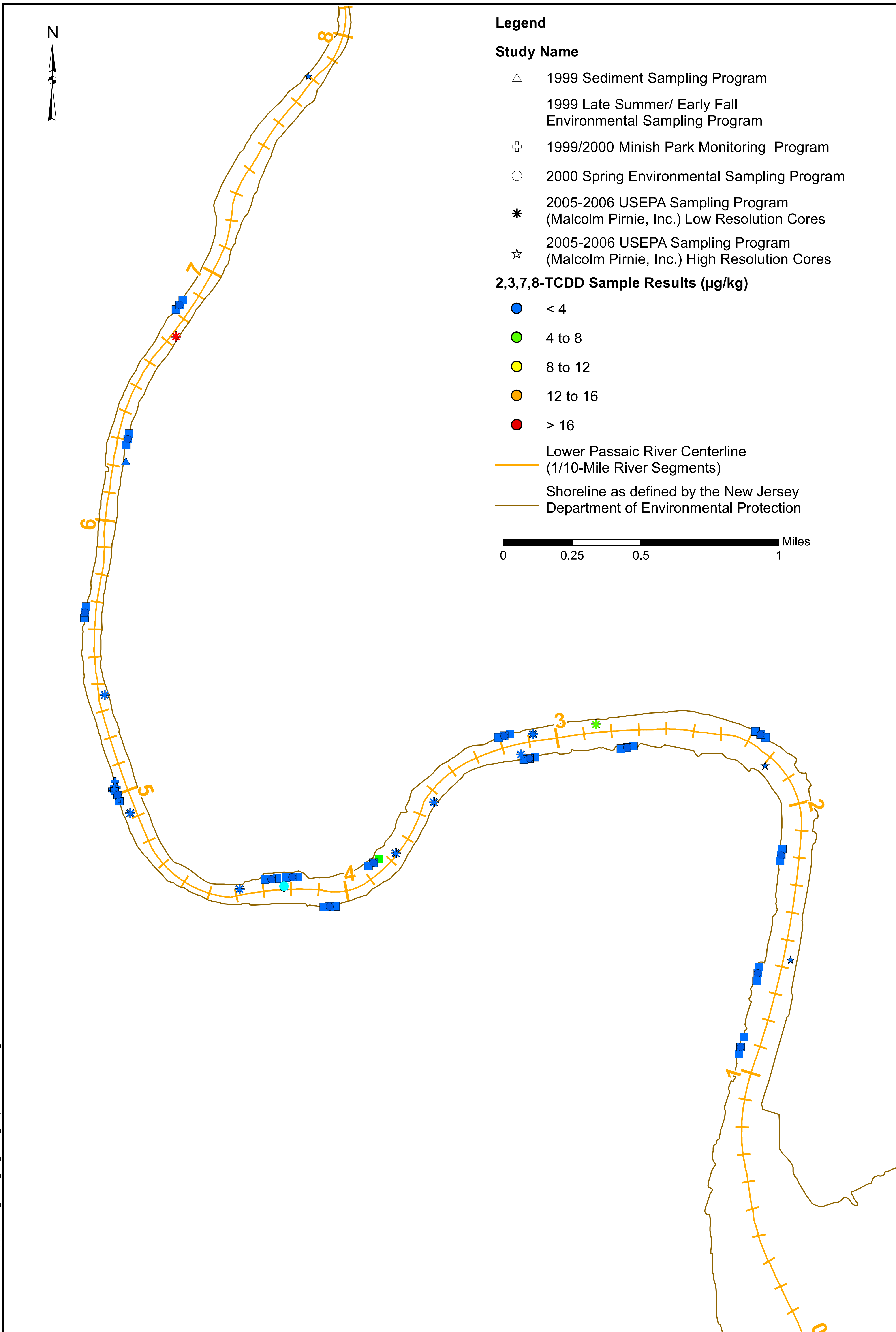
Available Total PCB Surface Sediment Samples from 1997 to 2006

Lower Passaic River Restoration Project

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. However, low resolution cores represent sediments from a depth of 0 to 2.3 feet. 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 2-3e

February 2007



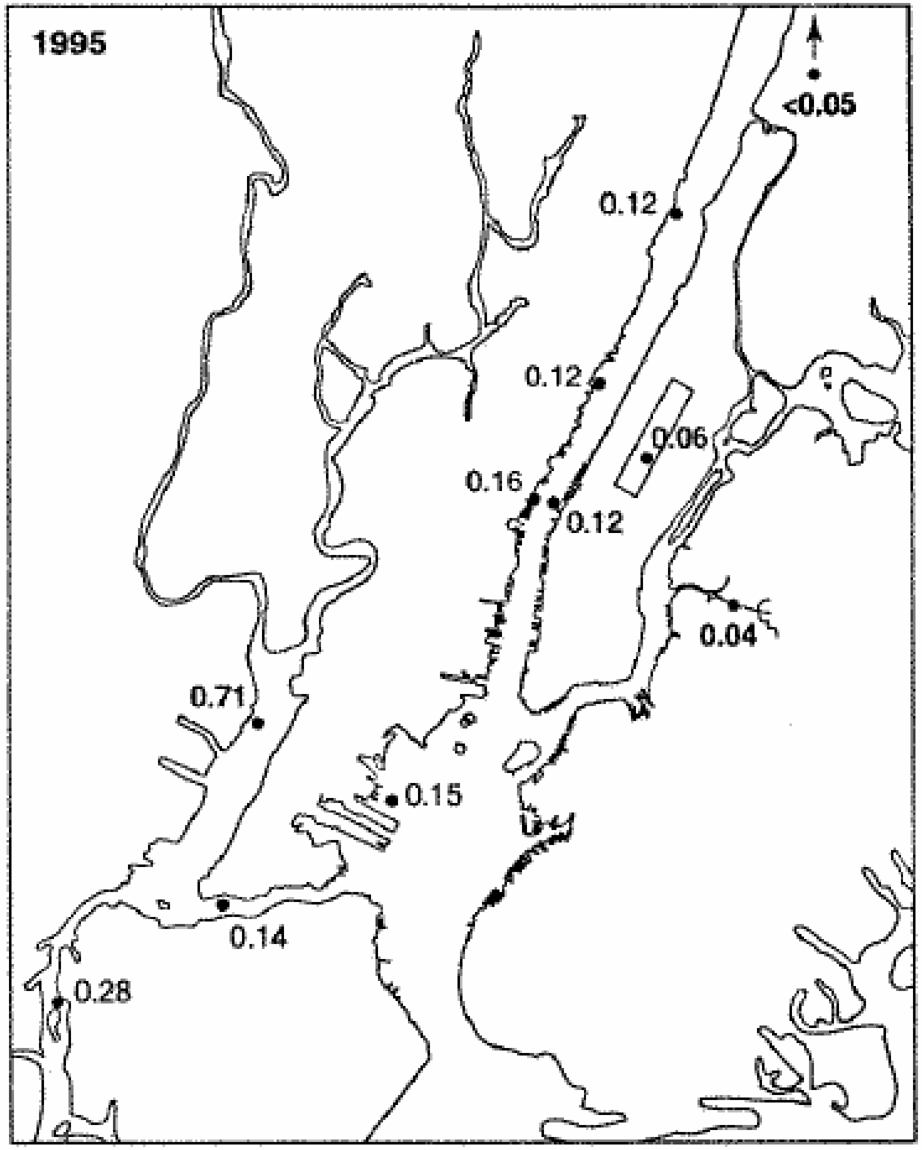
Available 2,3,7,8-TCDD Surface Sediment Samples from 1997 to 2006

Lower Passaic River Restoration Project

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. However, low resolution cores represent sediments from a depth of 0 to 2.3 feet. 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 2-3f

February 2007



Legend

● 2,3,7,8-TCDD/Total TCDD Ratio

Notes

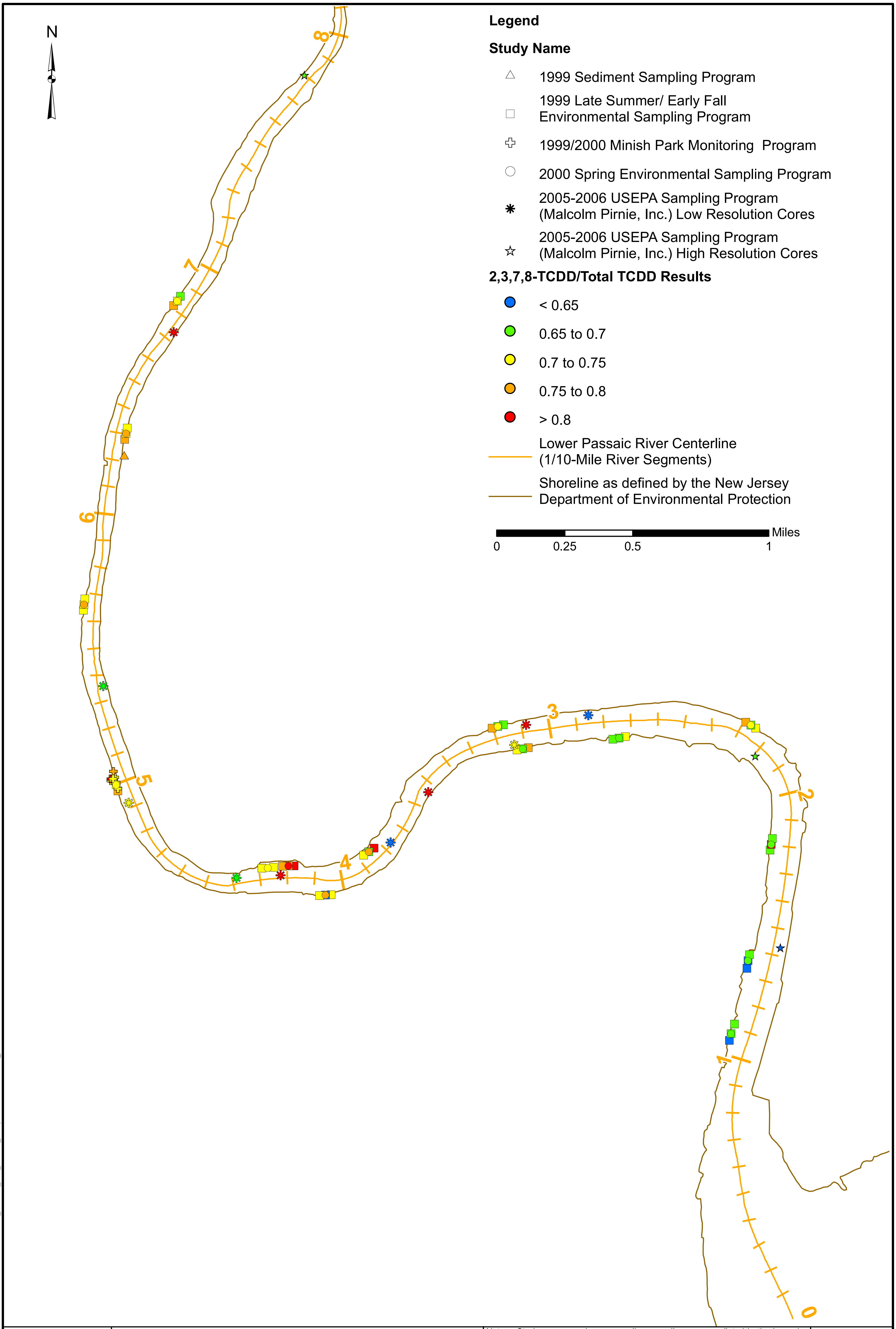
Chaky DA, 2003. "Polychlorinated Biphenyls, Polychlorinated Dibenzo-p-Dioxins and Furans in the New York Metropolitan Area; Interpreting Atmospheric Deposition and Sediment Chronologies." PhD Thesis, Rensselaer Polytechnic Institute, Troy, NY. August 2003.

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

Lower Passaic River Restoration Project

Figure 2-4

February 2007



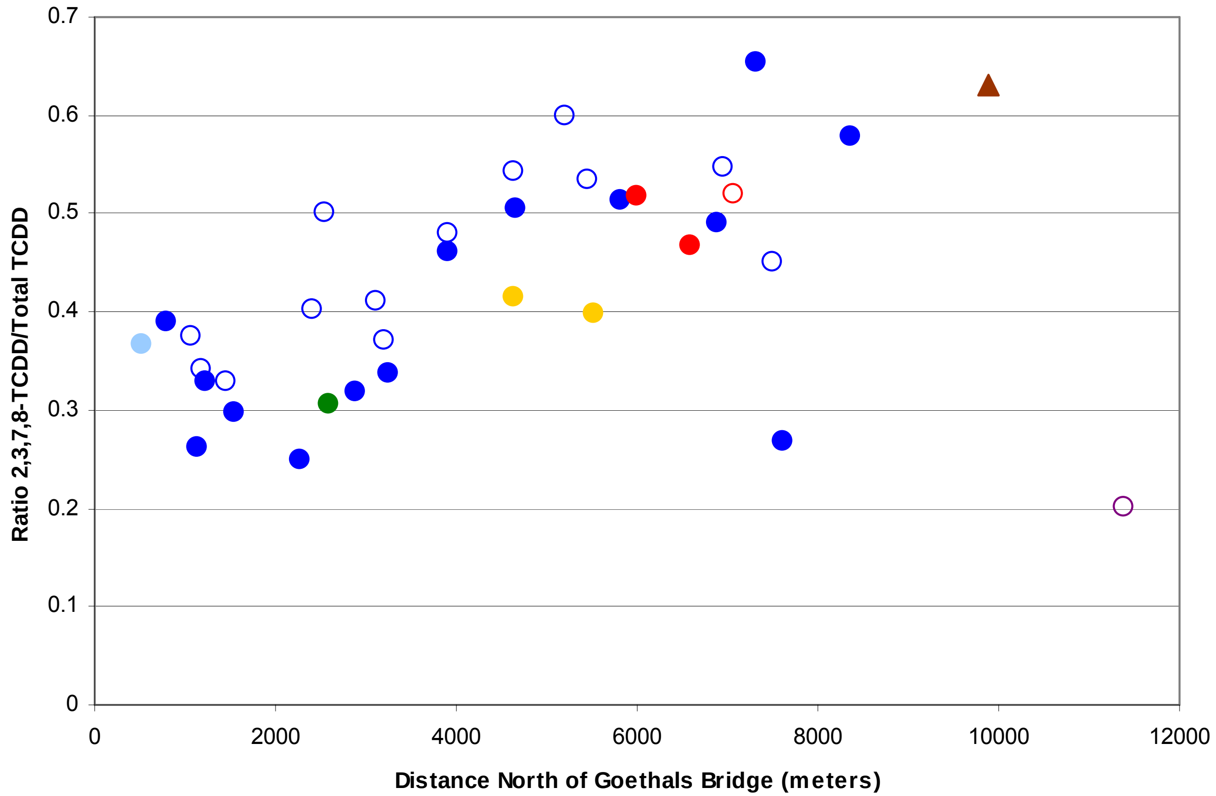
Available 2,3,7,8-TCDD/Total TCDD Surface Sediment Samples from 1997 to 2006

Lower Passaic River Restoration Project

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. However, low resolution cores represent sediments from a depth of 0 to 2.3 feet. 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 2-5

February 2007



Colors Legend

- Newark Bay
- Confluence of unnamed creek with Hackensack River
- Port Newark Channel
- Port Elizabeth Channel
- South Elizabeth Channel
- Arthur Kill
- Lower Passaic River (2005)

Symbols Legend

- Coring Locations in Navigation Channels
- Coring Locations outside Navigation Channels

Notes:

1. 2,3,7,8-TCDD and Total TCDD surface concentrations represent the top 6 inches of the core.
2. When duplicate 2,3,7,8-TCDD or Total TCDD values are provided by the laboratory, the average ratio is plotted.
3. No nondetected 2,3,7,8-TCDD or Total TCDD values were reported for the surface sediment.
4. Concentration ratios are plotted only for depositional environments, indicated by Beryllium-7 detections more than 0.5 pCi/g in the top inch of the core.
5. Data Source: Malcolm Pirnie, Inc. High Resolution Sediment Core in the Lower Passaic River (RM1.4). USEPA 2005-2006 Sampling Program.
6. Data Source: Newark Bay Phase 2 Remedial Investigation Work Plan (October 2006). Samples collected in October to December 2005.

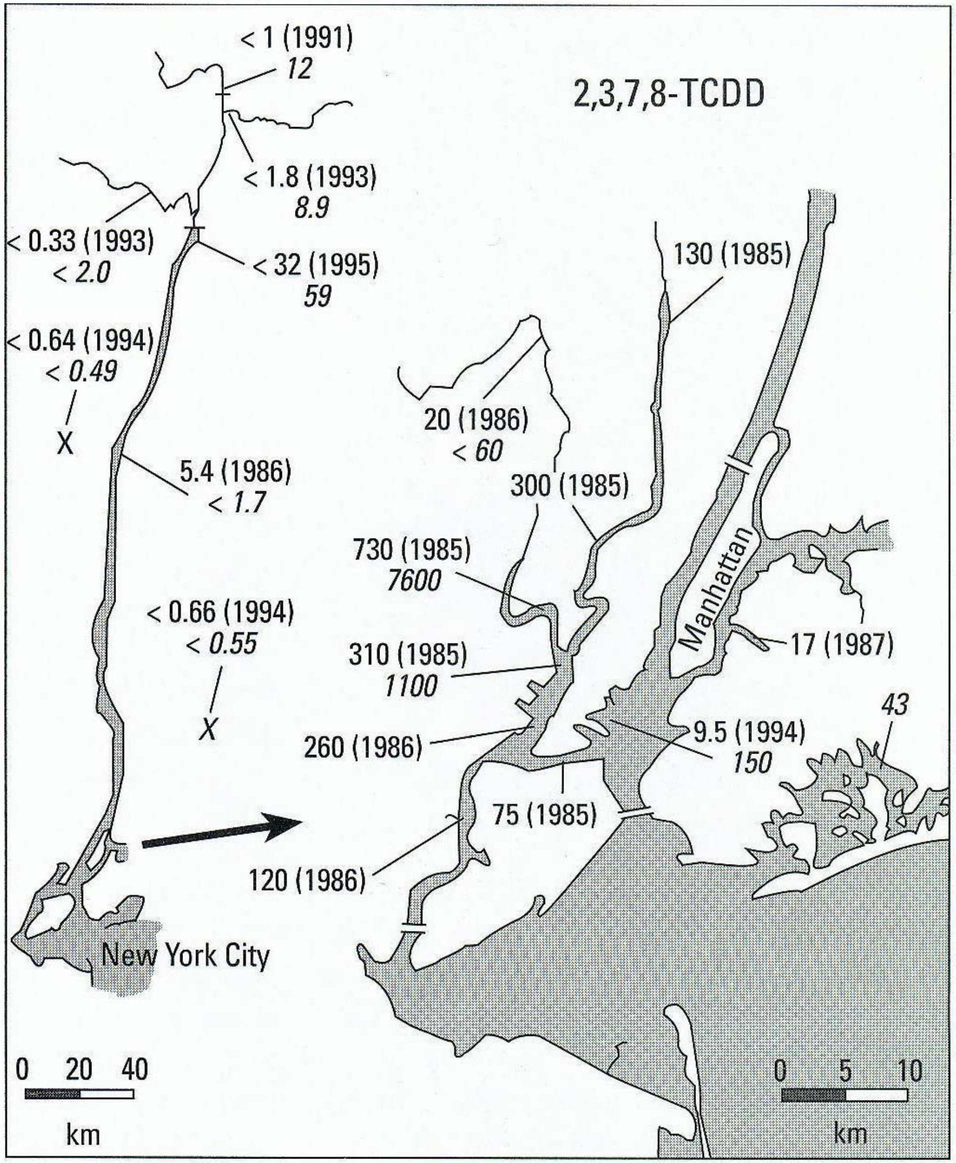
US Army Corp of Engineers

Ratio of 2,3,7,8-TCDD/Total TCDD in Newark Bay Surface Sediments

Lower Passaic River Restoration Project

Figure 2-6

February 2007



Legend

2,3,7,8-TCDD Concentration in ng/kg (Year Sample was collected)

Notes

Levels of 2,3,7,8-TCDD, measured in ng/kg, in sediment samples. Upper numbers represent the concentrations in samples deposited between the mid-1980s and the mid-1990s. Numbers in italics are concentrations in mid-1960s samples.

Bopp, R.F., S.N. Chillrud, E.L. Shuster, H.J. Simpson and F.D. Estabrooks, Trends in Chlorinated Hydrocarbon Levels in Hudson River Basin Sediments, *Environ. Health Perspect*., *106*, Supplement 4, 1075-81, 1998.

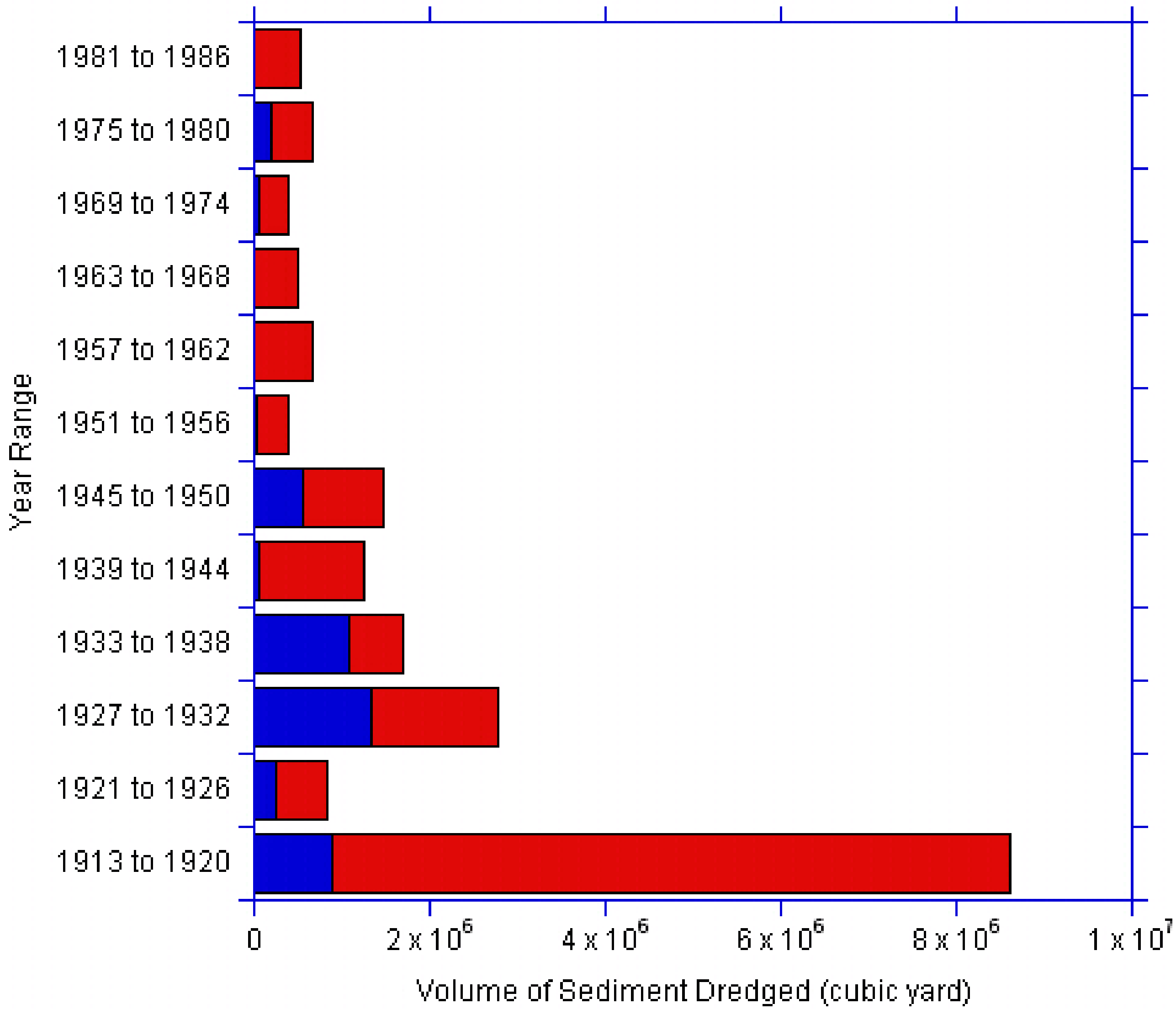
US Army Corps of Engineers

Reprint from Bopp et al., 1998: 2,3,7,8-TCDD Concentrations in Dated Sediment Samples from the Hudson-Raritan Estuary

Lower Passaic River Restoration Project

Figure 2-7

February 2007



Legend

Below RM2

Above RM2

Notes

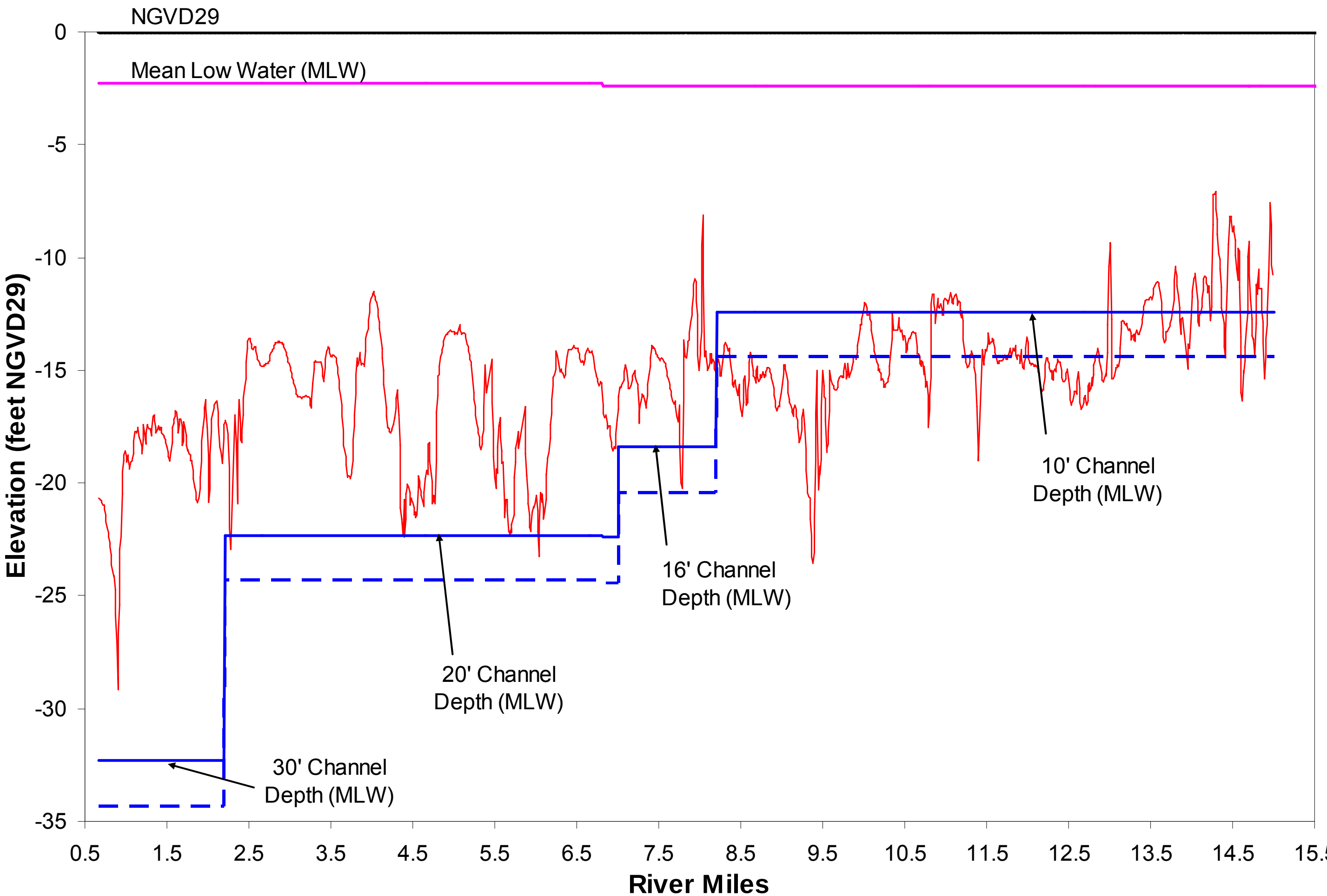
Data Sources: USACE, 1880, USACE, 1884, USACE, 1900, USACE, 1907, USACE, 1913, USACE, 1915, USACE, 1916, and USACE, 1917 as cited in Iannuzzi, *et al*., 2002 (refer to Section 10 “References” for complete citation).

The History of Dredging in the Lower Passaic River

Lower Passaic River Restoration Project

Figure 2-8

February 2007



Legend

- Navigational Channel Centerline Bathymetry
- Navigational Channel Depth
- Navigational Channel Depth + 2 feet

Notes

Channel depths were dredged relative to mean low water (MLW). The difference between NGVD29 and MLW is approximately 2.3 feet.

Solid blue line represents federally mandated channel depth.

Dashed blue line represents the channel depth +2 feet which would have been the dredged depth in order to maintain the federally specified channel depth.

Elevation data estimated from 2004 bathymetric data surveyed by Rogers Survey,Inc. for USACE.

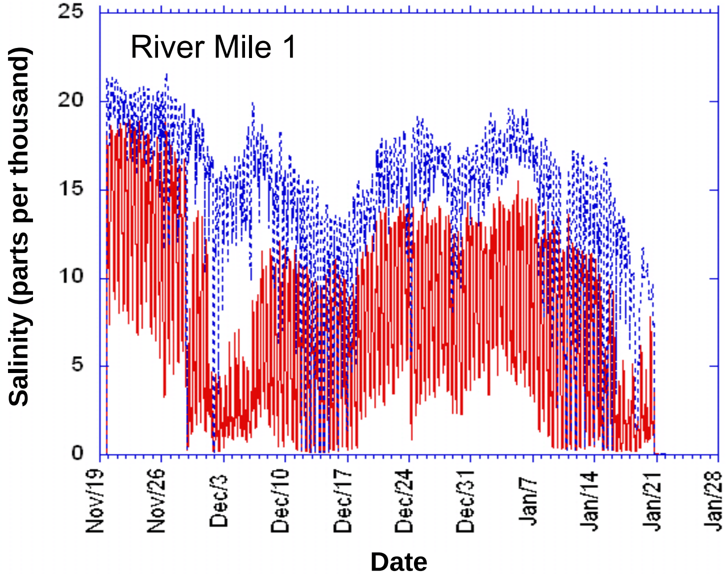
US Army Corps of Engineers

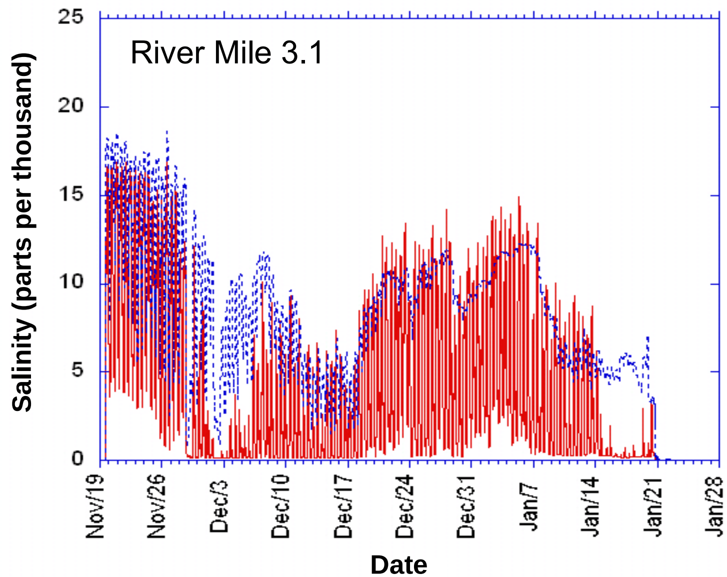
River Bottom Elevation and Authorized Channel Depths

Lower Passaic River Restoration Project

Figure 2-9

February 2007





Legend

Salinity measurements collected by Rutgers University near the river surface

Salinity measurements collected by Rutgers University near the river bottom

Notes

Measurements were collected between November 20, 2004 and January 25, 2005 by Rutgers University.

River Mile 1 – Data collected from Rutgers University Buoy #M1.

River Mile 3.1 – Data collected from Rutgers University Buoy #M2a.

Source for Rutgers University data: http://marine.rutgers.edu/cool/passaic

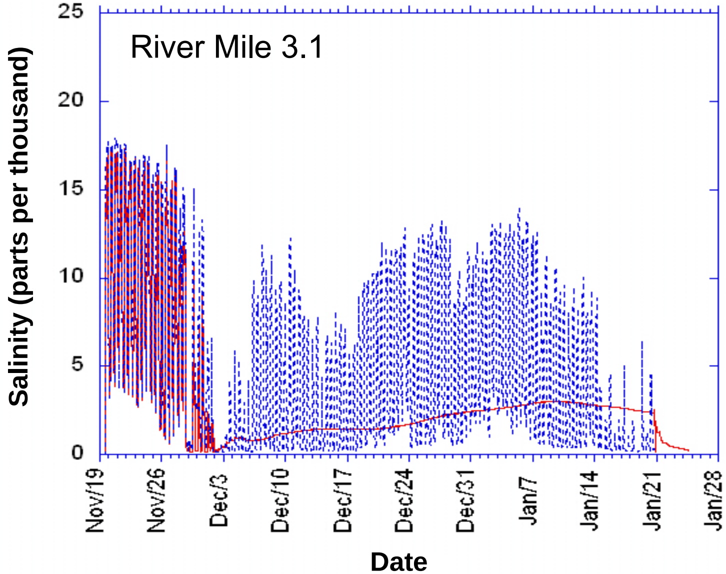
US Army Corps of Engineers

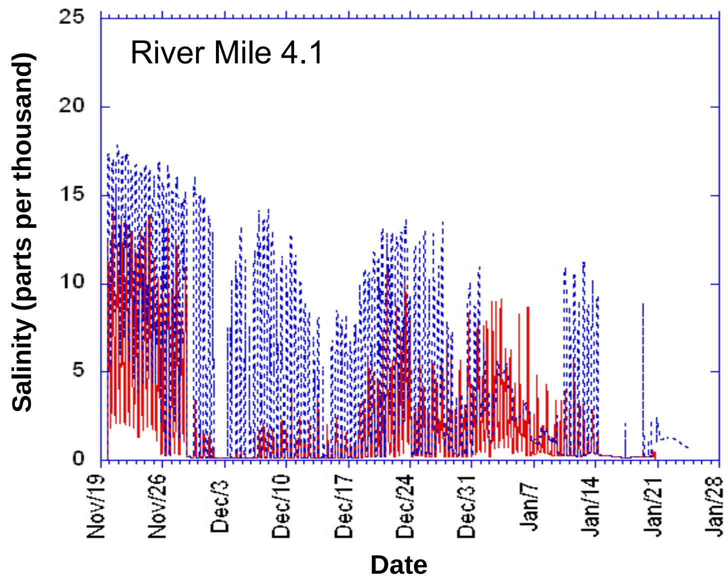
Temporal Trends in Salinity at RM1 and RM3.1

Lower Passaic River Restoration Project

Figure 3-1a

February 2007





Legend

Salinity measurements collected by Rutgers University near the river surface

Salinity measurements collected by Rutgers University near the river bottom

Notes

Measurements were collected between November 20, 2004 and January 25, 2005 by Rutgers University.

River Mile 3.1 – Data collected from Rutgers University Buoy #M2b, which was located next to Buoy #M2a.

River Mile 4.1 – Data collected from Rutgers University Buoy #M3.

Source for Rutgers University data:
http://marine.rutgers.edu/cool/passaic

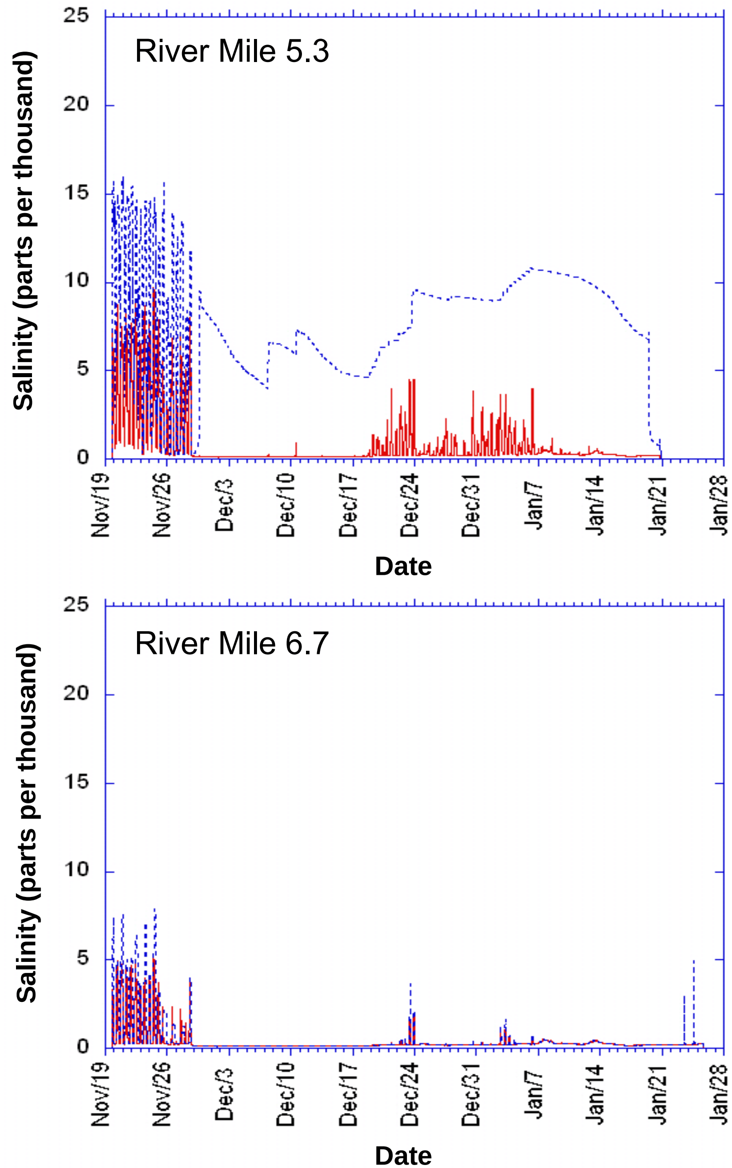
US Army Corp of Engineers

Temporal Trends in Salinity at RM3.1 and RM4.1

Lower Passaic River Restoration Project

Figure 3-1b

February 2007



Legend

Salinity measurements collected by Rutgers University near the river surface

Salinity measurements collected by Rutgers University near the river bottom

Notes

Measurements were collected between November 20, 2004 and January 25, 2005 by Rutgers University.

River Mile 5.3 – Data collected from Rutgers University Buoy #M4.

River Mile 6.7 –Data collected from Rutgers University Buoy #M5.

Source for Rutgers University data: http://marine.rutgers.edu/cool/passaic

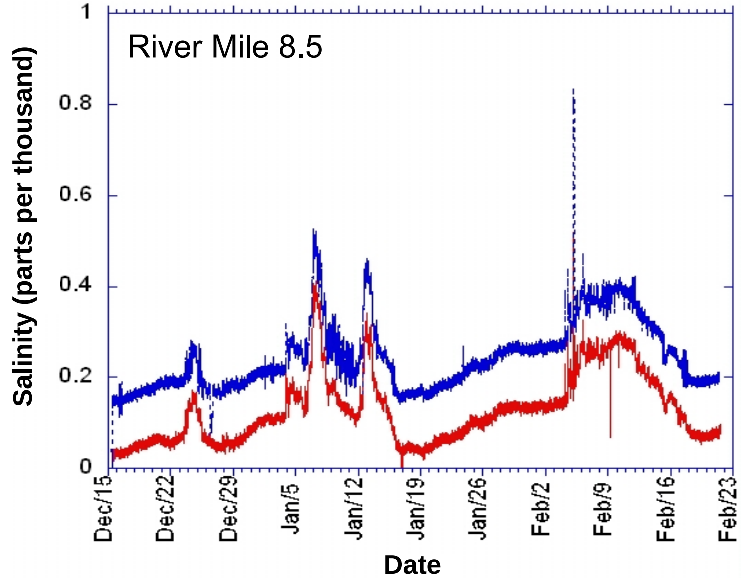
US Army Corps of Engineers

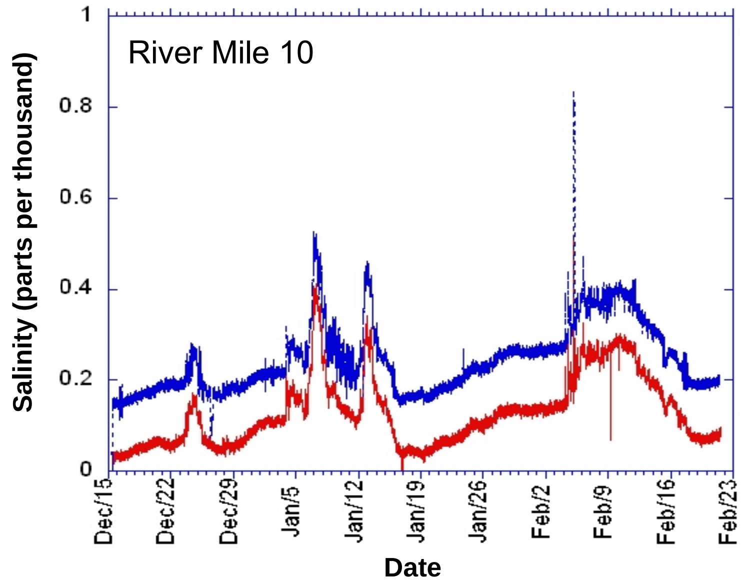
Temporal Trends in Salinity at RM5.3 and RM6.7

Lower Passaic River Restoration Project

Figure 3-1c

February 2007





Legend

Salinity measurements collected 1 meter from the river surface

Salinity measurements collected 1 meter from the river bottom

Notes

Salinity values were calculated from conductivity, temperature, and depth data recorded by a conductivity temperature depth probe.

Data collected from December 15, 2004 to February 21, 2005 by Malcolm Pirnie, Inc.

River Mile 8.5 – Data collected from Malcolm Pirnie, Inc. Buoy #3.

River Mile 10 – Data collected from Malcolm Pirnie, Inc. Buoy #2.

Salinity values less than 0.5 parts per thousand do not represent “true” salinity, but a calculated value based on dissolved minerals in water.

Salinity values less than 0.5 parts per thousand are considered “freshwater,” which are free of seawater influences.

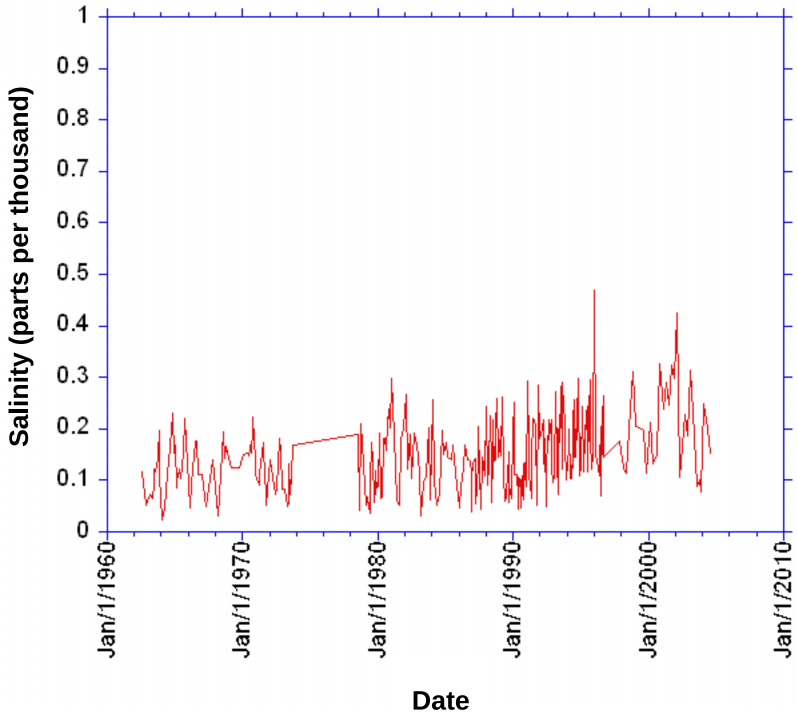
US Army Corps of Engineers

Temporal Trends in Salinity at RM8.5 and RM10

Lower Passaic River Restoration Project

Figure 3-1d

February 2007



Legend

Salinity measurements recorded by a United States Geological Survey gauging station

Notes

Salinity measurements were taken between July 30, 1962 and August 19, 2004 at the USGS Gauge at Little Falls.

Salinity values less than 0.5 parts per thousand do not represent "true" salinity, but a calculated value based on dissolved minerals in water.

Salinity values less than 0.5 parts per thousand are considered "freshwater," which are free of seawater influences.

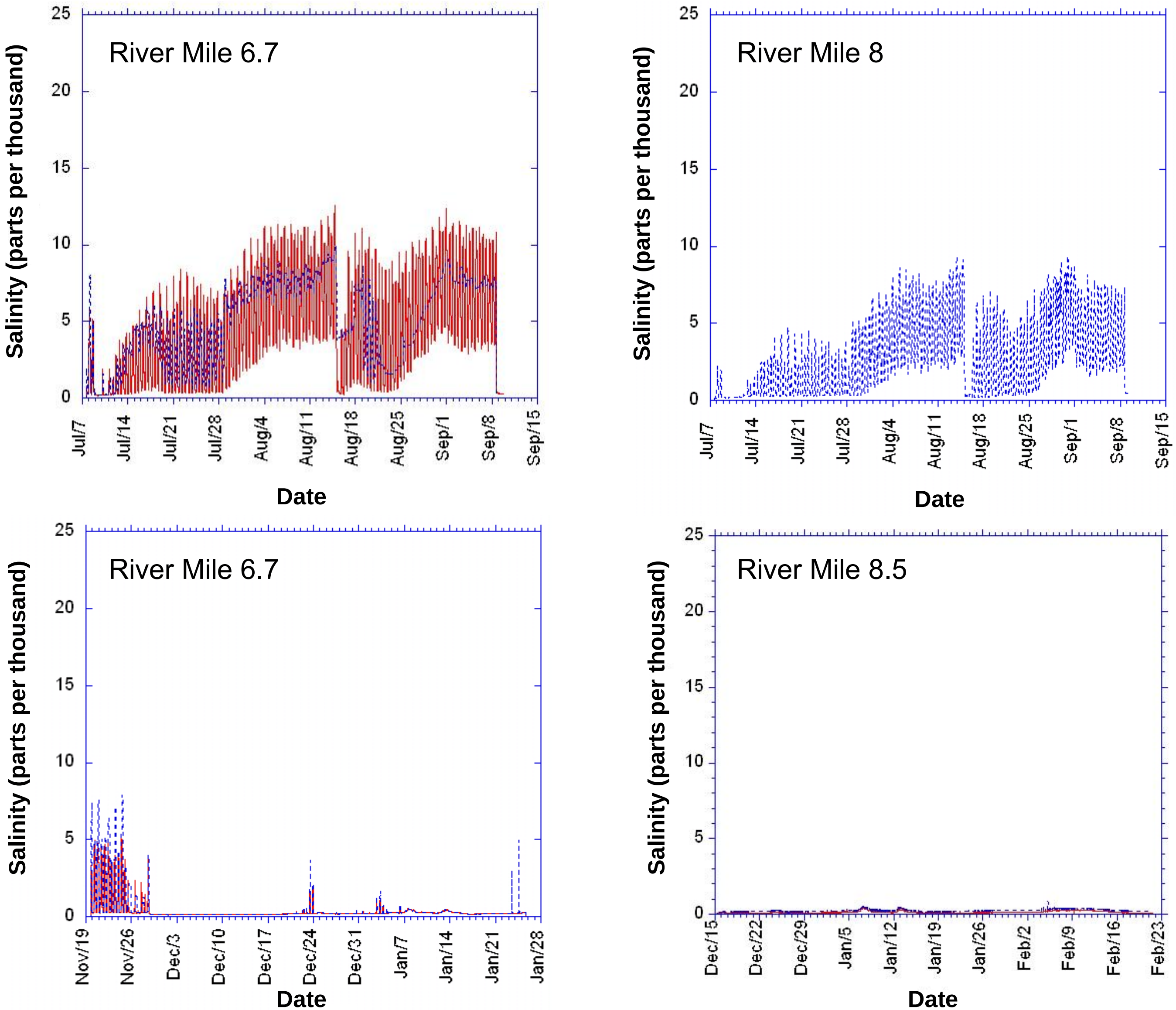
US Army Corps of Engineers

Temporal Trends in Salinity at U.S. Geological Survey Gauge at Little Falls

Lower Passaic River Restoration Project

Figure 3-1e

February 2007



Legend

Salinity measurements collected from the river surface

Salinity measurements collected from the river bottom

Notes

River Mile 6.7 – Data collected from July 8, 2004 to September 10, 2004 at Rutgers University Buoy #M5.

River Mile 8 – Data collected from July 8, 2004 to September 10, 2004 at Rutgers University Buoy #M6.

River Mile 6.7 – Data collected from November 20, 2004 to January 25, 2005 at Rutgers University Buoy #M5.

River Mile 8.5 – Data collected from December 15, 2004 to February 21, 2005 at Malcolm Pirnie, Inc. Buoy #3. Same data as Figure 3-1d on a different scale.

Source for Rutgers University data: http://marine.rutgers.edu/cool/passaic

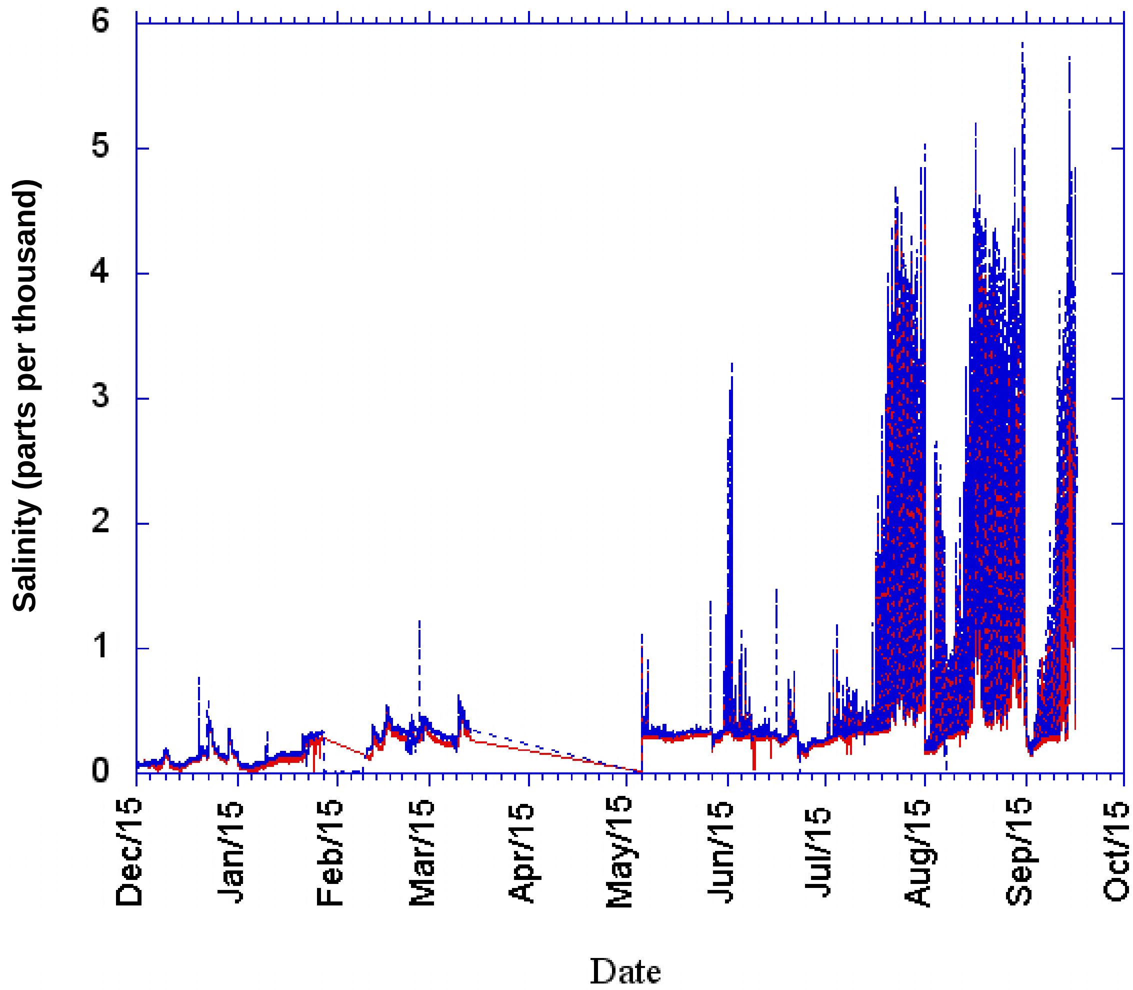
US Army Corps of Engineers

Seasonal Effects on Salinity

Lower Passaic River Restoration Project

Figure 3-1f

February 2007



Legend

Salinity measurements collected from the river surface

Salinity measurements collected from the river bottom

Notes

Salinity values were calculated from conductivity, temperature, and depth data recorded by a conductivity temperature depth probe.

Data collected from December 15, 2004 to September 30, 2005 by Malcolm Pirnie, Inc.

River Mile 10 – Data collected from Malcolm Pirnie, Inc. Buoy #2.

US Army Corps of Engineers

Temporal Trends in Salinity at RM10

Lower Passaic River Restoration Project

Figure 3-1g

February 2007

Legend

- Rock and Coarse gravel
- Gravel and Sand
- Sand
- Silt and Sand
- Silt
- River Mile Post

2004 USACE Bathymetric Survey

Elevation (Feet) Relative to NGVD29

- -30 to -20
- -8 to 0
- -18 to -10
- 2 to 10

Notes

Data Sources:
Buildings: CADD drawing, 09994X01, dated January 1, 2002 received from BBL.

Roads: 2000 TIGER line data.

Sediment Texture: 2005 Side scan SONAR data from Aqua Survey, Inc.

US Army Corps of Engineers

Side-Scan Sonar Survey Interpretation of Lower Passaic River Bottom Sediments near RM8

Lower Passaic River Restoration Project

Figure 3-2

February 2007

River Mile 1.4 (left-bank descending) Kearny, NJ

River Mile 1.6 (left-bank descending) Kearny, NJ

River Mile 1.7 (left-bank descending) Kearny, NJ

River Mile 2.1 (right-bank descending) Newark, NJ

Photolog of Shoreline Conditions and Surrounding Habitat
Brackish River Section (Part 1)

Lower Passaic River Restoration Project

Figure 3-3a

February 2007

River Mile 3.5 (left-bank descending) Newark, NJ

River Mile 4.0 (right-bank descending) Newark, NJ

River Mile 5.1 (right-bank descending) Newark, NJ

River Mile 5.5 (left-bank descending) Harrison, NJ

Photolog of Shoreline Conditions and Surrounding Habitat
Brackish River Section (Part 2)

Lower Passaic River Restoration Project

Figure 3-3b

February 2007

River Mile 6.3 (left-bank descending) Kearny, NJ

River Mile 6.8 (left-bank descending) Kearny, NJ

River Mile 7.1 (left-bank descending) Kearny, NJ

River Mile 7.8 (right-bank descending) Kearny, NJ

Photolog of Shoreline Conditions and Surrounding Habitat
Transitional River Section

Lower Passaic River Restoration Project

Figure 3-3c

February 2007

River Mile 12.8 (right-bank descending) Passaic, NJ

River Mile 15.8 (right-bank descending) Passaic, NJ

River Mile 15.9 (right-bank descending) Passaic, NJ

US Army Corps of Engineers

Photolog of Shoreline Conditions and Surrounding Habitat
Freshwater River Section (Part 1)

Lower Passaic River Restoration Project

Figure 3-3d

February 2007

River Mile 16.6 (left-bank descending) Garfield, NJ

River Mile 17.2 (left-bank descending) Garfield, NJ

River Mile 17.2 (left-bank descending) Garfield, NJ

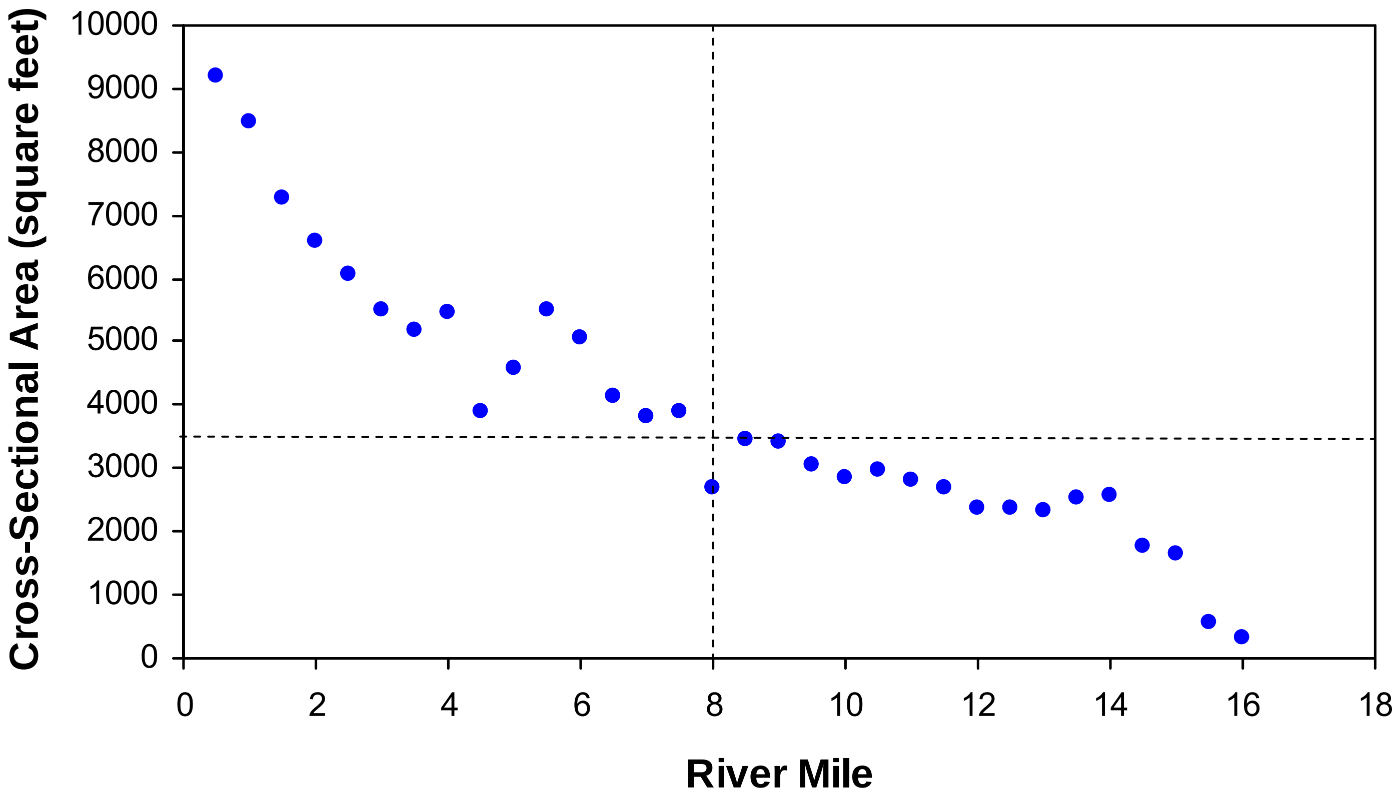
River Mile 17.4 (Dundee Dam) Clifton and Garfield, NJ

Photolog of Shoreline Conditions and Surrounding Habitat
Freshwater River Section (Part 2)

Lower Passaic River Restoration Project

Figure 3-3e

February 2007



Legend

Cross-Sectional Area (square feet)

Highlights the change to a river cross sectional area of 3,500 square feet at RM8

Notes

Cross-sectional area estimated from 2004 bathymetric data surveyed by Rogers Survey, Inc. for USACE.

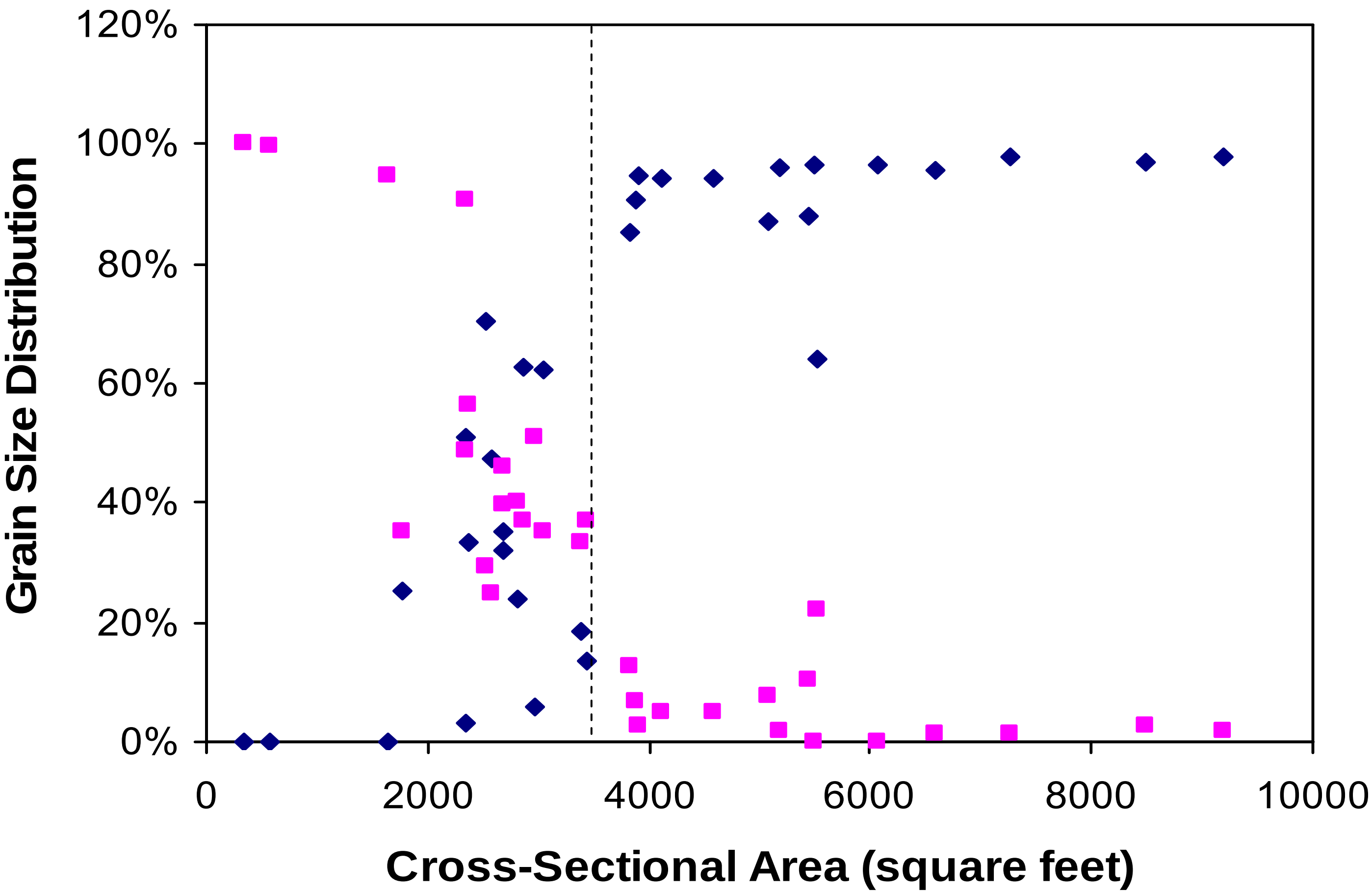
Cross-sectional area refers to the water filled area of the river channel when water level is equal to 0 feet elevation at NGVD29.

Variation of Lower Passaic River Cross-Sectional Area with River Mile

Lower Passaic River Restoration Project

Figure 3-4

February 2007



Legend

Fine-grained sediment

Coarse-grained sediment

Highlights the change to a river cross sectional area of 3,500 square feet

Notes

Cross-sectional area estimated from 2004 bathymetric data surveyed by Rogers Survey, Inc. for USACE.

Sediment texture was evaluated based on data interpolated by Aqua Survey, Inc. using side-scan sonar images (Aqua Survey, Inc., 2006). Sediment texture data extends from RM0 to RM16.5.

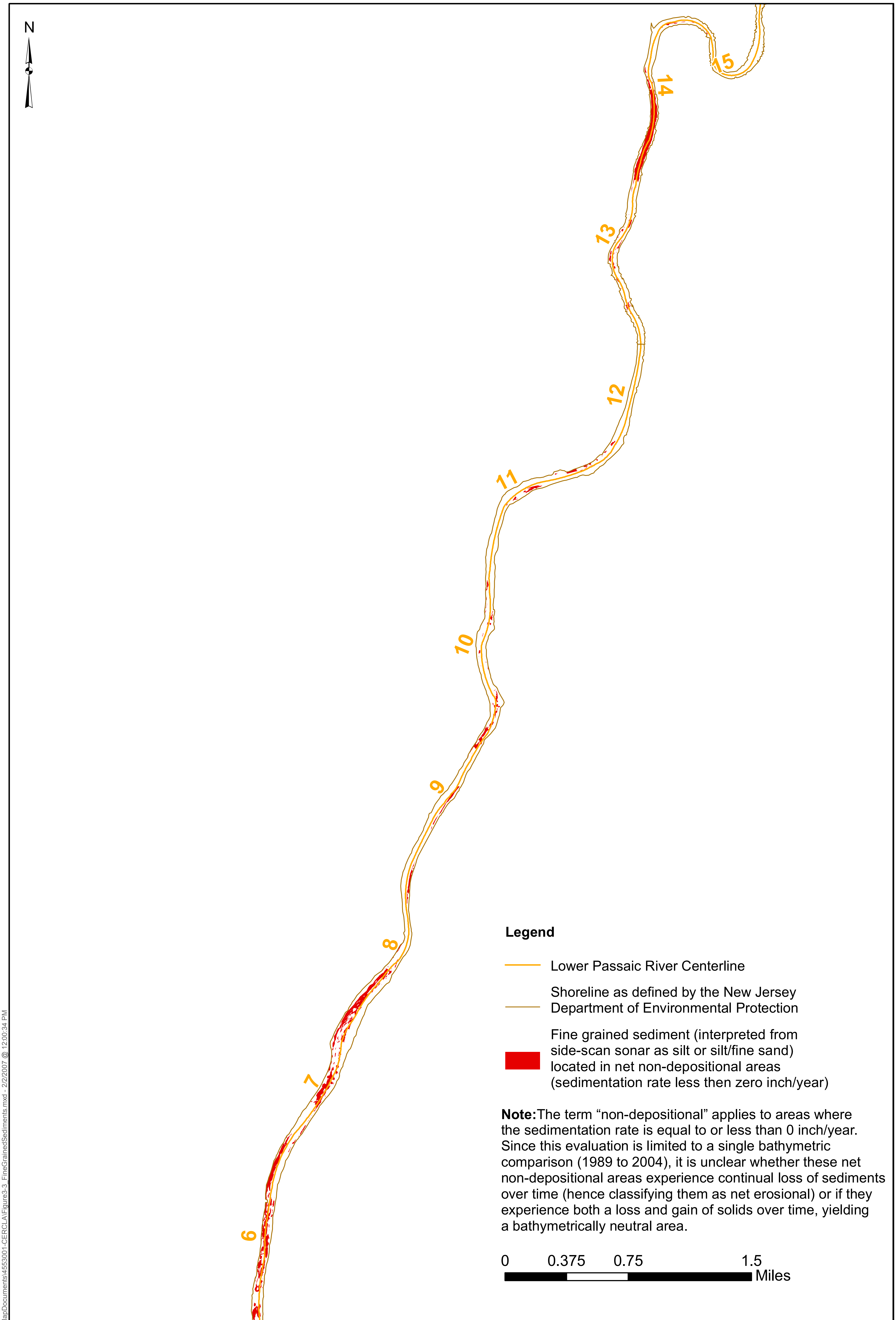
Refer to Figure 1-6 for relationship between river mile and cross-sectional area.

Variation of Lower Passaic River Sediment Type with River Cross-Sectional Area

Lower Passaic River Restoration Project

Figure 3-5

February 2007



Fine-Grained Sediments in Net Non-Depositional Areas Upriver of RM6

Lower Passaic River Restoration Project

Data Source:
1989 Bathymetric Survey: Topo Metrics,Inc for USACE
2004 Bathymetric Survey: Rogers Surveying for USACE
2005 Sediment Texture: Aqua Survey, Inc.
Note: Analysis was limited by the extent of the 1989 bathymetric survey (RM0 to RM15).

Figure 3-6

February 2007

S:\Projects\PASSAIC\MapDocuments\4553001-CERCLA\Figure3-3_FineGrainedSediments.mxd - 2/2/2007 @ 12:00:34 PM

Legend

Elevation (feet) relative to NGVD29

Notes

Elevation data estimated from 2004 bathymetric data surveyed by Rogers Survey, Inc. for USACE.

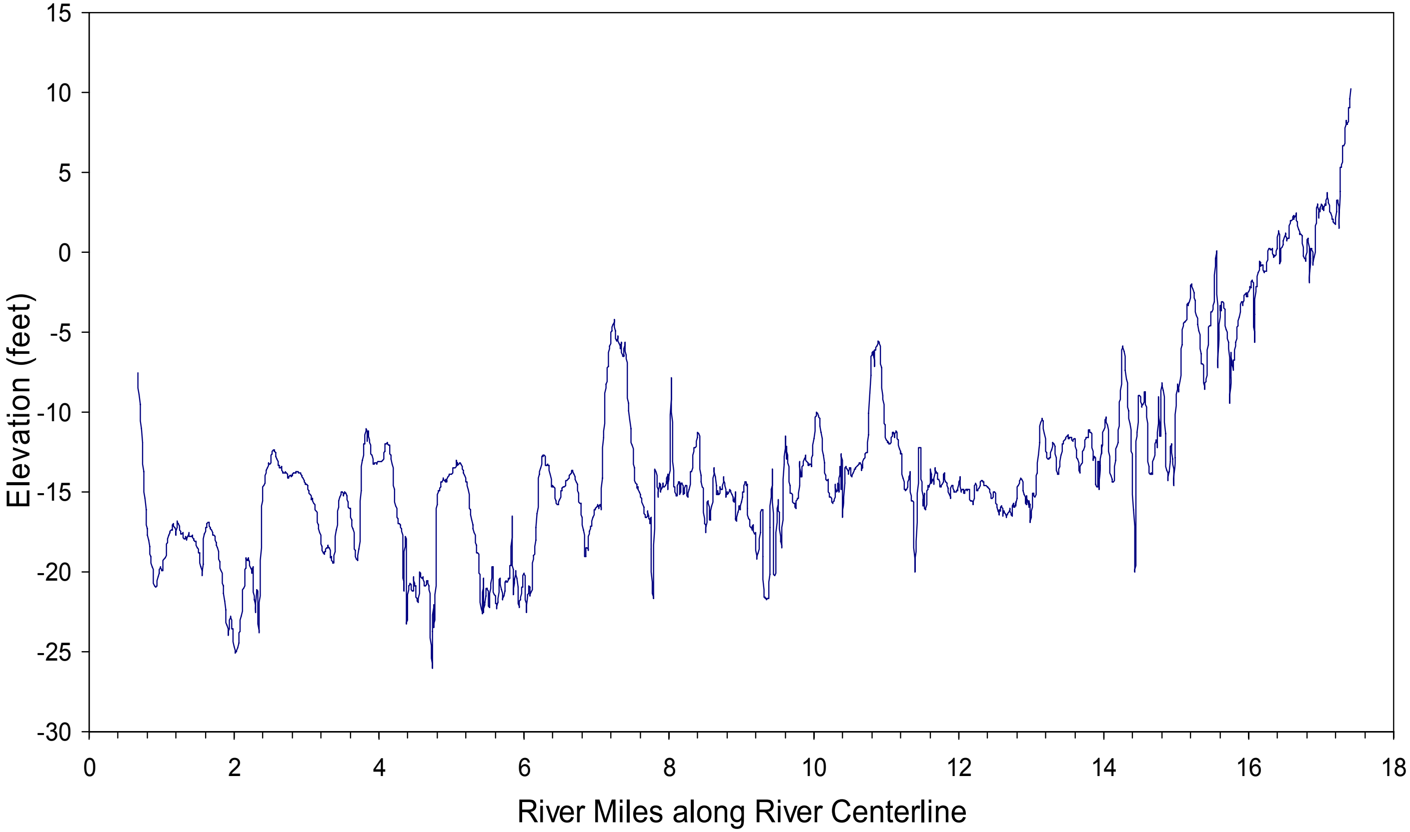
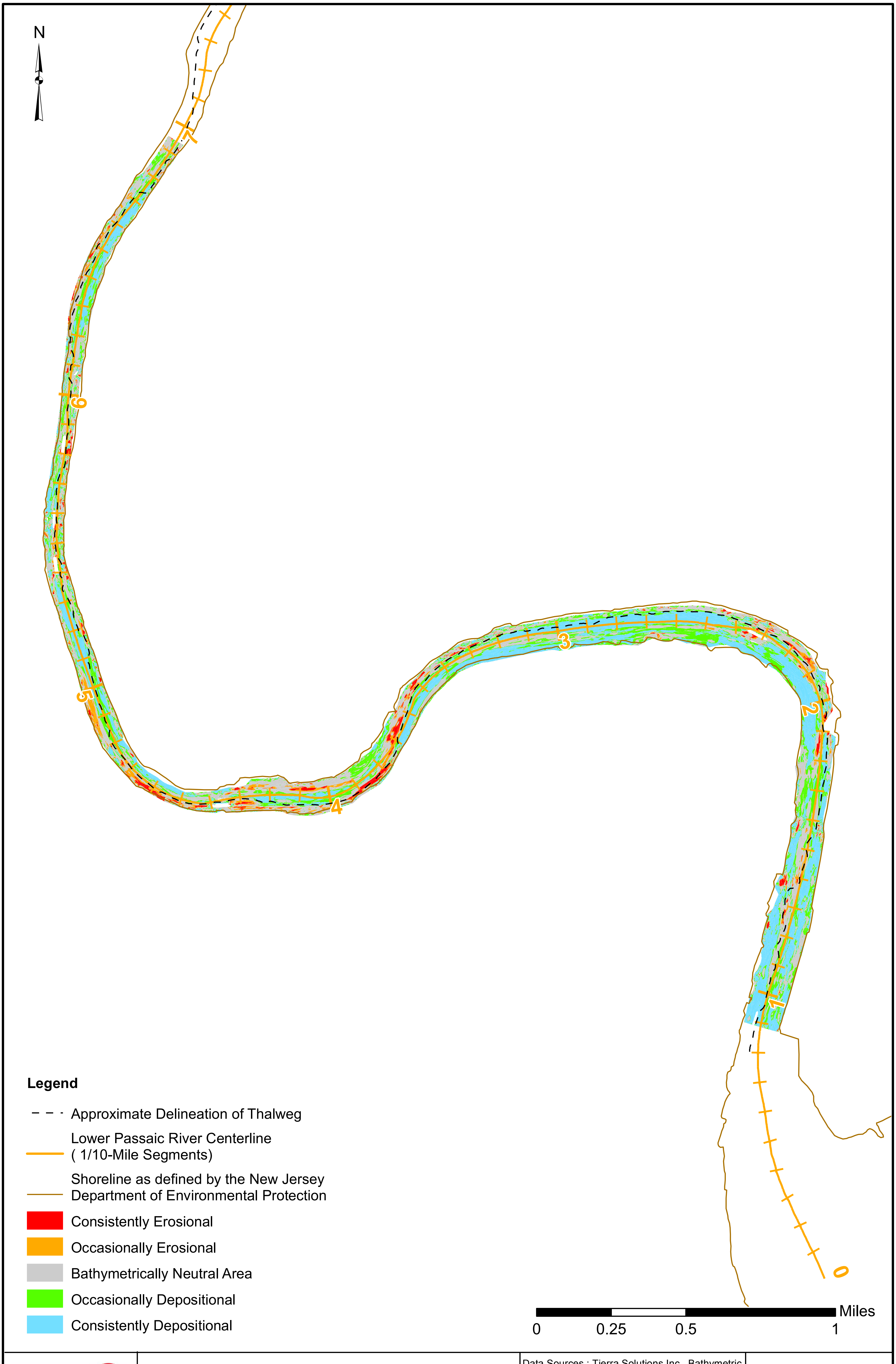


Figure 3-7

River Bottom Elevation

Lower Passaic River Restoration Project

February 2007



Net Erosional and Net Depositional Areas (RM0.9 to RM7)

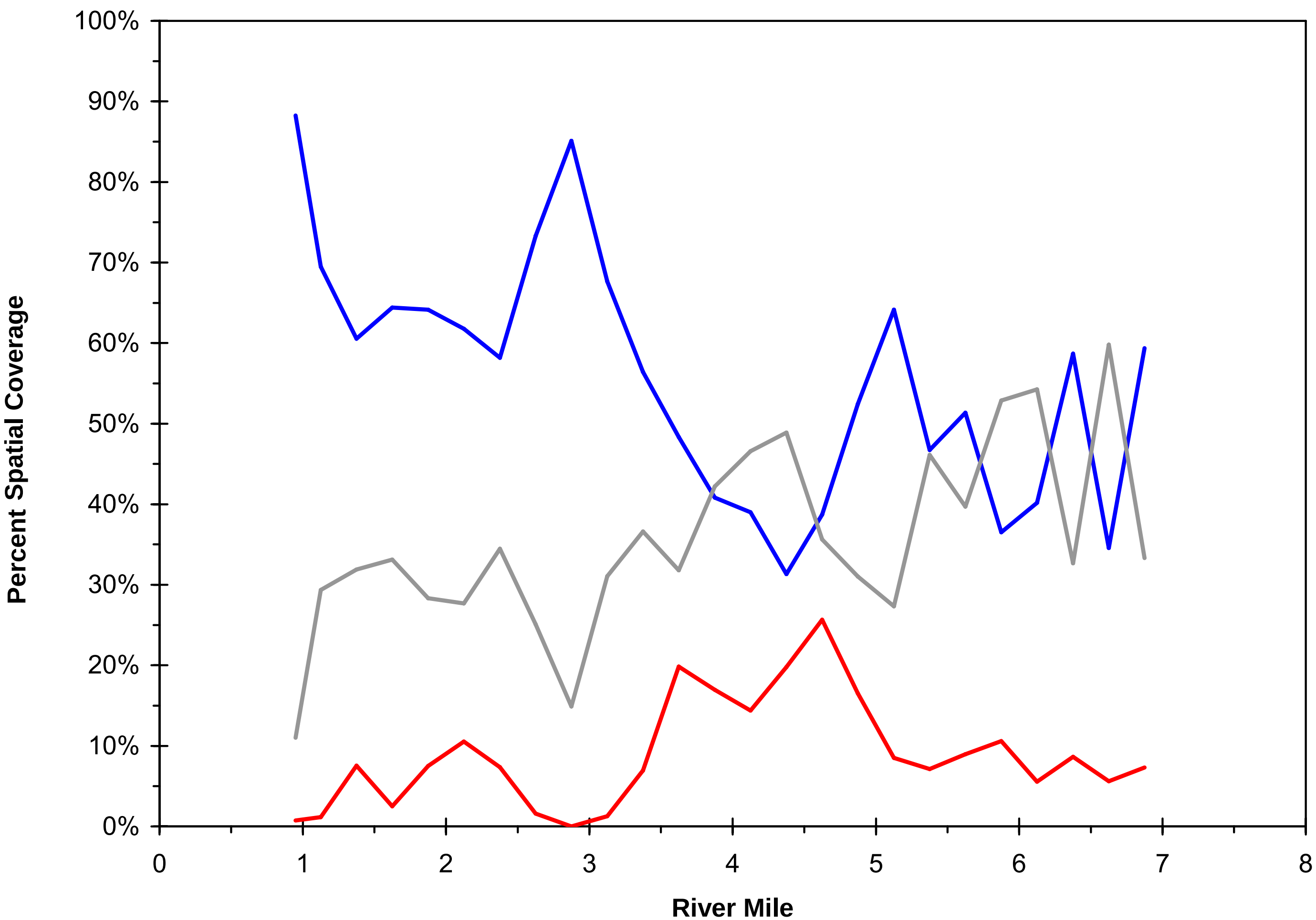
Lower Passaic River Restoration Project

Data Sources : Tierra Solutions Inc., Bathymetric Surveys for 1995,1996,1997,1999 and 2001

Figure 5-1

February 2007

Map Document: (S:\Projects\PASSAIC\MapDocuments\4553001-CERCLA\Figure4-1.mxd) 8/25/2006 -- 3:55:03 PM



Legend

Consistently and Occasionally Erosional

Consistently and Occasionally Depositional

Bathymetrically Neutral Area

Notes

Refer to Figure 5-1 for more detail on net erosional, net depositional, and bathymetrically neutral areas.

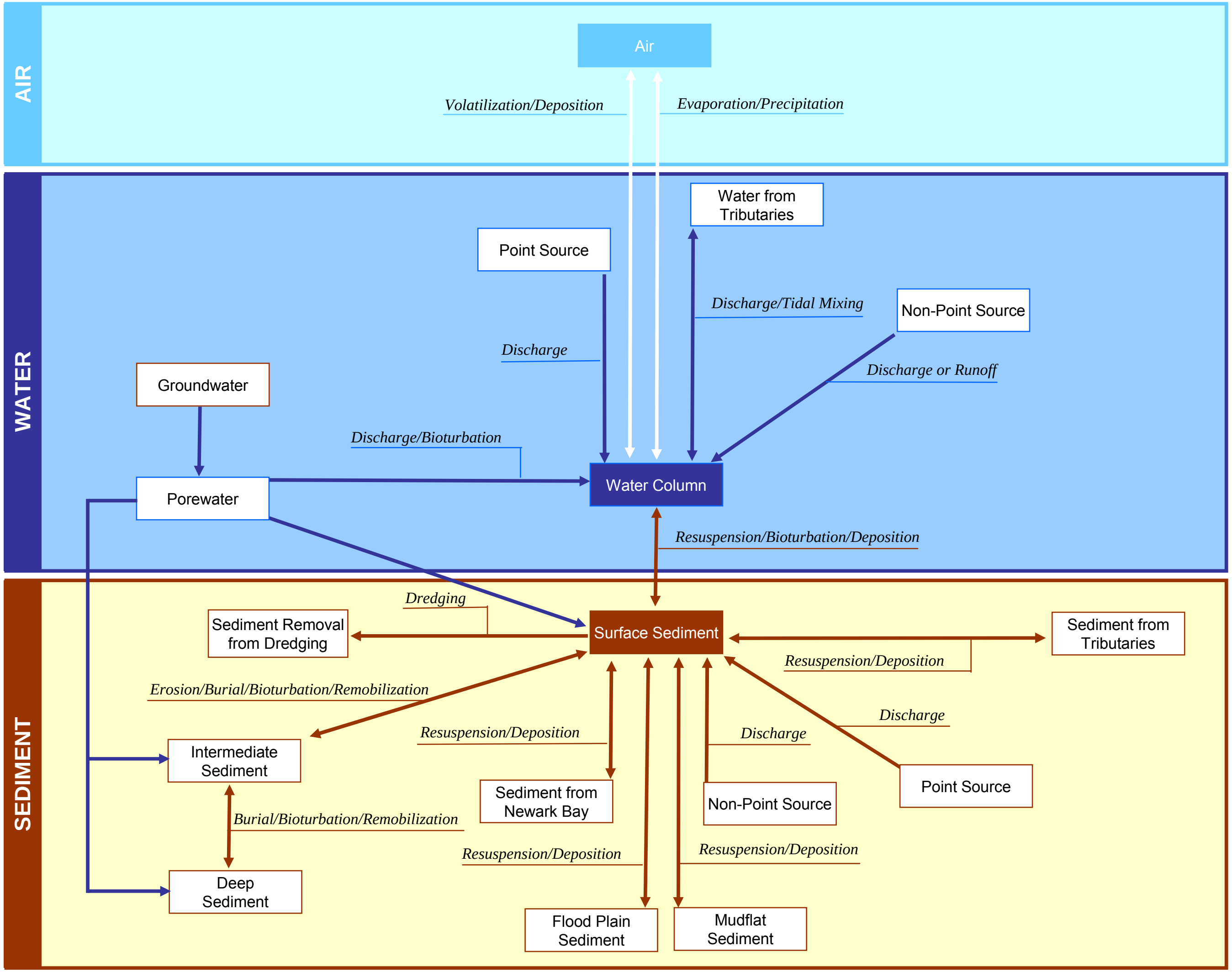
US Army Corps of Engineers

Percent Spatial Coverage of Net Erosional, Net Depositional, and Bathymetrically Neutral Areas

Lower Passaic River Restoration Project

Figure 5-2

February 2007



NOTES

Figure 6-1 depicts substantive physical processes that affect the transport of contaminants between different media. Some physical processes may be less significant or absent in certain river sections. Future iterations of the CSM will prioritize these physical processes. Note that the chemical fate and transport processes are depicted in subsequent figures.

The color scheme used in Figure 6-1 reflects different media, including air (light blue), water (dark blue), and sediment (brown), and it represents the media depicted in Figure 2-2.

LEGEND

Groundwater	Sources of contaminants to the Lower Passaic River
	Release mechanisms connecting associated inventories (bi-directional arrows are marked with two mechanisms separated by a slash mark)

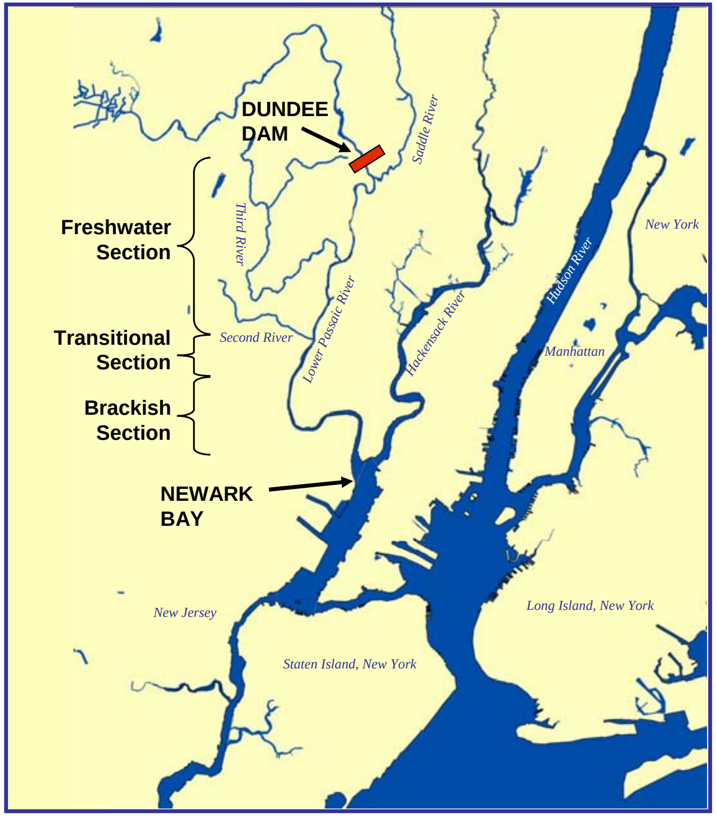
Input to Human Health and Ecological Evaluations

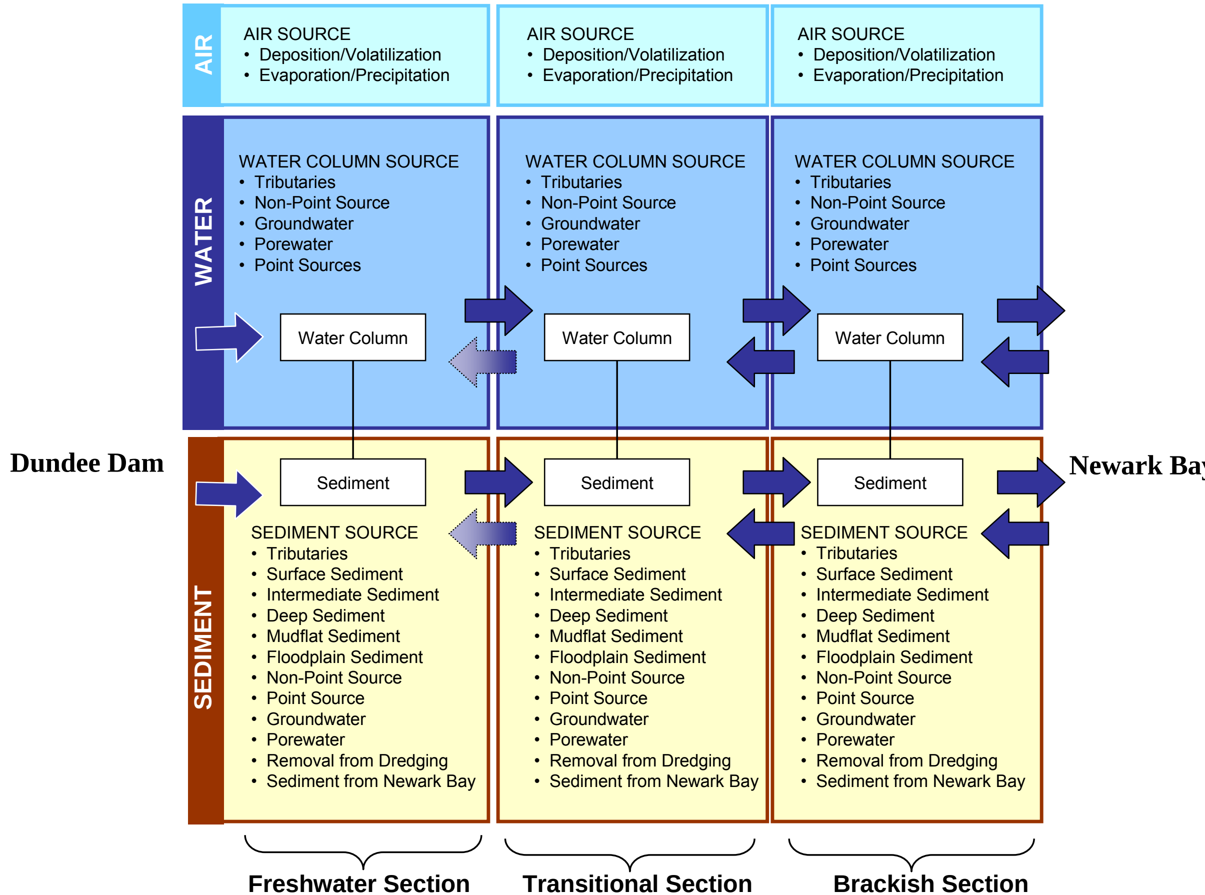
General Sources and Physical Release Mechanisms for Contaminants in Sediment, Water, and Air

Lower Passaic River Restoration Project

Figure 6-1

February 2007





LEGEND

Direction of substantive water flow and sediment transport on the Lower Passaic River

Direction of potential water flow and sediment transport on the Lower Passaic River

NOTES

Sources and processes shown in Figure 6-1 are applicable to Figure 6-2; however, for simplicity, arrows presented in Figure 6-1 are not duplicated in Figure 6-2. Note that some sources may be less significant or absent in certain river sections; future iteration of the CSM will prioritize these sources.

The color scheme and boxes used in Figure 6-2 reflect different media, including air (light blue box), water (dark blue box), and sediment (brown box), and they represent the sources, mechanisms, and media depicted in Figure 2-2 and Figure 6-1.

Future iterations of the CSM will prioritize these sources.

Input to Human Health and Ecological Evaluations

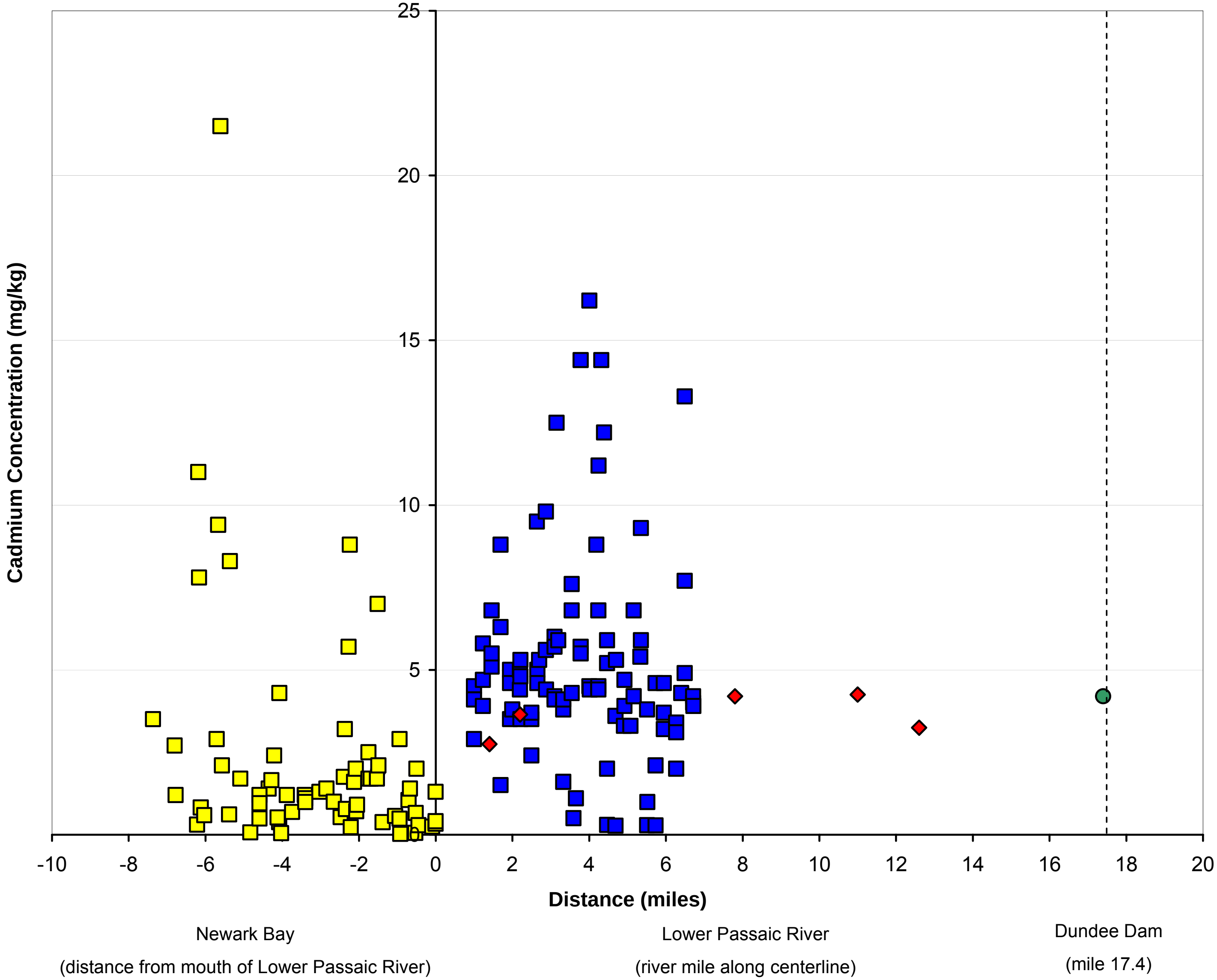
US Army Corp of Engineers

General Sources of Contamination in Each River Section

Lower Passaic River Restoration Project

Figure 6-2

February 2007



Legend

Malcolm Pirnie, Inc. (2005) (represents 2003-2005 time horizon)

TSI (2005) (represents 0-6 inches of sediment)

TSI (1995) (represents 0-6 inches of sediment)

Bopp *et al.* (2006) (represents 1985-1986 time horizon)

Notes

Malcolm Pirnie, Inc. Data Source: USEPA 2005-2006 Sampling Program.

TSI Data Source: 2005 Newark Bay Phase I Investigation and 1995 TSI Dataset.

Bopp Data Source: "Contaminant Chronologies from Hudson River Sedimentary Records," Bopp *et al.* (2006).

Nondetect (lab qualifier containing a U) plotted as half the reported value.

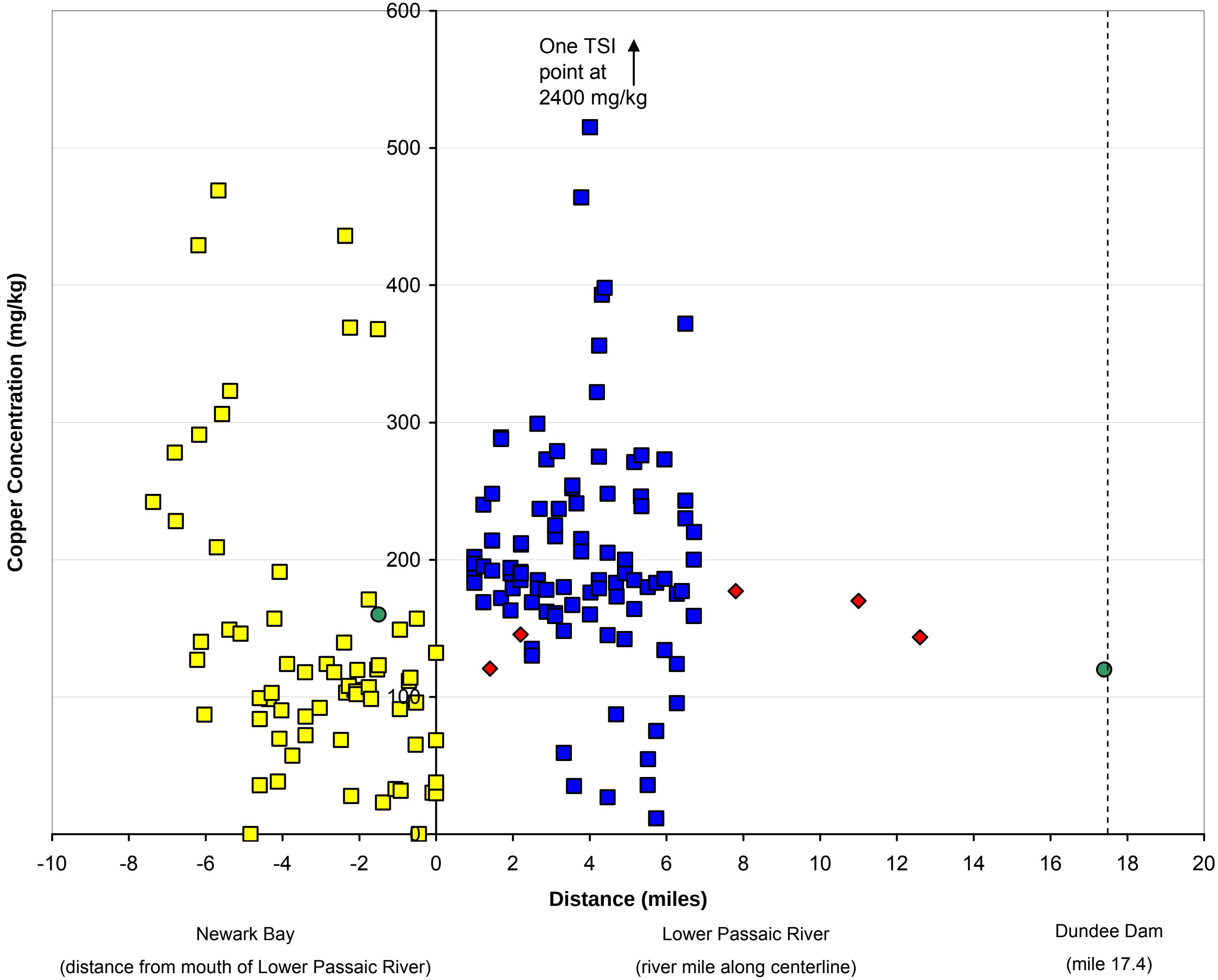
Surface concentrations represent a depth of 0 to <1 foot.

Comparison of Surface Cadmium Concentrations in 1985-1986, 1995, and 2005

Lower Passaic River Restoration Project

Figure 6-3a

February 2007



Legend

- Malcolm Pirnie, Inc. (2005) (represents 2003-2005 time horizon)
- TSI (2005) (represents 0-6 inches of sediment)
- TSI (1995) (represents 0-6 inches of sediment)
- Bopp *et al.* (2006) (represents 1985-1986 time horizon)

Notes

Malcolm Pirnie, Inc. Data Source: USEPA 2005-2006 Sampling Program.

TSI Data Source: 2005 Newark Bay Phase I Investigation and 1995 TSI Dataset.

Bopp Data Source: "Contaminant Chronologies from Hudson River Sedimentary Records," Bopp *et al.* (2006).

Nondetect (lab qualifier containing a U) plotted as half the reported value.

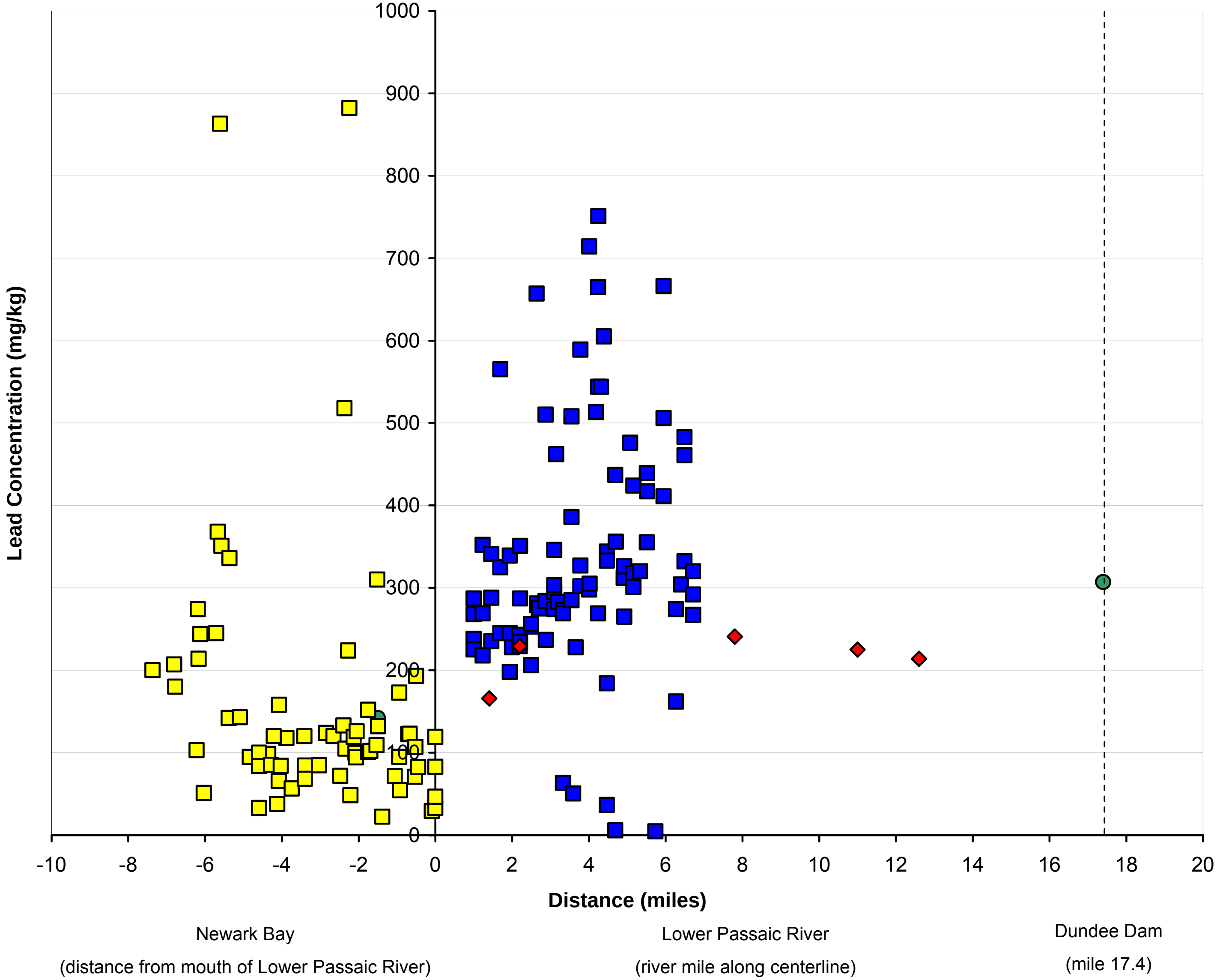
Surface concentrations represent a depth of 0 to <1 foot.

Comparison of Surface Copper Concentrations in 1985-1986, 1995, and 2005

Lower Passaic River Restoration Project

Figure 6-3b

February 2007



Legend

Malcolm Pirnie, Inc. (2005) (represents 2003-2005 time horizon)

TSI (2005) (represents 0-6 inches of sediment)

TSI (1995) (represents 0-6 inches of sediment)

Bopp *et al.* (2006) (represents 1985-1986 time horizon)

Notes

Malcolm Pirnie, Inc. Data Source: USEPA 2005-2006 Sampling Program.

TSI Data Source: 2005 Newark Bay Phase I Investigation and 1995 TSI Dataset.

Bopp Data Source: "Contaminant Chronologies from Hudson River Sedimentary Records," Bopp *et al.* (2006).

Nondetect (lab qualifier containing a U) plotted as half the reported value.

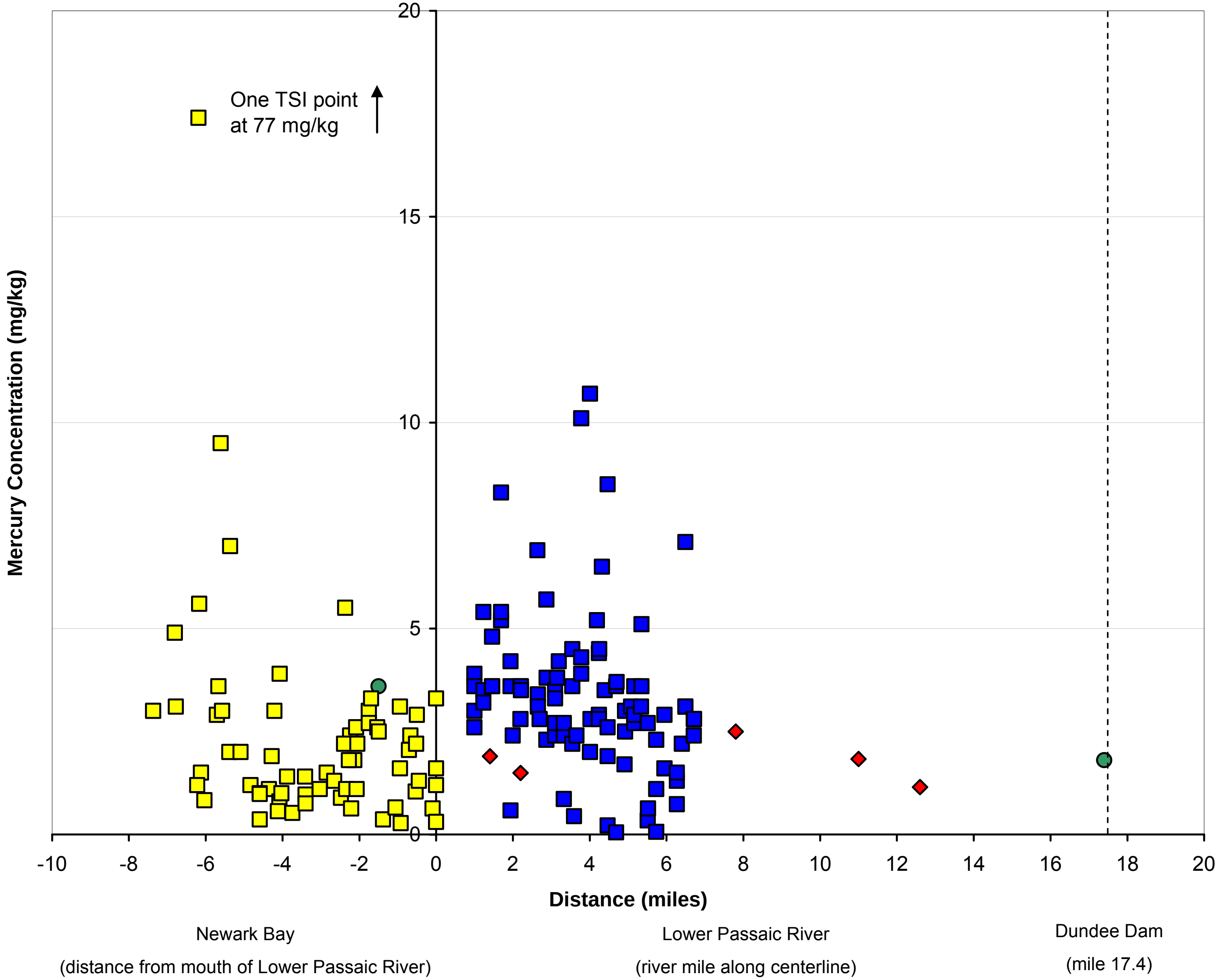
Surface concentrations represent a depth of 0 to <1 foot.

Comparison of Surface Lead Concentrations in 1985-1986, 1995, and 2005

Lower Passaic River Restoration Project

Figure 6-3c

February 2007



Legend

Malcolm Pirnie, Inc. (2005) (represents 2003-2005 time horizon)

TSI (2005) (represents 0-6 inches of sediment)

TSI (1995) (represents 0-6 inches of sediment)

Bopp *et al.* (2006) (represents 1985-1986 time horizon)

Notes

Malcolm Pirnie, Inc. Data Source: USEPA 2005-2006 Sampling Program.

TSI Data Source: 2005 Newark Bay Phase I Investigation and 1995 TSI Dataset.

Bopp Data Source: "Contaminant Chronologies from Hudson River Sedimentary Records," Bopp *et al.* (2006).

Nondetect (lab qualifier containing a U) plotted as half the reported value.

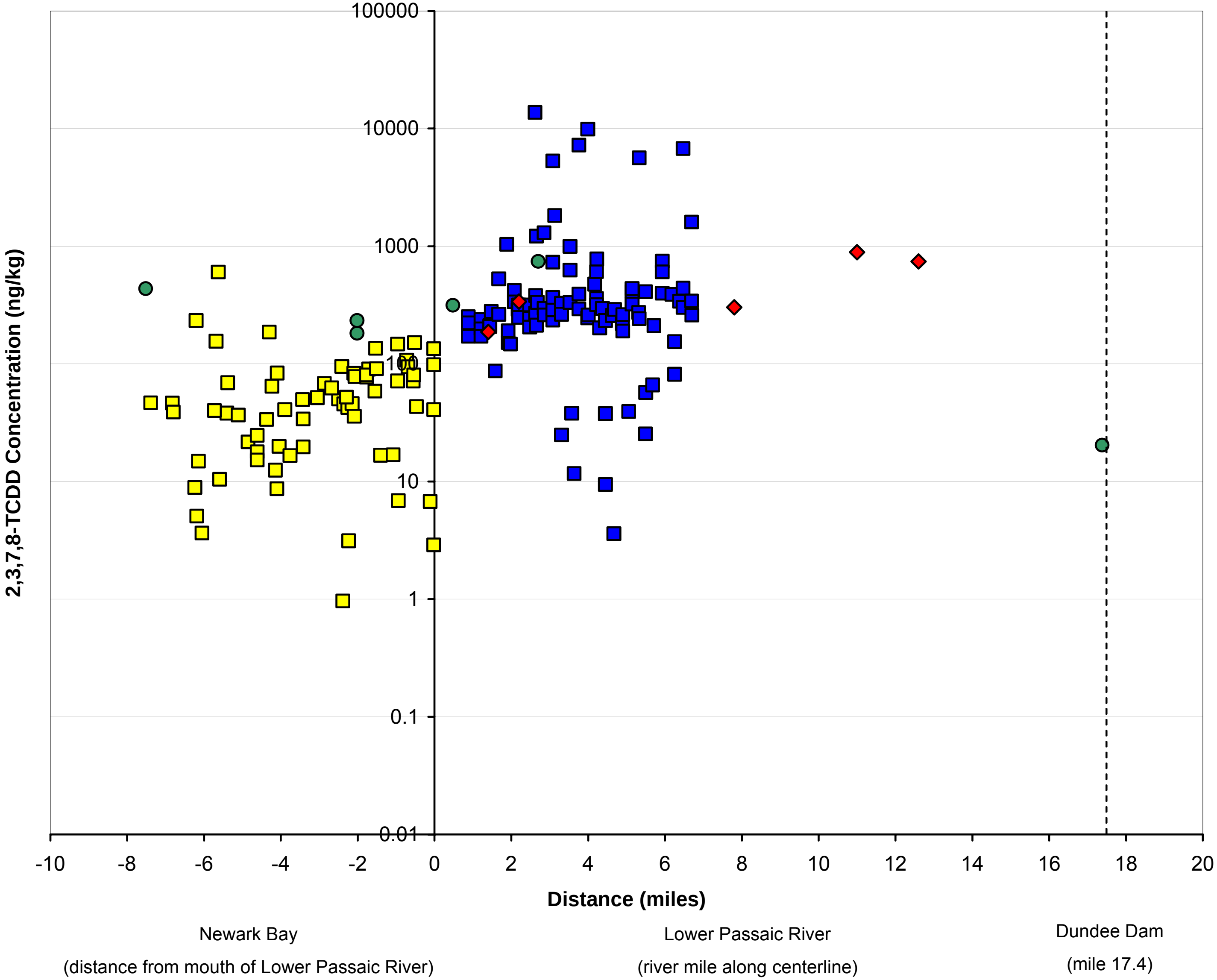
Surface concentrations represent a depth of 0 to <1 foot.

Comparison of Surface Mercury Concentrations in 1985-1986, 1995, and 2005

Lower Passaic River Restoration Project

Figure 6-3d

February 2007



Legend

- Malcolm Pirnie, Inc. (2005) (represents 2003-2005 time horizon)
- TSI (2005) (represents 0-6 inches of sediment)
- TSI (1995) (represents 0-6 inches of sediment)
- Bopp *et al.* (2006) (represents 1985-1986 time horizon)

Notes

Malcolm Pirnie, Inc. Data Source: USEPA 2005-2006 Sampling Program.

TSI Data Source: 2005 Newark Bay Phase I Investigation and 1995 TSI Dataset.

Bopp Data Source: "Contaminant Chronologies from Hudson River Sedimentary Records," Bopp *et al.* (2006).

Nondetect (lab qualifier containing a U) plotted as half the reported value.

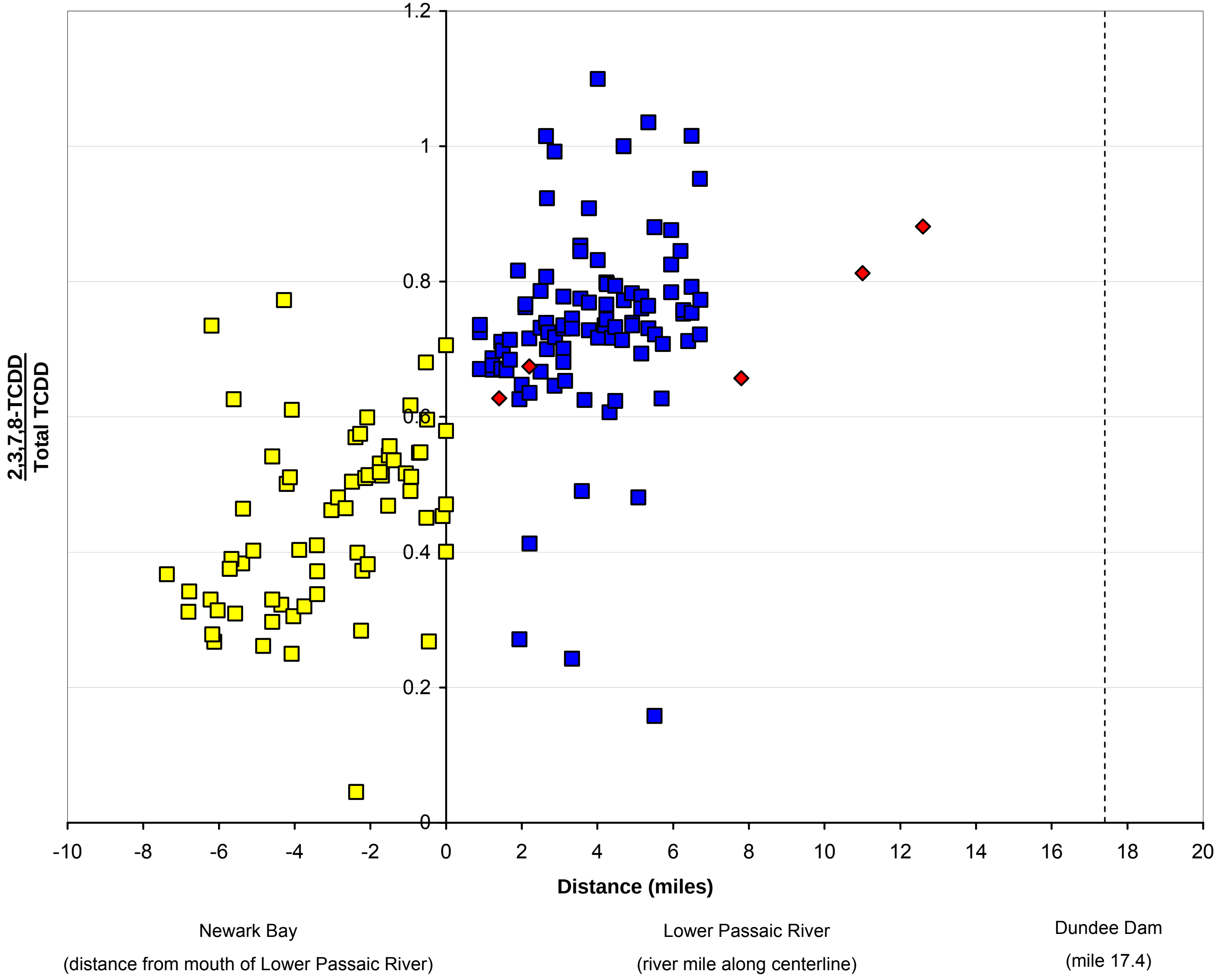
Surface concentrations represent a depth of 0 to <1 foot.

Comparison of Surface 2,3,7,8-TCDD Concentrations in 1985-1986, 1995, and 2005

Lower Passaic River Restoration Project

Figure 6-3e

February 2007



Legend

Malcolm Pirnie, Inc. (2005) (represents 2003-2005 time horizon)

TSI (2005) (represents 0-6 inches of sediment)

TSI (1995) (represents 0-6 inches of sediment)

Notes

Malcolm Pirnie, Inc. Data Source: USEPA 2005-2006 Sampling Program.

TSI Data Source: 2005 Newark Bay Phase I Investigation and 1995 TSI Dataset.

Nondetect (lab qualifier containing a U) plotted as half the reported value.

Surface concentrations represent a depth of 0 to <1 foot.

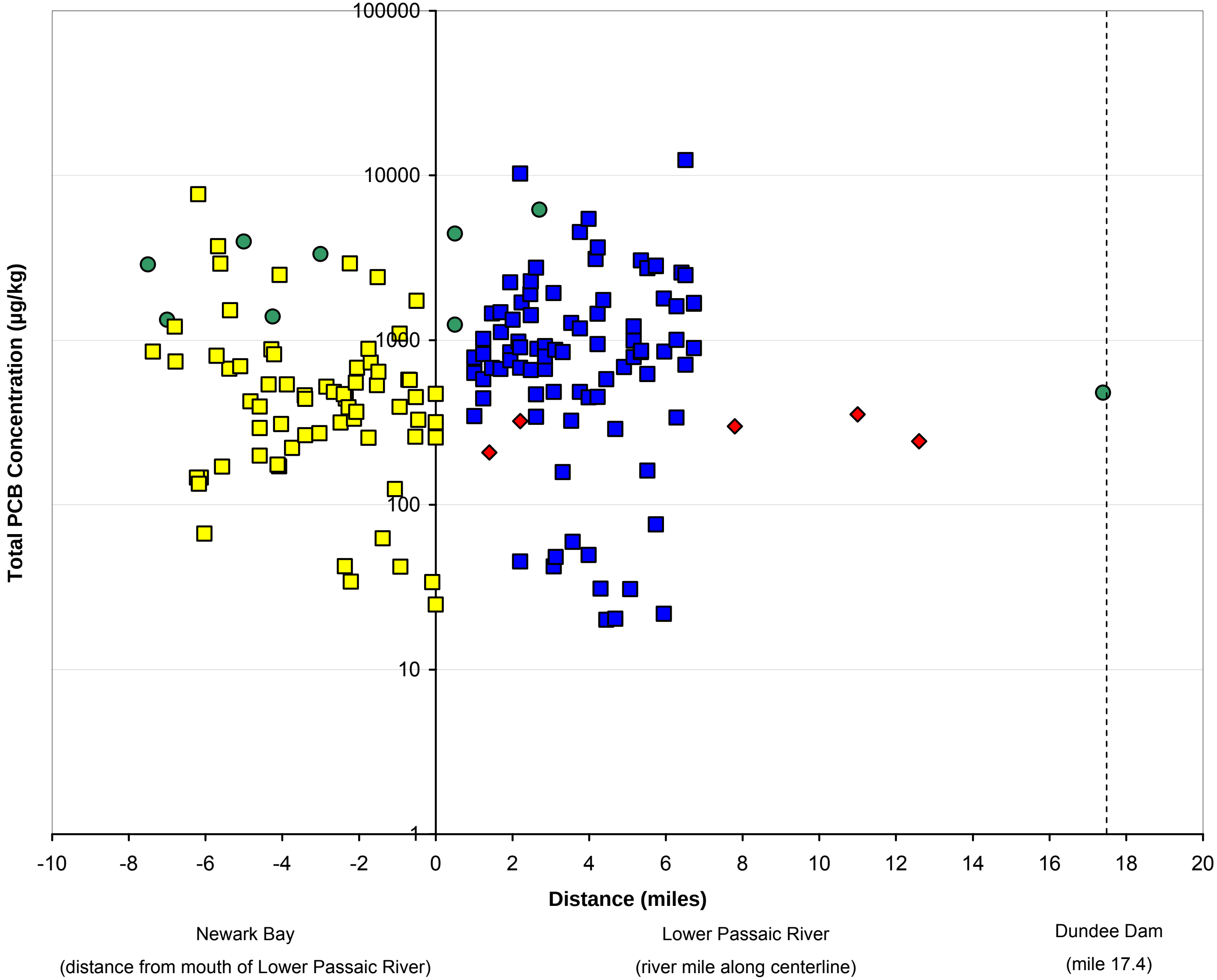
US Army Corp of Engineers

Comparison of Surface 2,3,7,8-TCDD/Total TCDD Ratio
in 1985-1986, 1995, and 2005

Lower Passaic River Restoration Project

Figure 6-3f

February 2007



Legend

- Malcolm Pirnie, Inc. (2005) (represents 2003-2005 time horizon)
- TSI (2005) (represents 0-6 inches of sediment)
- TSI (1995) (represents 0-6 inches of sediment)
- Bopp *et al.* (2006) (represents 1985-1986 time horizon)

Notes

Malcolm Pirnie, Inc. Data Source: USEPA 2005-2006 Sampling Program.

TSI Data Source: 2005 Newark Bay Phase I Investigation and 1995 TSI Dataset.

Bopp Data Source: "Contaminant Chronologies from Hudson River Sedimentary Records," Bopp *et al.* (2006).

Nondetect (lab qualifier containing a U) plotted as half the reported value.

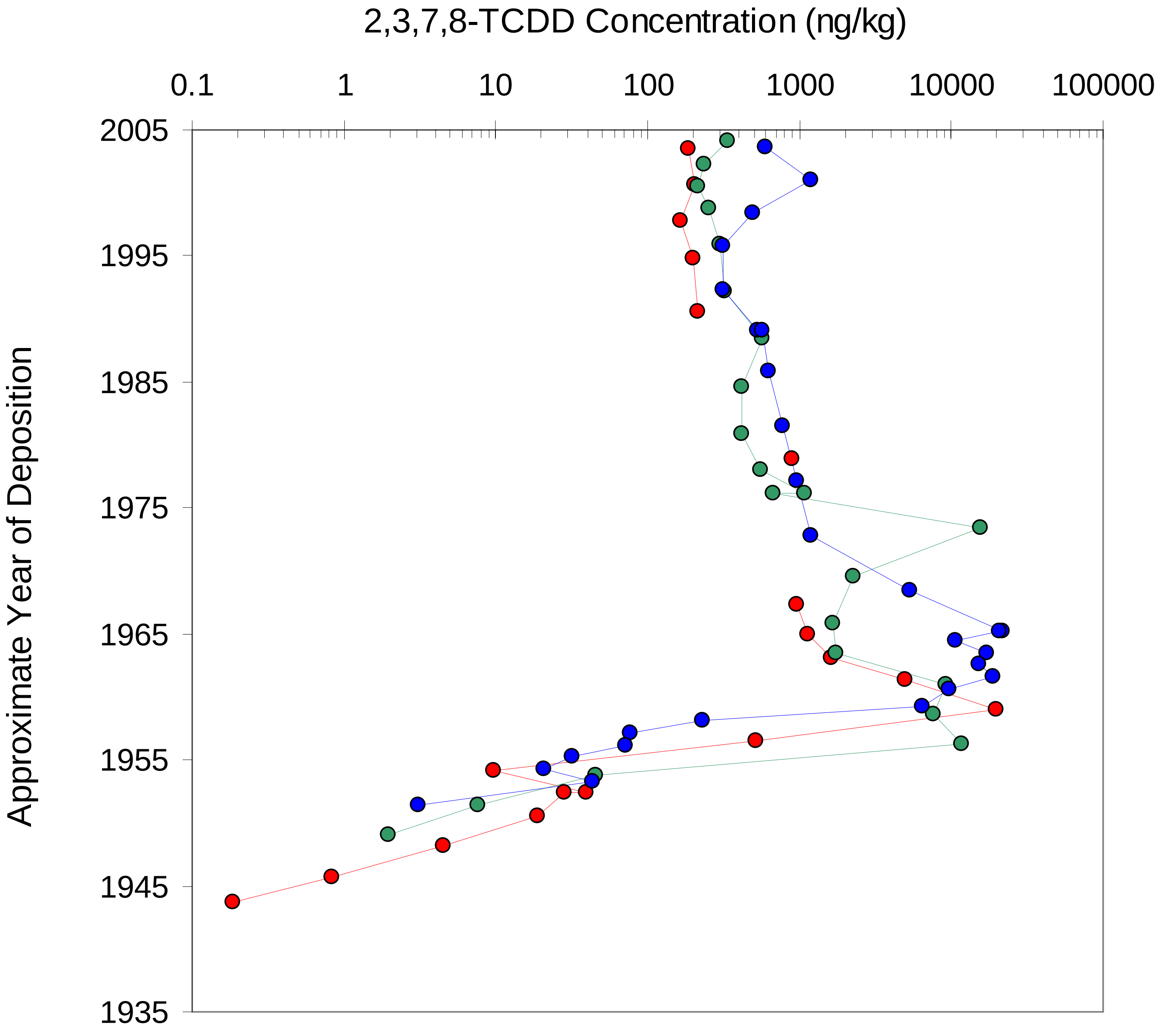
Surface concentrations represent a depth of 0 to <1 foot.

Comparison of Surface Total PCB Concentrations in 1985-1986, 1995, and 2005

Lower Passaic River Restoration Project

Figure 6-3g

February 2007



Legend

- 2,3,7,8-TCDD at RM 1.4
- 2,3,7,8-TCDD at RM 2.2
- 2,3,7,8-TCDD at RM 11

Notes

2005 Malcolm Pirnie, Inc. High Resolution Sediment Core Programs.

Depositional years calculated using cesium-137 concentrations.

Note that one criterion for a high resolution sediment core is that the location experiences continuous deposition over time.

The determination of the 1954 horizon in core at RM11 is based on the absence of cesium-137 detection below 191 centimeters. There are some uncertainties with this assignment, and the core may extend 4 years longer than is shown here.

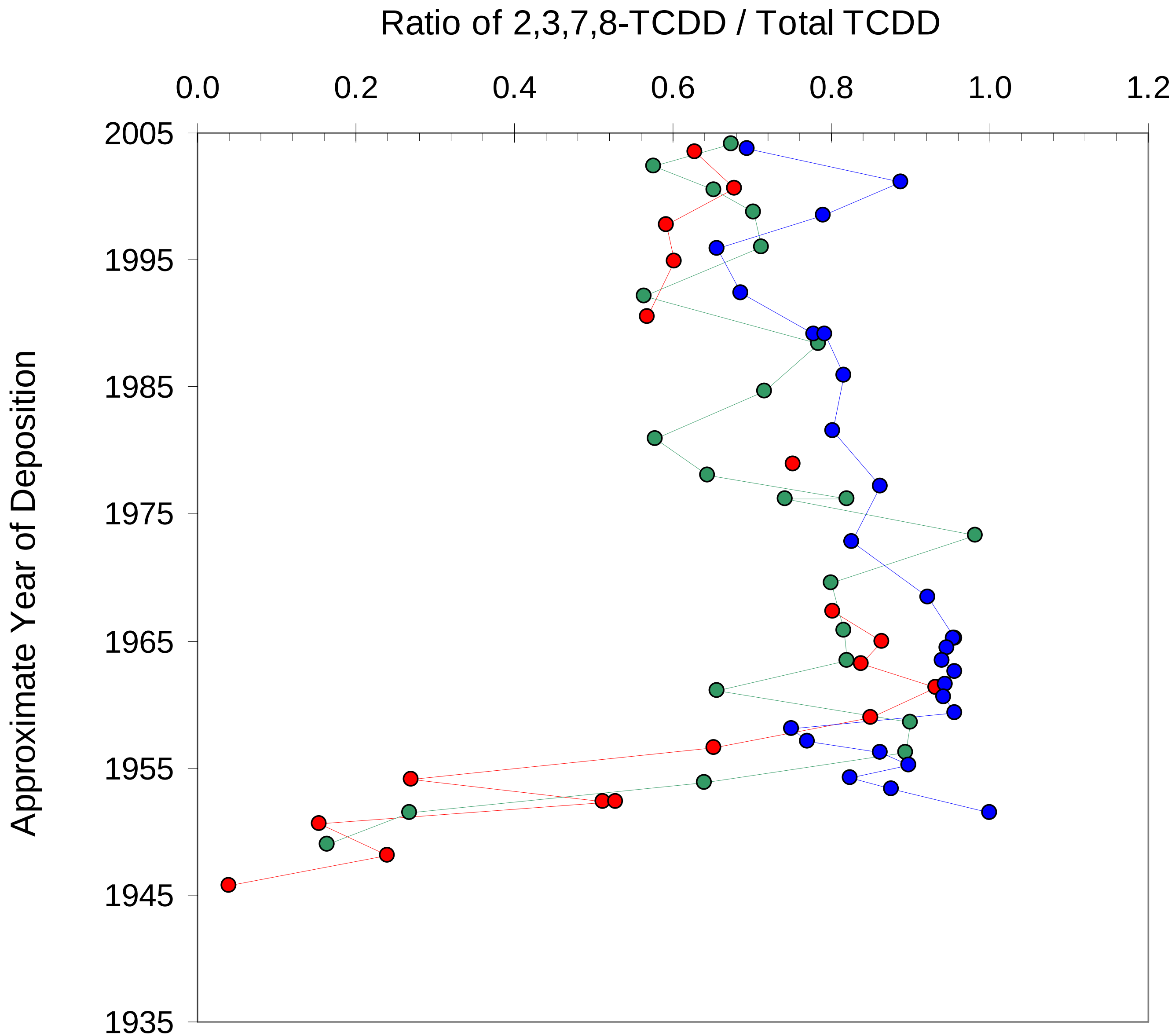
US Army Corp of Engineers

Downcore Profiles of 2,3,7,8-TCDD Concentrations at RM 1.4, RM 2.2, and RM 11

Lower Passaic River Restoration Project

Figure 6-4

February 2007



Legend

- Ratio at RM 1.4
- Ratio at RM 2.2
- Ratio at RM 11

Notes

2005 Malcolm Pirnie, Inc. High Resolution Sediment Core Programs.

Depositional years calculated using cesium-137 concentrations.

Note that one criterion for a high resolution sediment core is that the location experience continuous deposition over time.

The determination of the 1954 horizon in core at RM11 is based on the absence of cesium-137 detection below 191 centimeters. There are some uncertainties with this assignment, and the core may extend 4 years longer than is shown here.

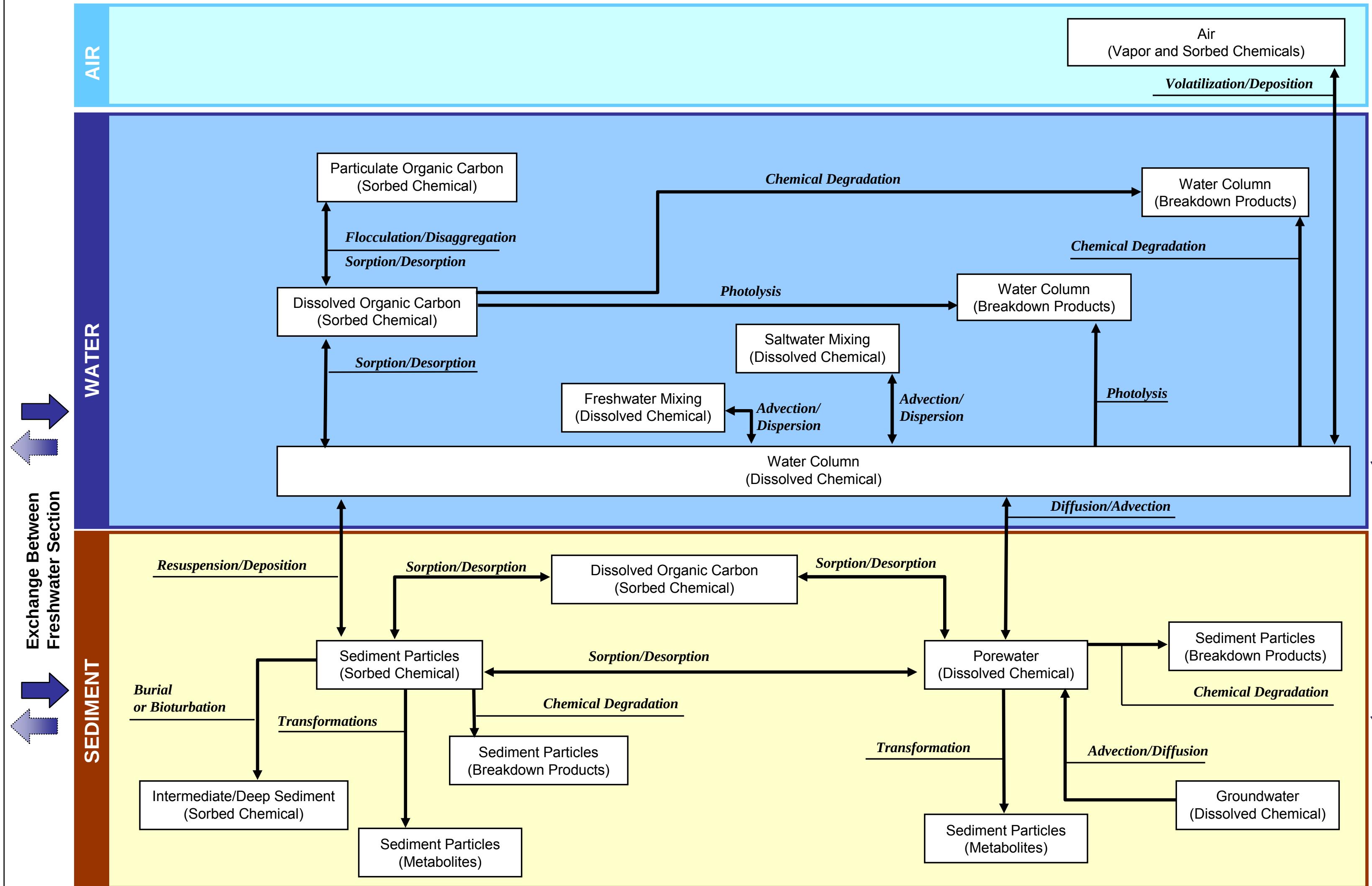
US Army Corps of Engineers

Downcore Profiles of 2,3,7,8-TCDD/Total TCDD Ratio
at RM 1.4, RM 2.2, and RM 11

Lower Passaic River Restoration Project

Figure 6-5

February 2007



NOTES

Figure 7-1 depicts substantive chemical processes that affect the transport of contaminants. Some chemical processes may be less significant or absent in certain river sections. Future iterations of the CSM will prioritize these processes. For simplicity, physical process shown on Figures 6-1 and 6-2 are not duplicated in this figure. Note that the biological processes are depicted in subsequent figures.

The color scheme and boxes used in Figure 7-1 reflect different media, including air (light blue box), water (dark blue box), and sediment (brown box), and they represent the sources, mechanisms, and media depicted in Figures 2-2, 6-1, and 6-2.

LEGEND for Figures 7-1 and 7-2

Inventory with chemical state marked in parentheses, where appropriate

Abiotic reactions or pathways connecting associated inventories

Biotic reactions or pathways connecting associated inventories (see Figure 7-2)

Direction of substantive water flow and sediment transport on the Lower Passaic River

Direction of potential water flow and sediment transport on the Lower Passaic River

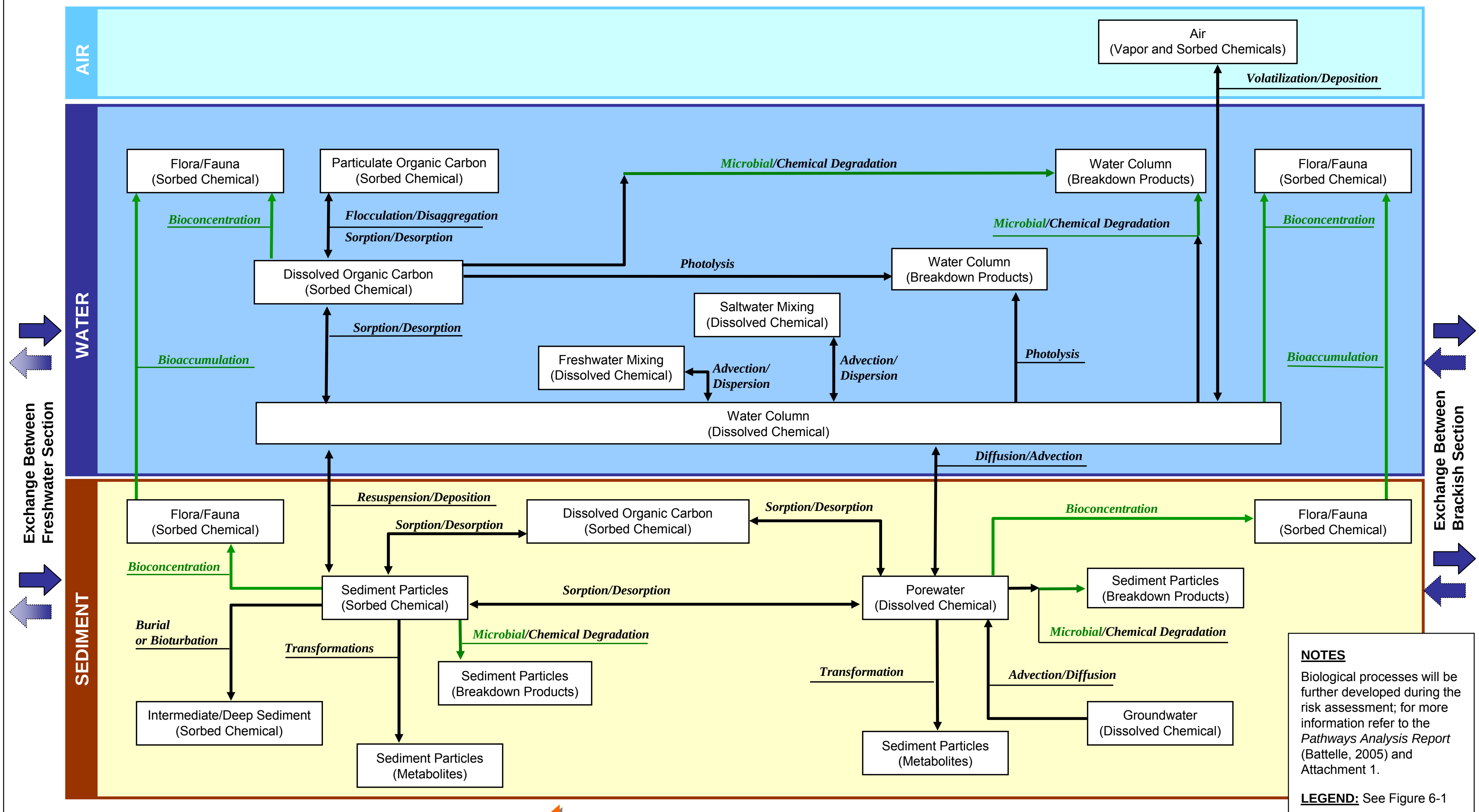
Input to Human Health and Ecological Evaluations

Chemical Fate and Transport Processes in Transitional Section

Lower Passaic River Restoration Project

Figure 7-1

February 2007



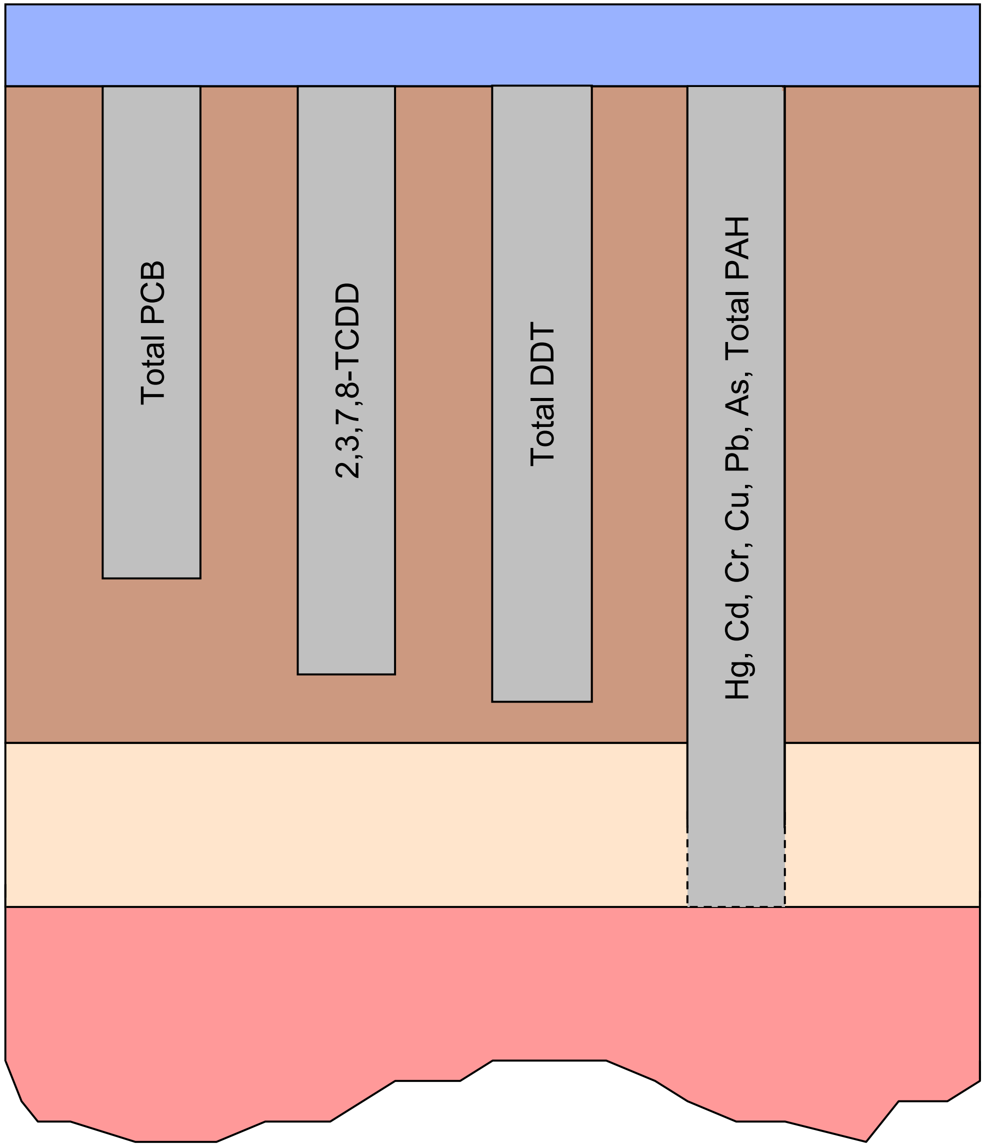
Input to
Human Health and
Ecological Evaluations

Chemical and Biological Fate and Transport Processes in Transitional Section

Lower Passaic River Restoration Project

Figure 7-2

February 2007



Legend

- Schematic of Sediment Core
- Water
- Fine-Grained Sediment
- Sand
- Clay

Notes

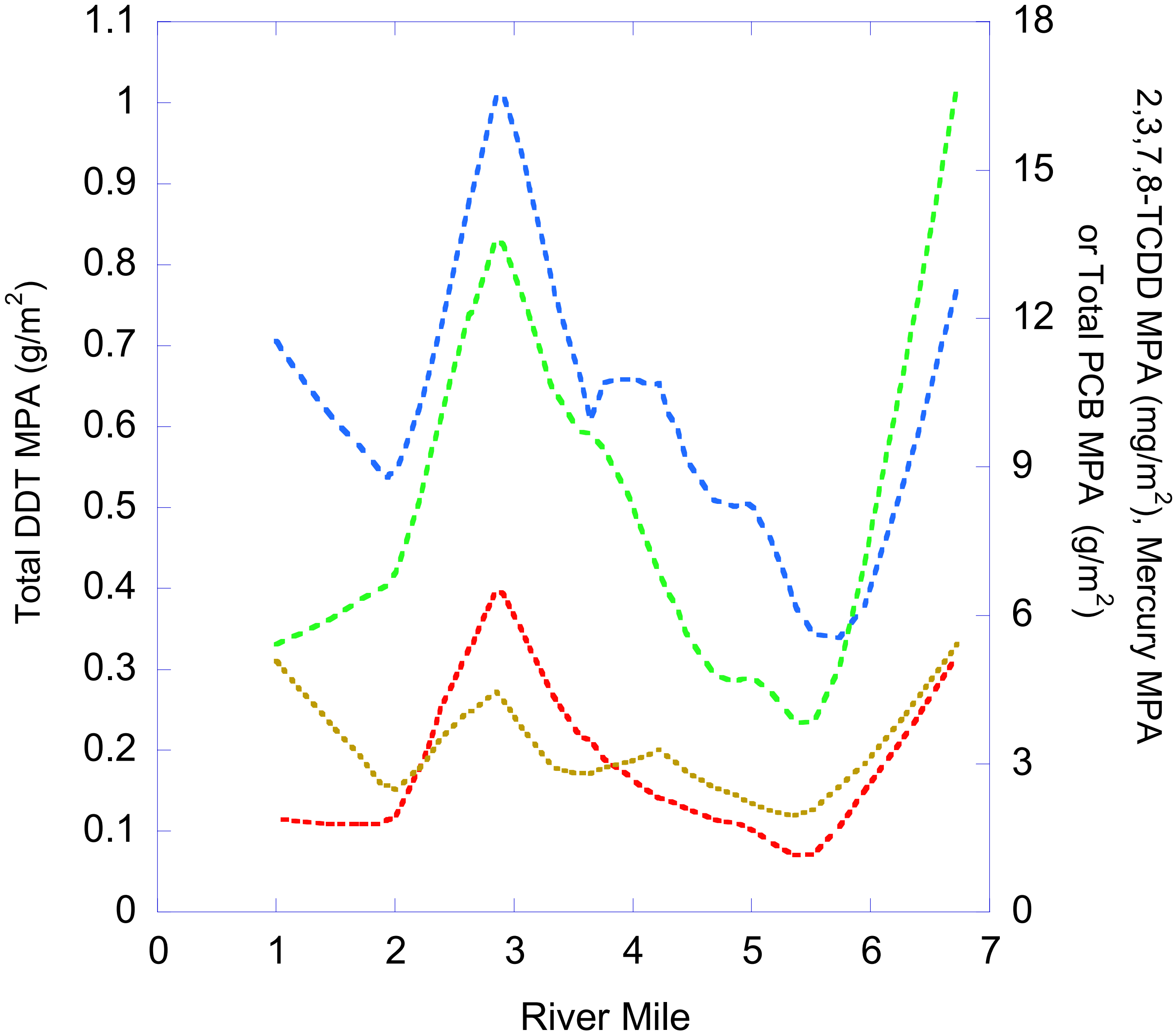
Hg = Mercury
Cd = Cadmium
Cr = Chromium
Pb = Lead
As = Arsenic

Schematic of Nature and Extent of Contamination in Sediment Beds

Lower Passaic River Restoration Project

Figure 7-3

February 2007



Legend

- Mercury
- 2,3,7,8-TCDD
- Total PCB
- Total DDT

Notes

MPA is mass per unit area

Weighted Curve Sediment Inventory from RM1 to RM7

Lower Passaic River Restoration Project

Figure 7-4

February 2007

Attachment A

Sediment Texture Map Book

Sediment Texture Map

Lower Passaic River Restoration Project

February 2007

Legend

- Rock and Coarse Gravel
- Gravel and Sand
- Sand
- Silt and Sand
- Silt
- River Mile Post

2004 USACE Bathymetric Survey

Elevation (Feet) Relative to NGVD29

- -30 to -20
- -18 to -10
- -8 to 0
- 2 to 10

Coordinate System: State Plane New Jersey
Datum: NAD 83 Units: Feet

N

0 250 500 1,000

1 " equals 500 '

Bathymetric Control Data:
Benchmark: X 71 (NGS PID: KV0256)
Elevation: 15.12 FEET (NGVD 29)
Benchmark: V 71 (NGS PID: KV0254)
Elevation: 15.76 FEET (NGVD 29)

Data Source:
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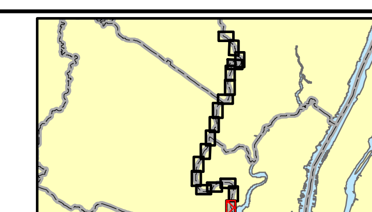
Roads: 2000 TIGER line data.
Sediment Texture: 2005 Side scan SONAR data from Aqua Survey, Inc.



Mile 0 to 1

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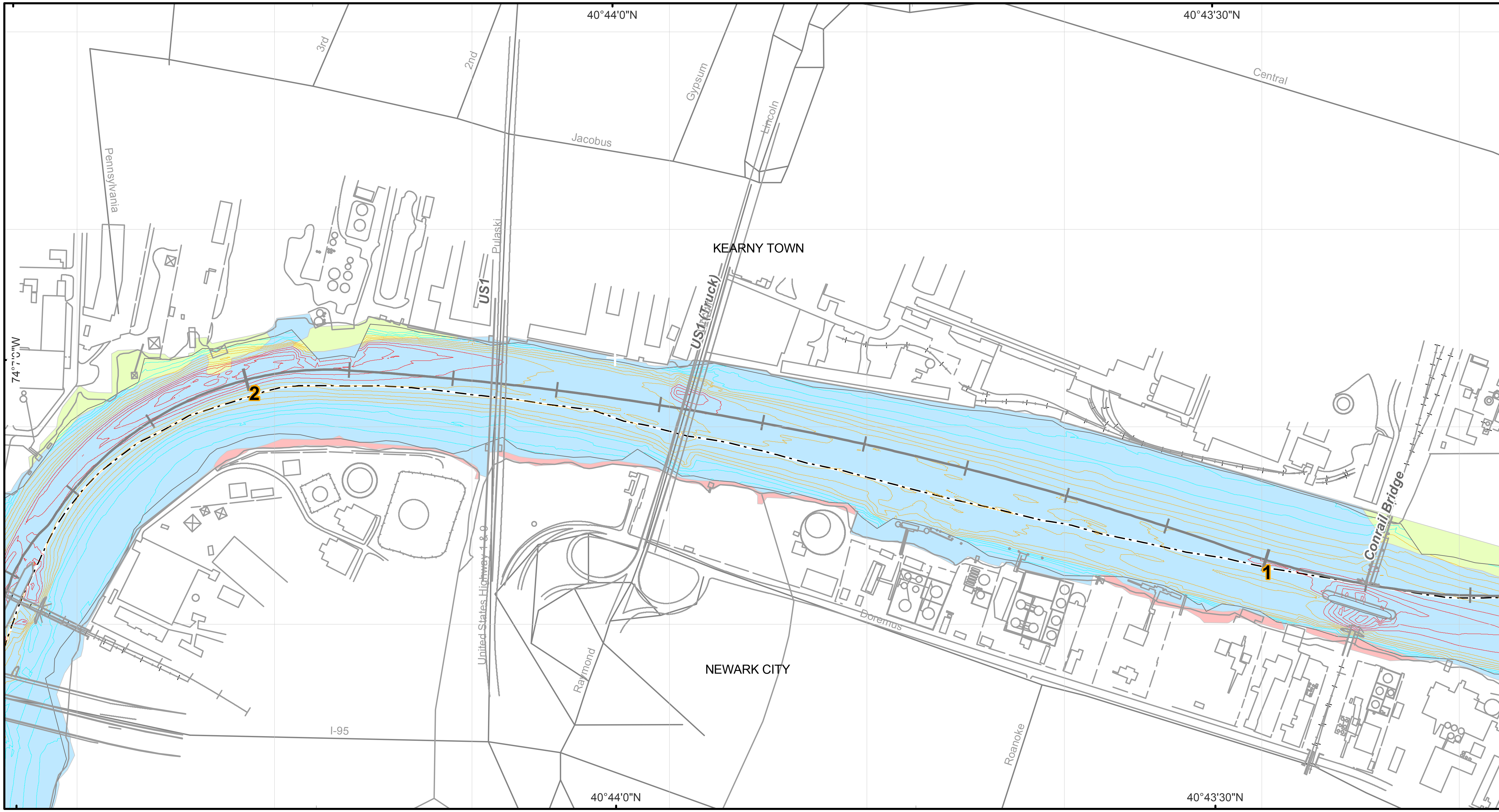

Sediment Texture Map

Lower Passaic River Restoration Project

February 2007

Legend

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Mile 1 to 2

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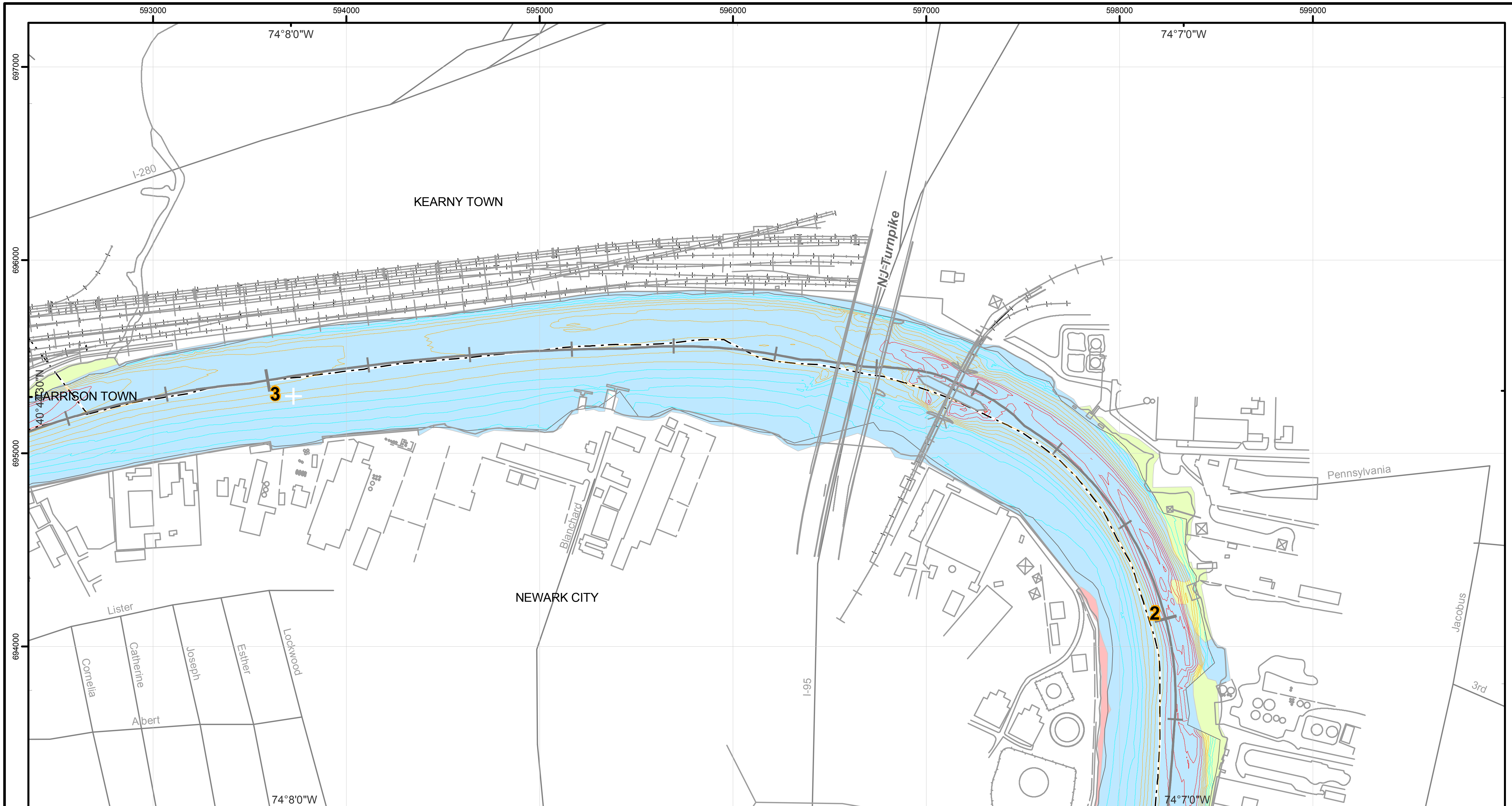

Sediment Texture Map

Lower Passaic River Restoration Project

February 2007

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Mile 2 to 3

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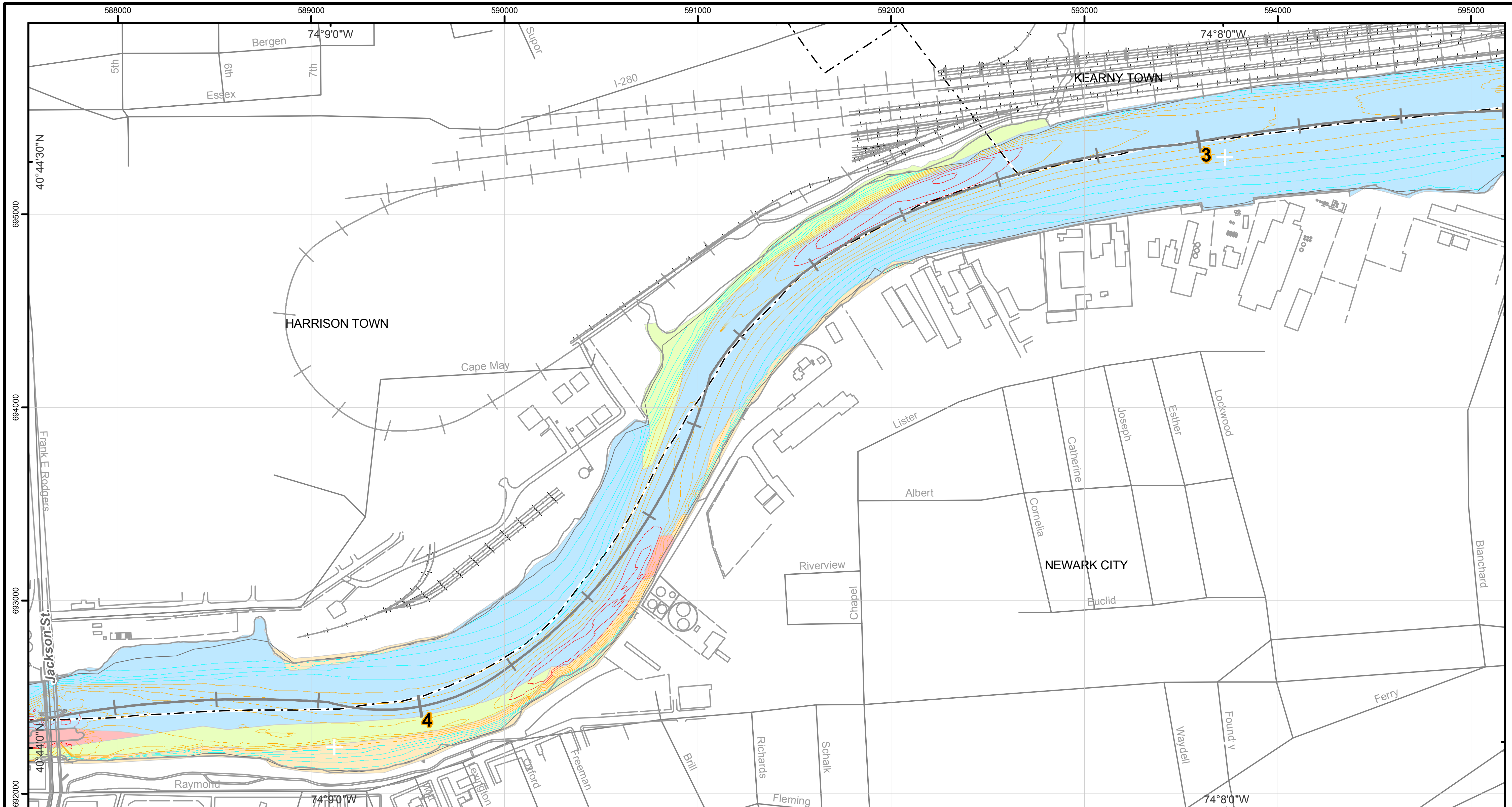

Sediment Texture Map

Lower Passaic River Restoration Project

February 2007

US Army Corps of Engineers

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Mile 3 to 4

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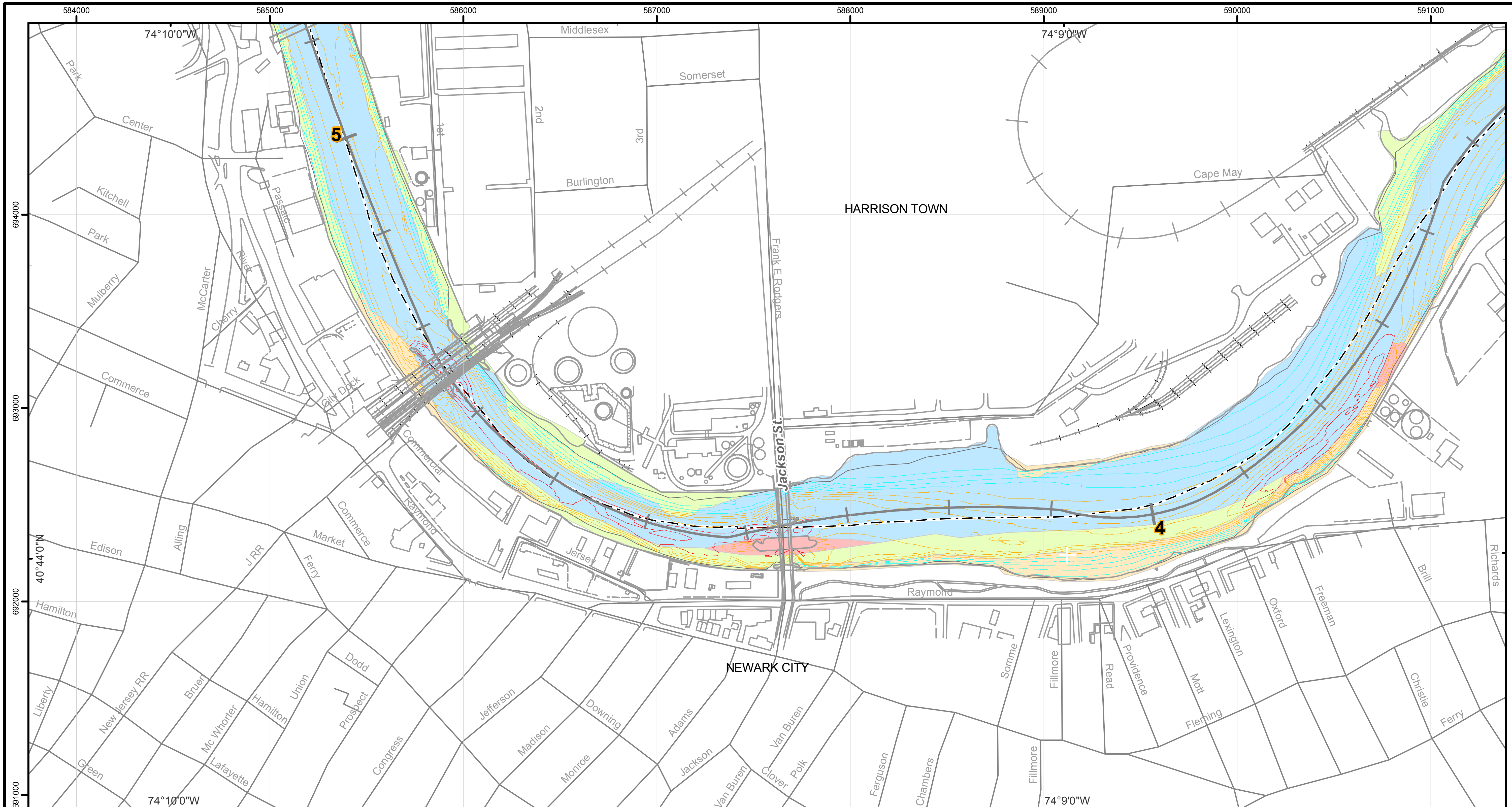

Sediment Texture Map

Lower Passaic River Restoration Project

February 2007

US Army Corps of Engineers

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Mile 4 to 5

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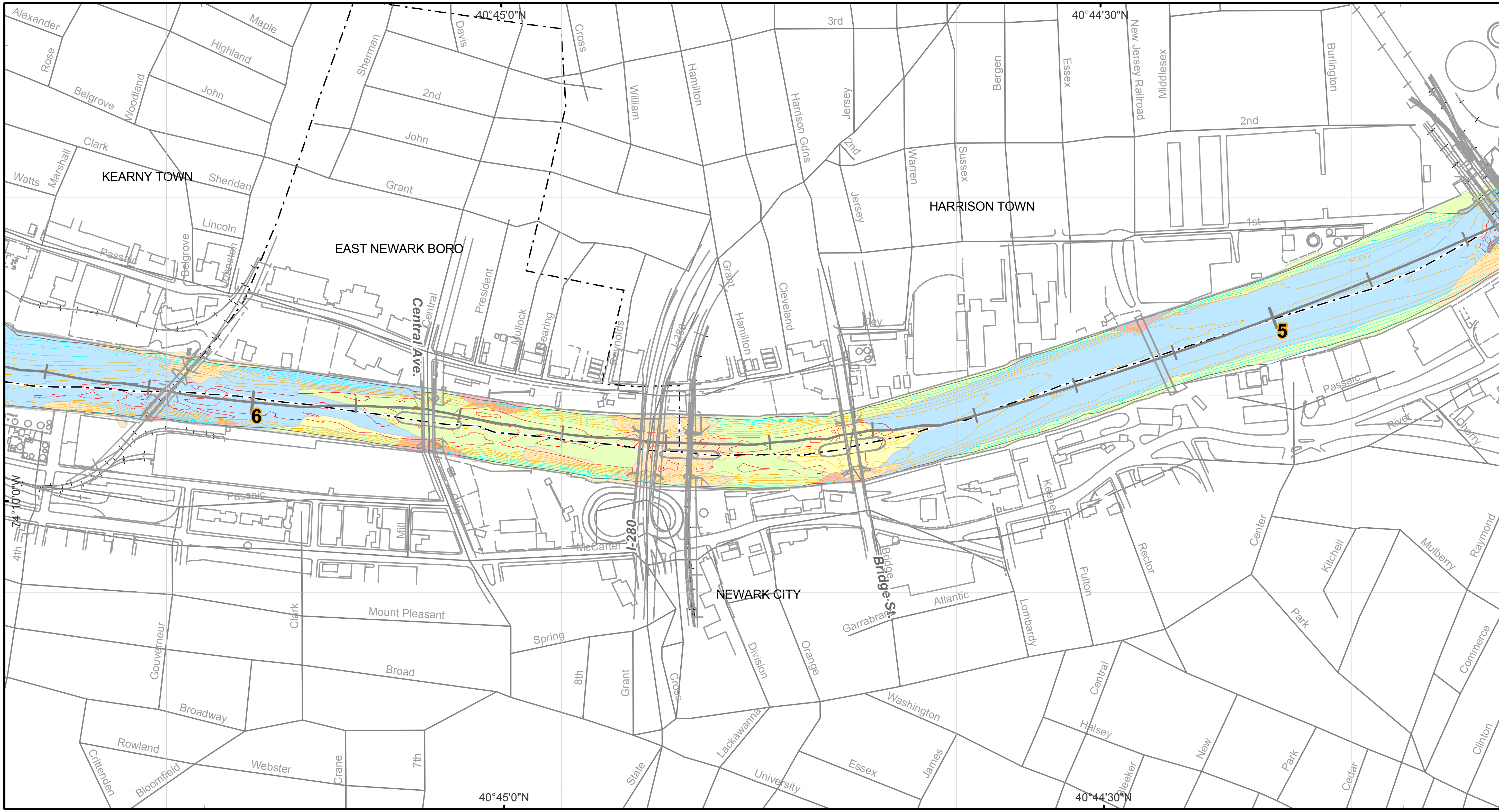

Sediment Texture Map

Lower Passaic River Restoration Project

February 2007

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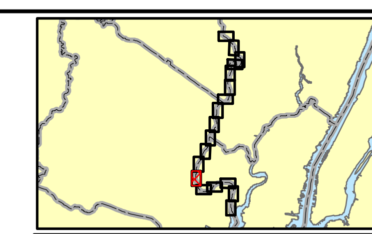

Mile 5 to 6

US Army Corps of Engineers

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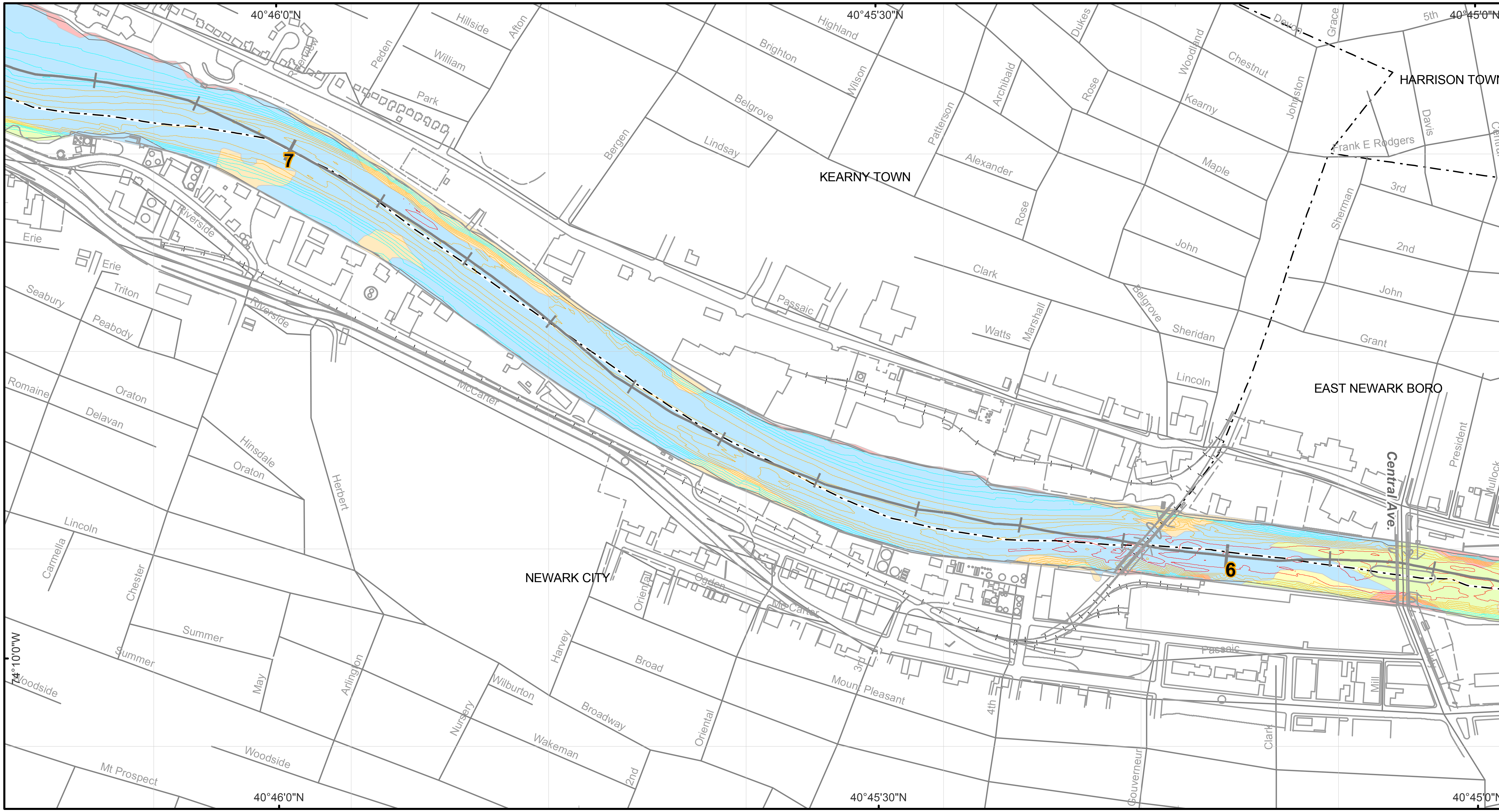

Sediment Texture Map

Lower Passaic River Restoration Project

February 2007

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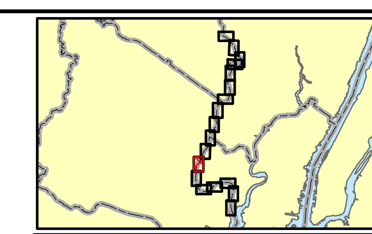

Mile 6 to 7

US Army Corps of Engineers®

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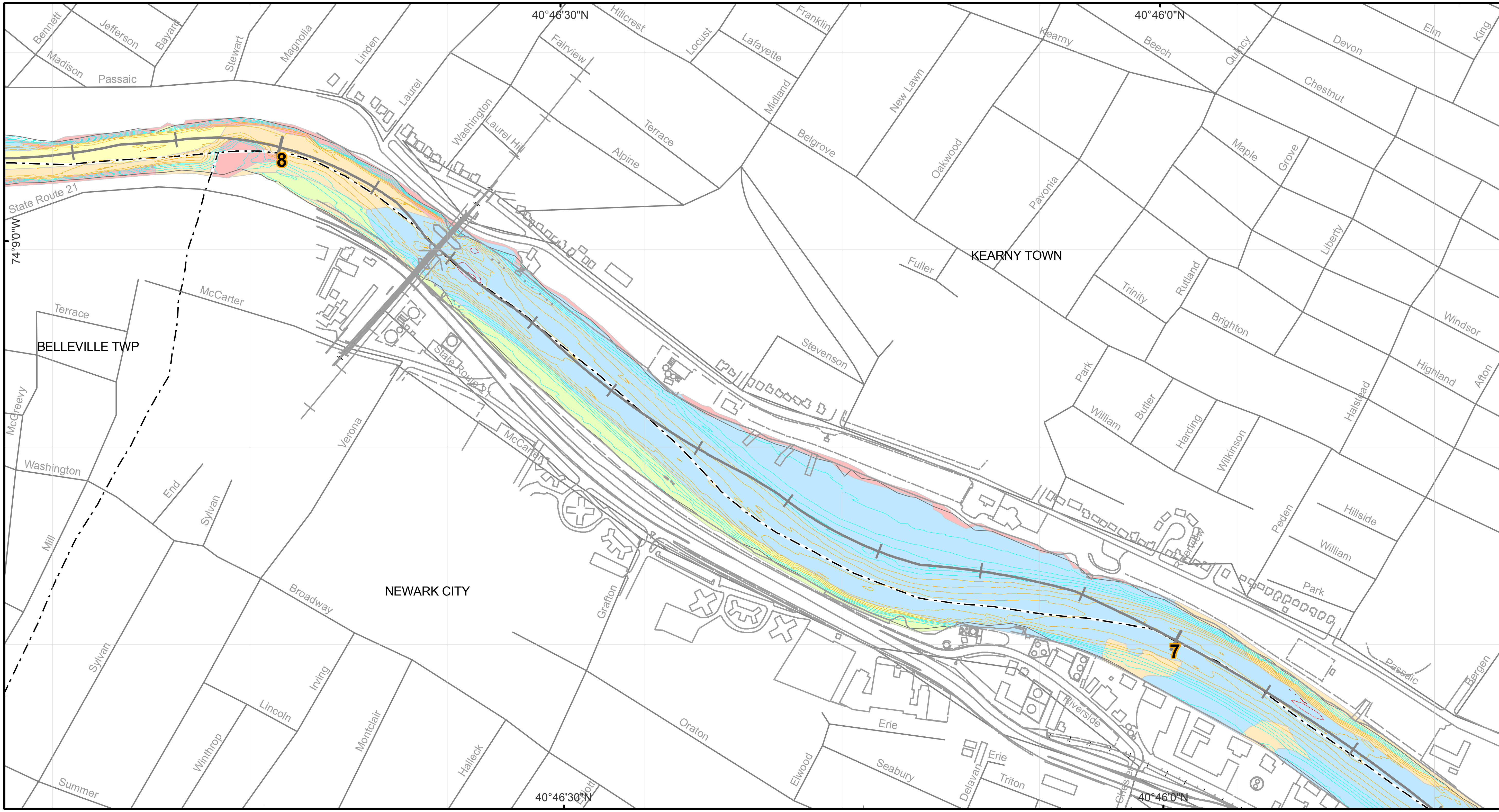

Sediment Texture Map

Lower Passaic River Restoration Project

February 2007

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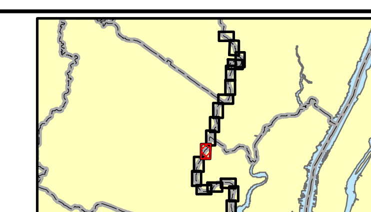

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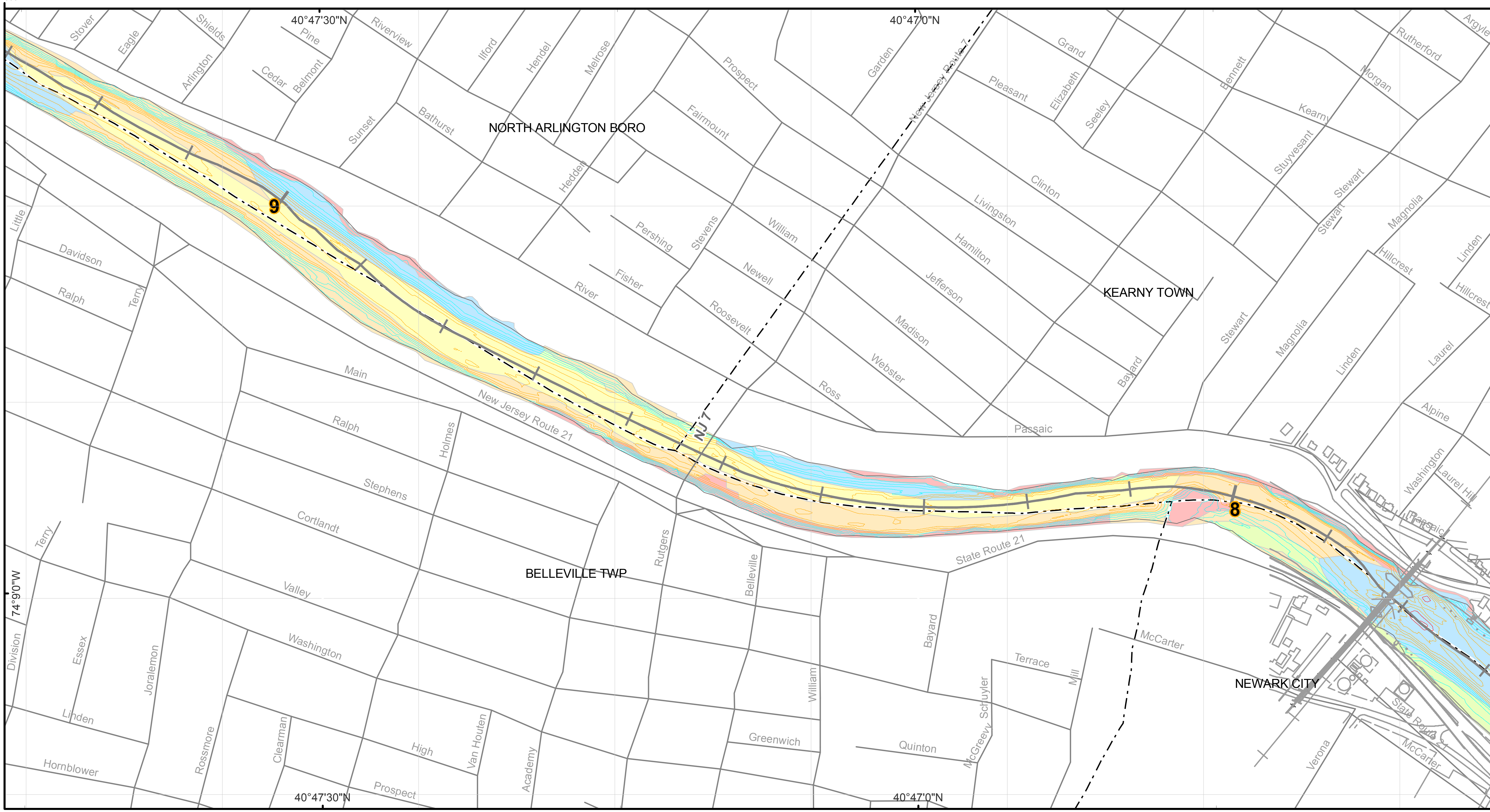

Sediment Texture Map

Lower Passaic River Restoration Project

February 2007

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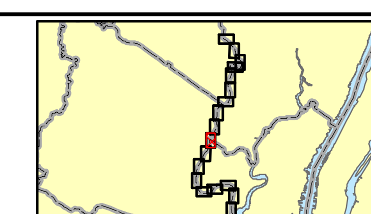

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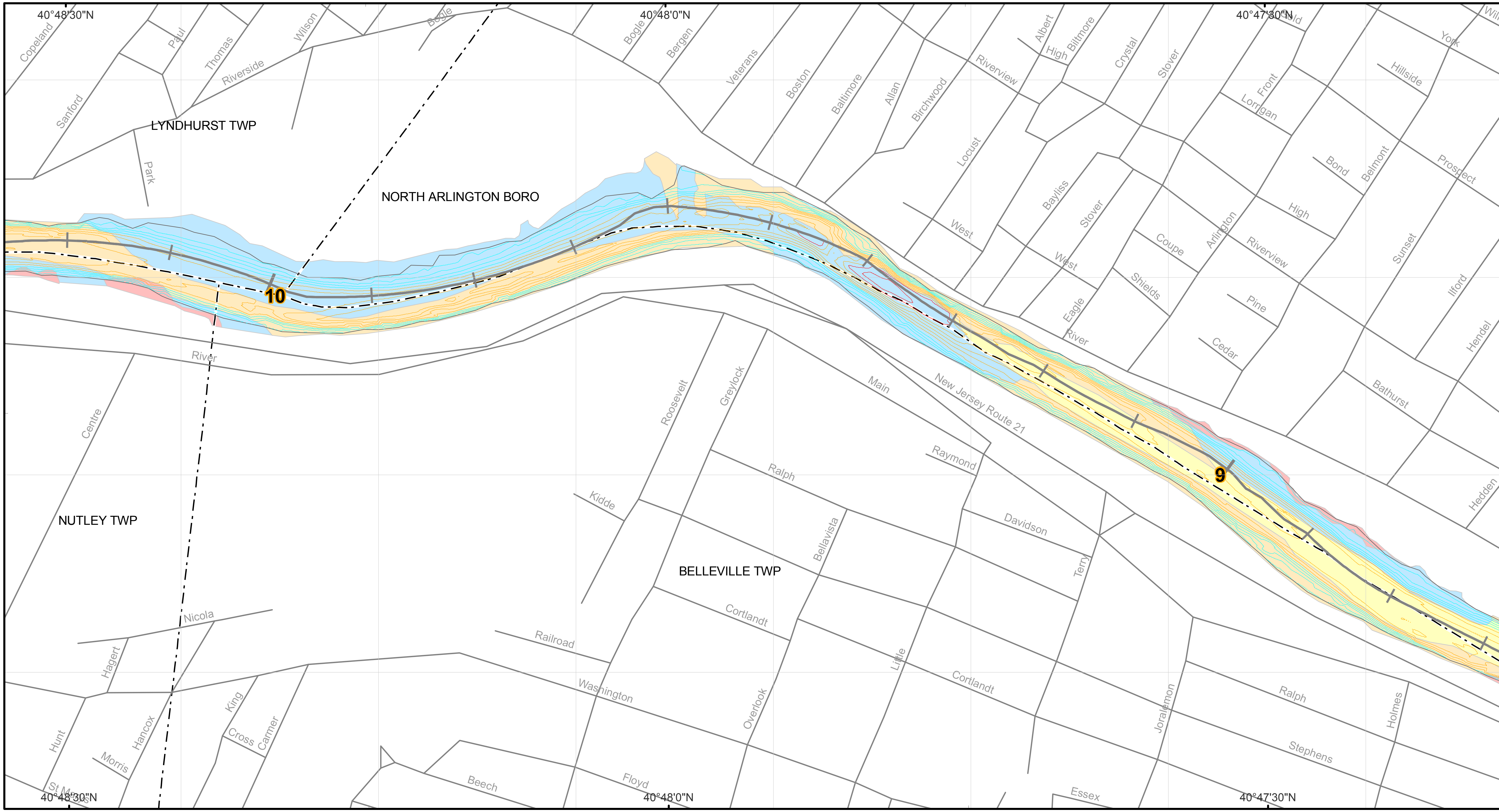

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US Army Corps of Engineers

Sediment Texture Map

Lower Passaic River Restoration Project

February 2007

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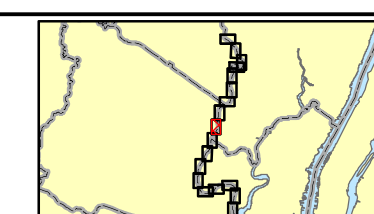
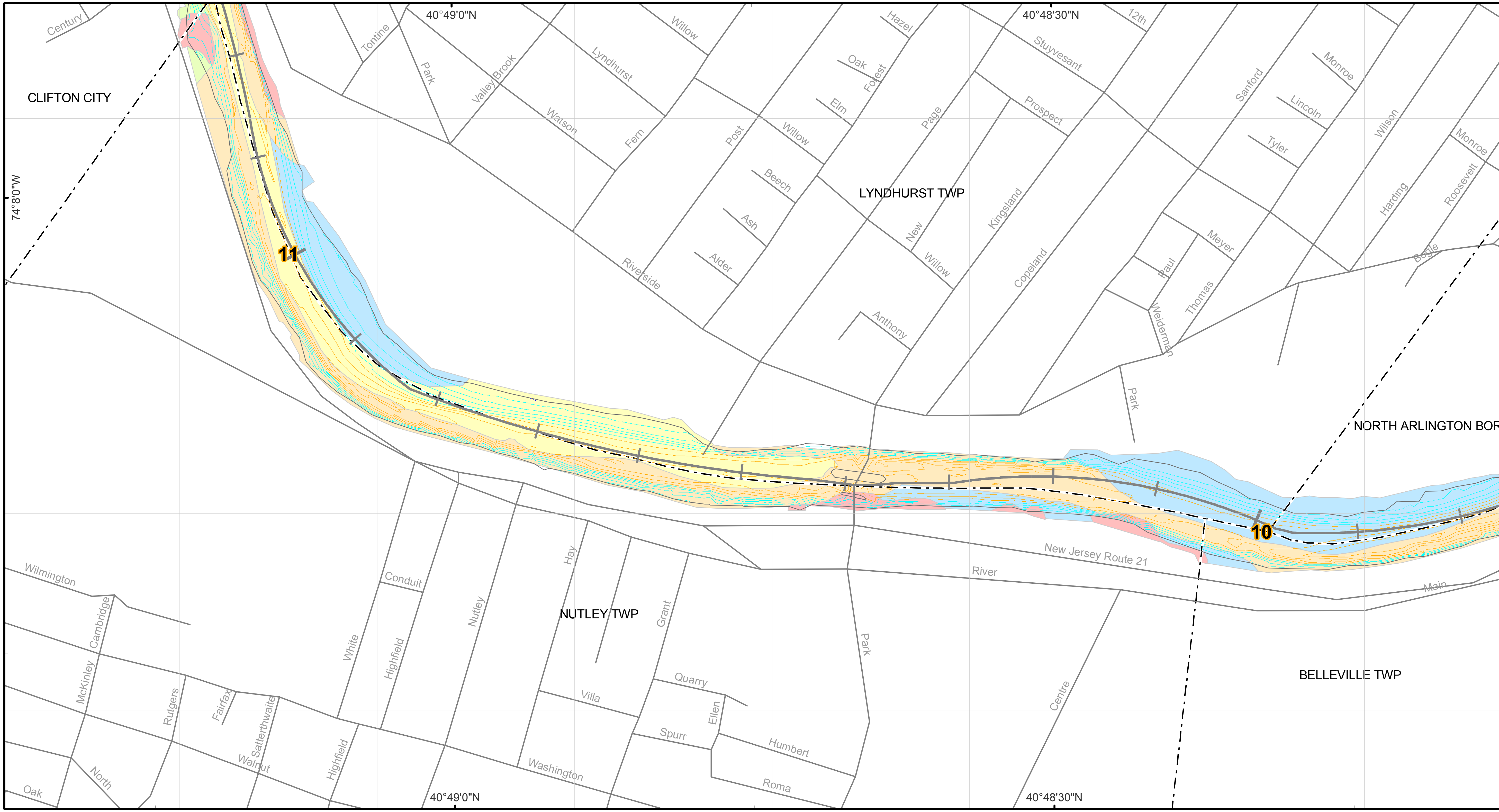


Mile 9 to 10



Sediment Texture Map

Lower Passaic River Restoration Project

February 2007

US Army Corps of Engineers

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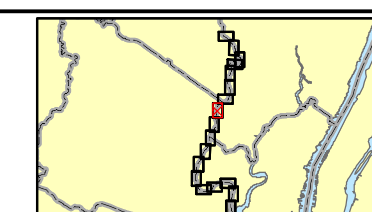

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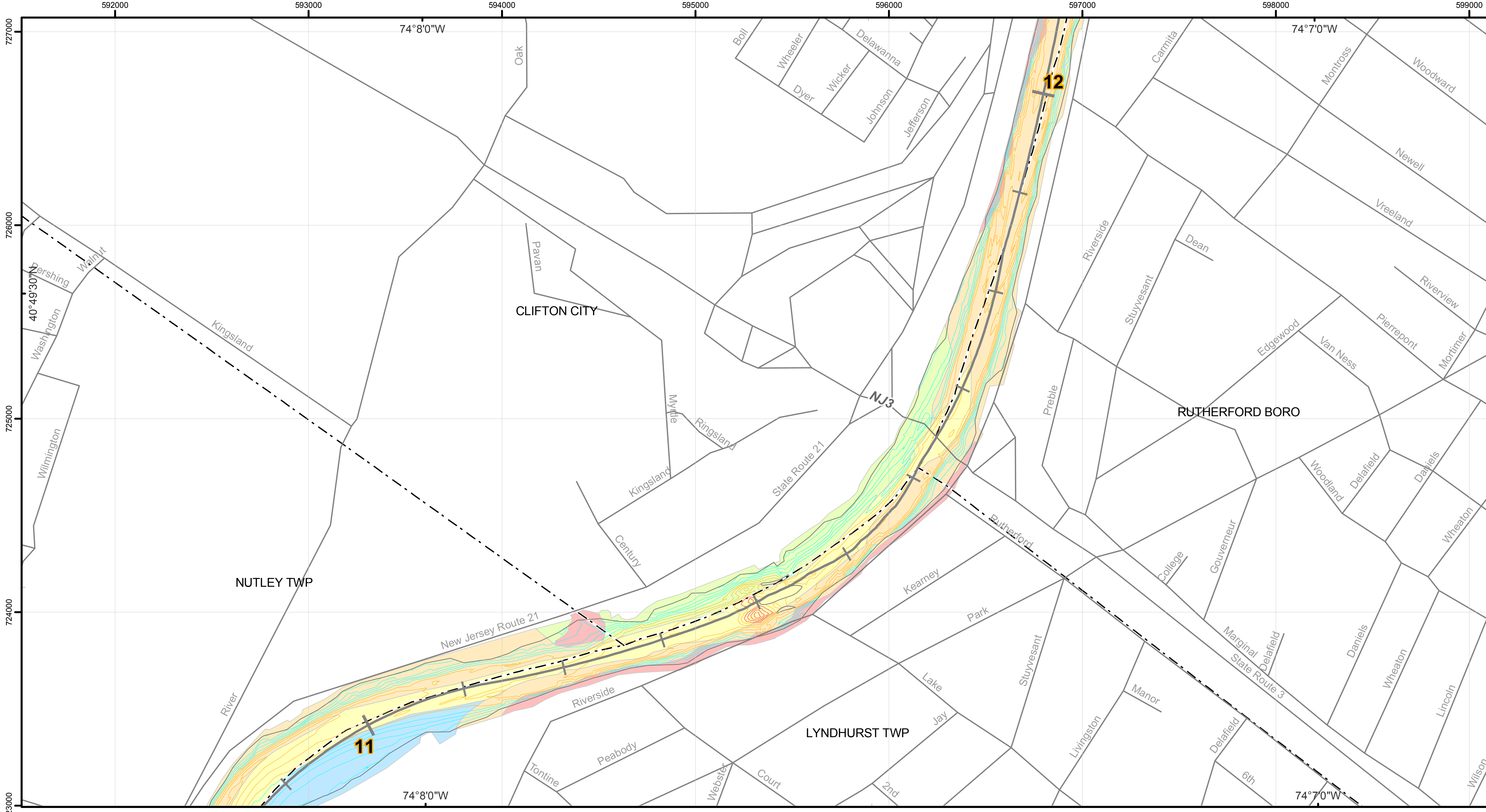

US Army Corps of Engineers

Sediment Texture Map

Lower Passaic River Restoration Project

February 2007

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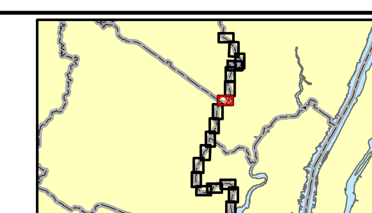

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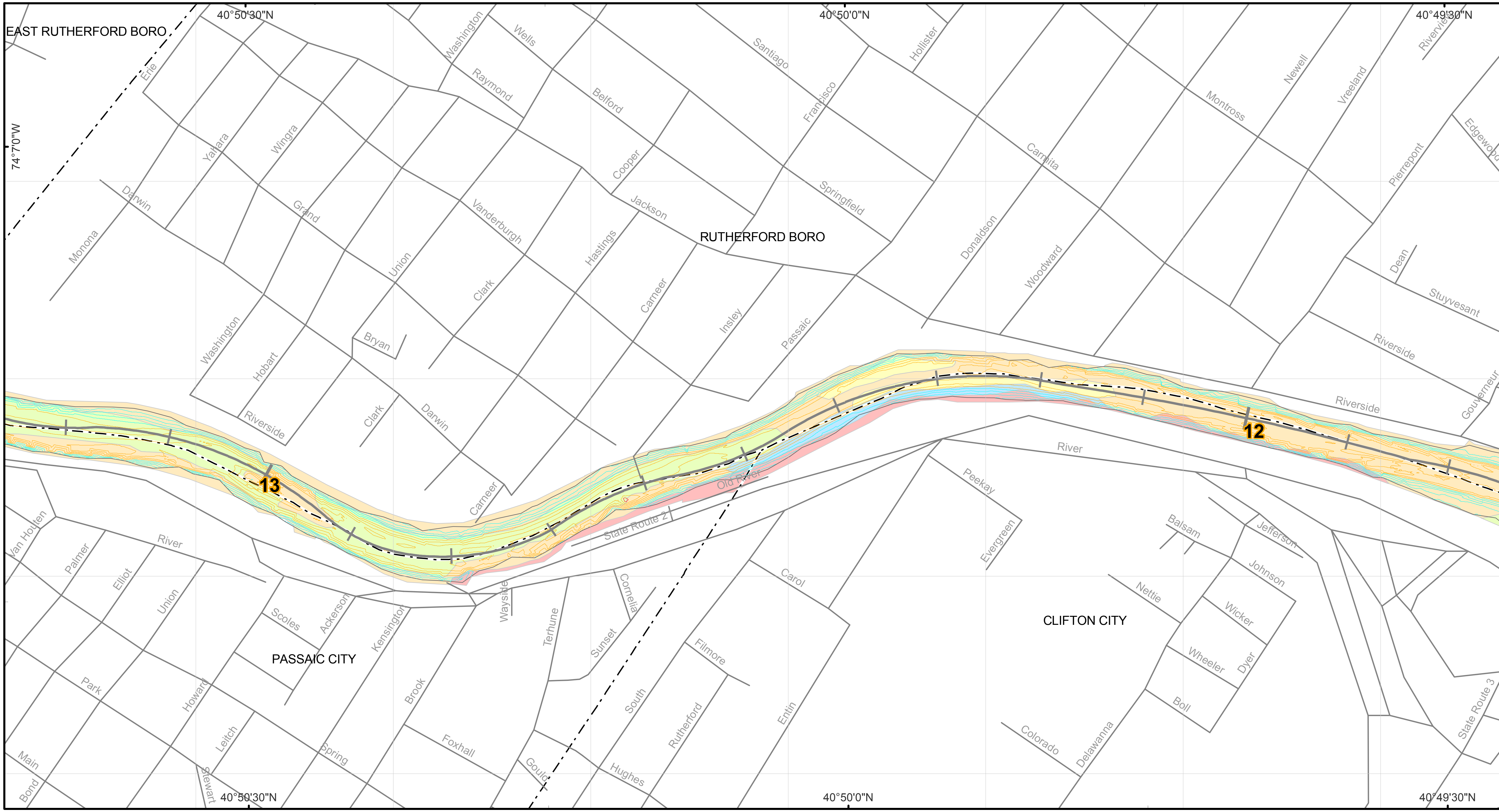

Sediment Texture Map

Lower Passaic River Restoration Project

February 2007

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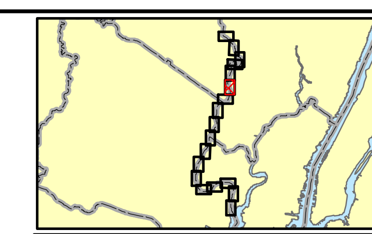

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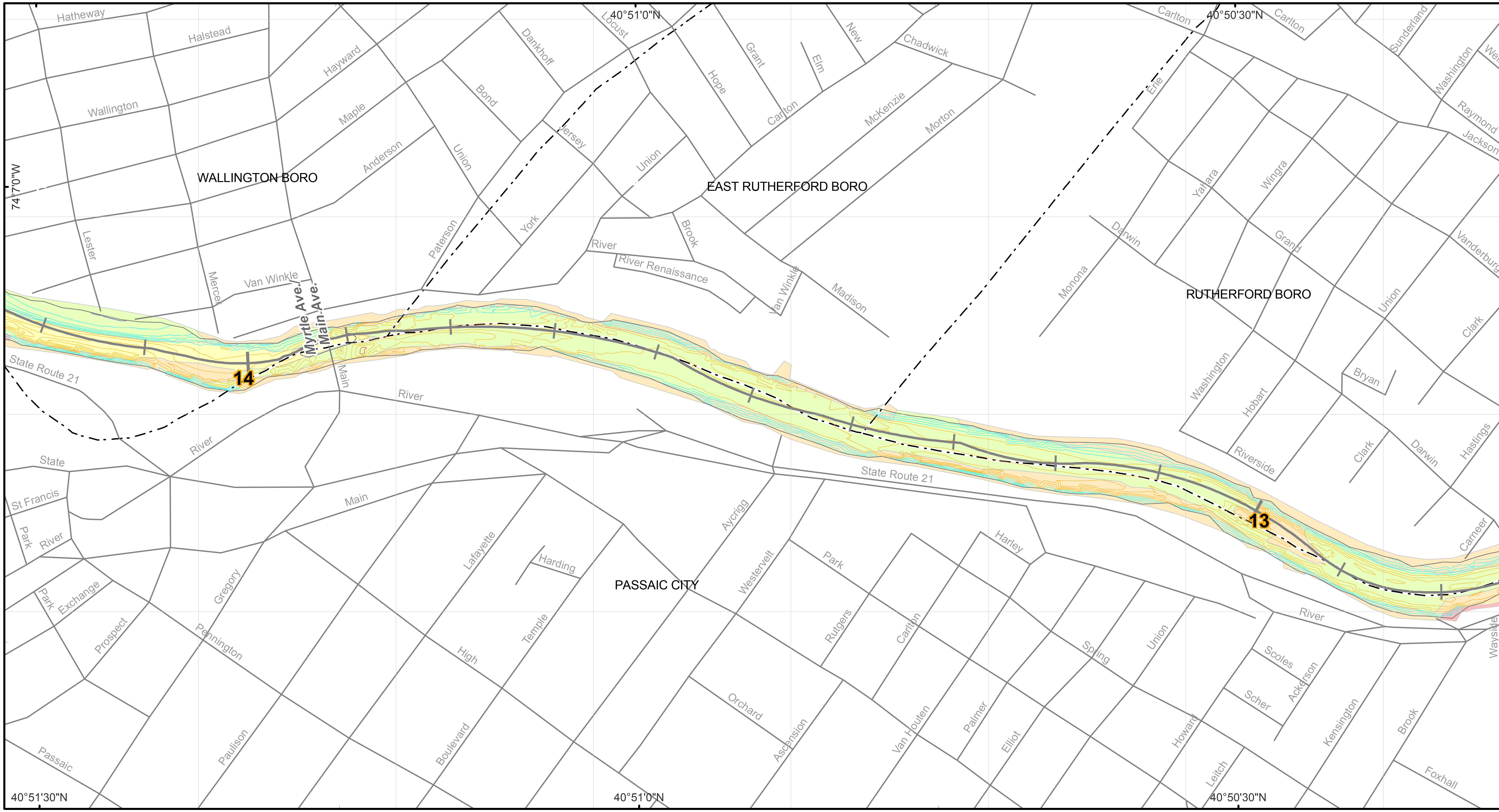

Sediment Texture Map

Lower Passaic River Restoration Project

February 2007

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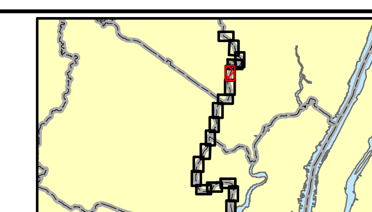

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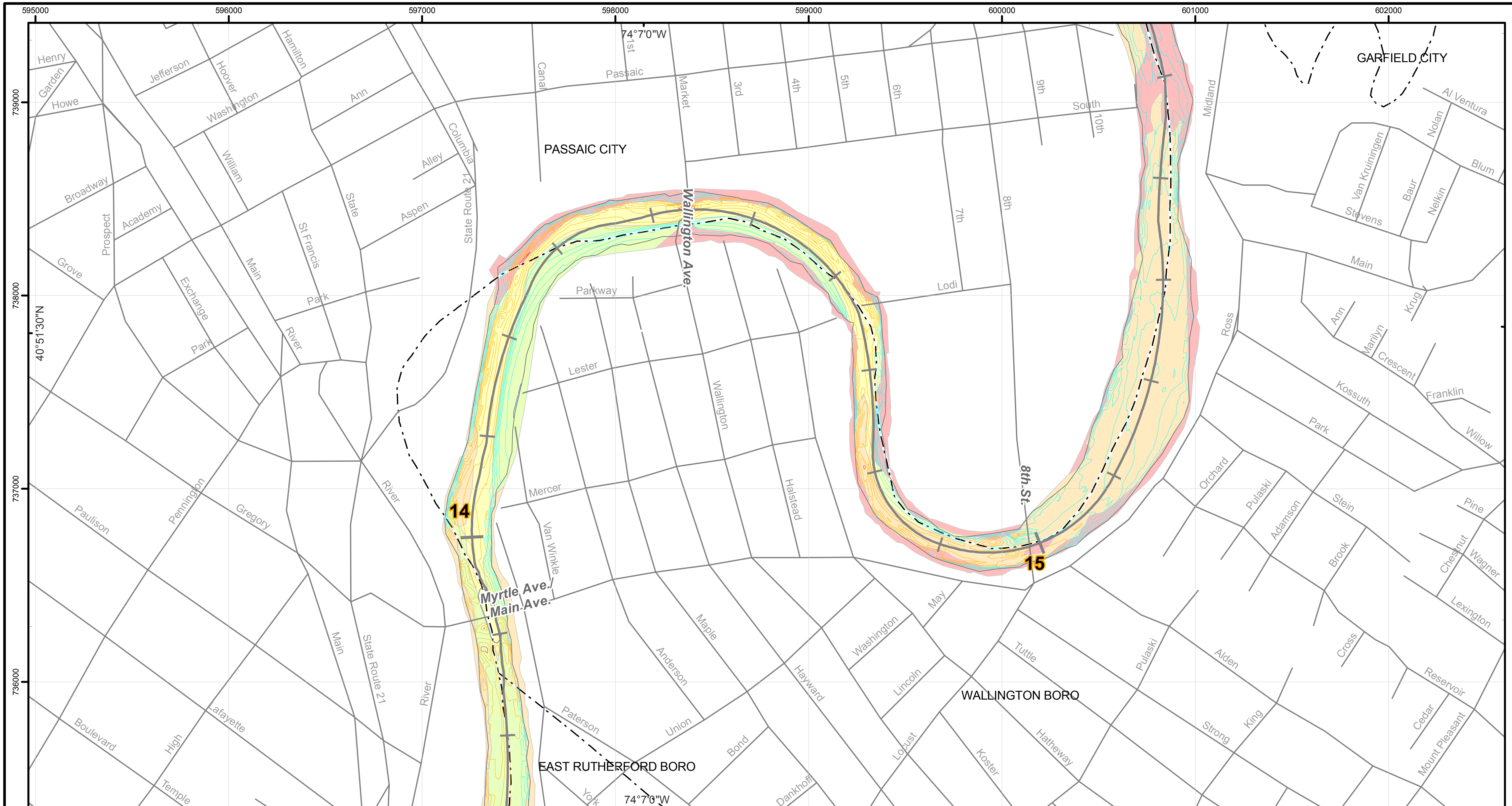


Sediment Texture Map

Lower Passaic River Restoration Project

February 2007

Legend

- Rock and Coarse Gravel
- Gravel and Sand
- Sand
- Silt and Sand
- Silt
- River Mile Post

2004 USACE Bathymetric Survey

Elevation (Feet) Relative to NGVD29

- -30 to -20
- -18 to -10
- -8 to 0
- 2 to 10

Coordinate System: State Plane New Jersey
Datum: NAD 83 Units: Feet

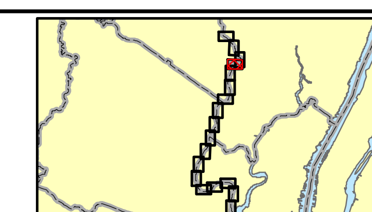
N

0 250 500 1,000

1 " equals 500 '

Bathymetric Control Data:
Benchmark: X 71 (NGS PID: KV0256)
Elevation: 15.12 FEET (NGVD 29)
Benchmark: V 71 (NGS PID: KV0254)
Elevation: 15.76 FEET (NGVD 29)

Data Source:
Buildings: CADD drawing, 09994X01, dated January 1, 2002 received from BBL.
Roads: 2000 TIGER line data.
Sediment Texture: 2005 Side scan SONAR data from Aqua Survey, Inc.



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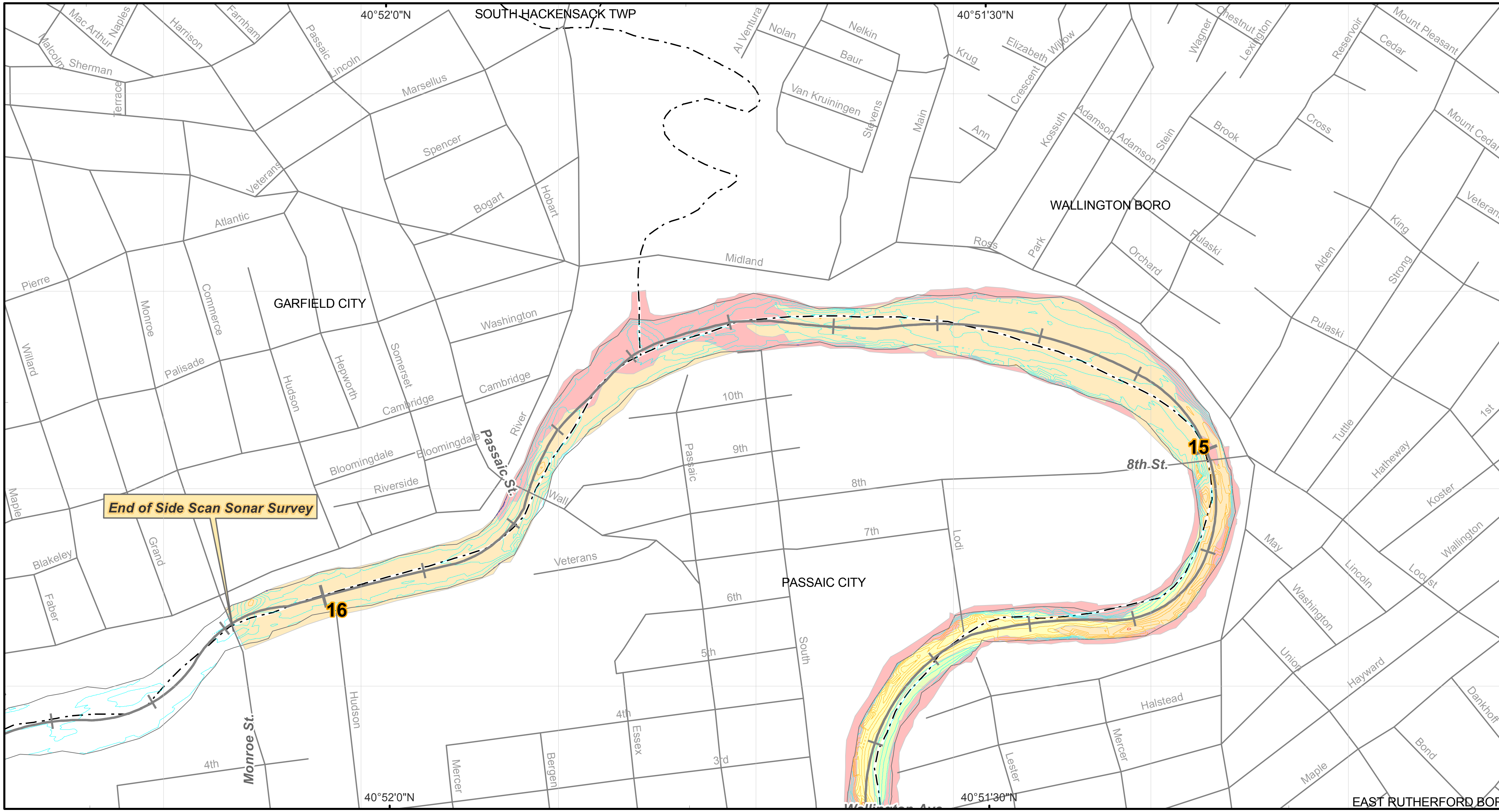

Sediment Texture Map

Lower Passaic River Restoration Project

February 2007

Legend

- Rock and Coarse Gravel
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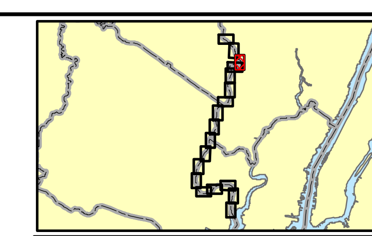

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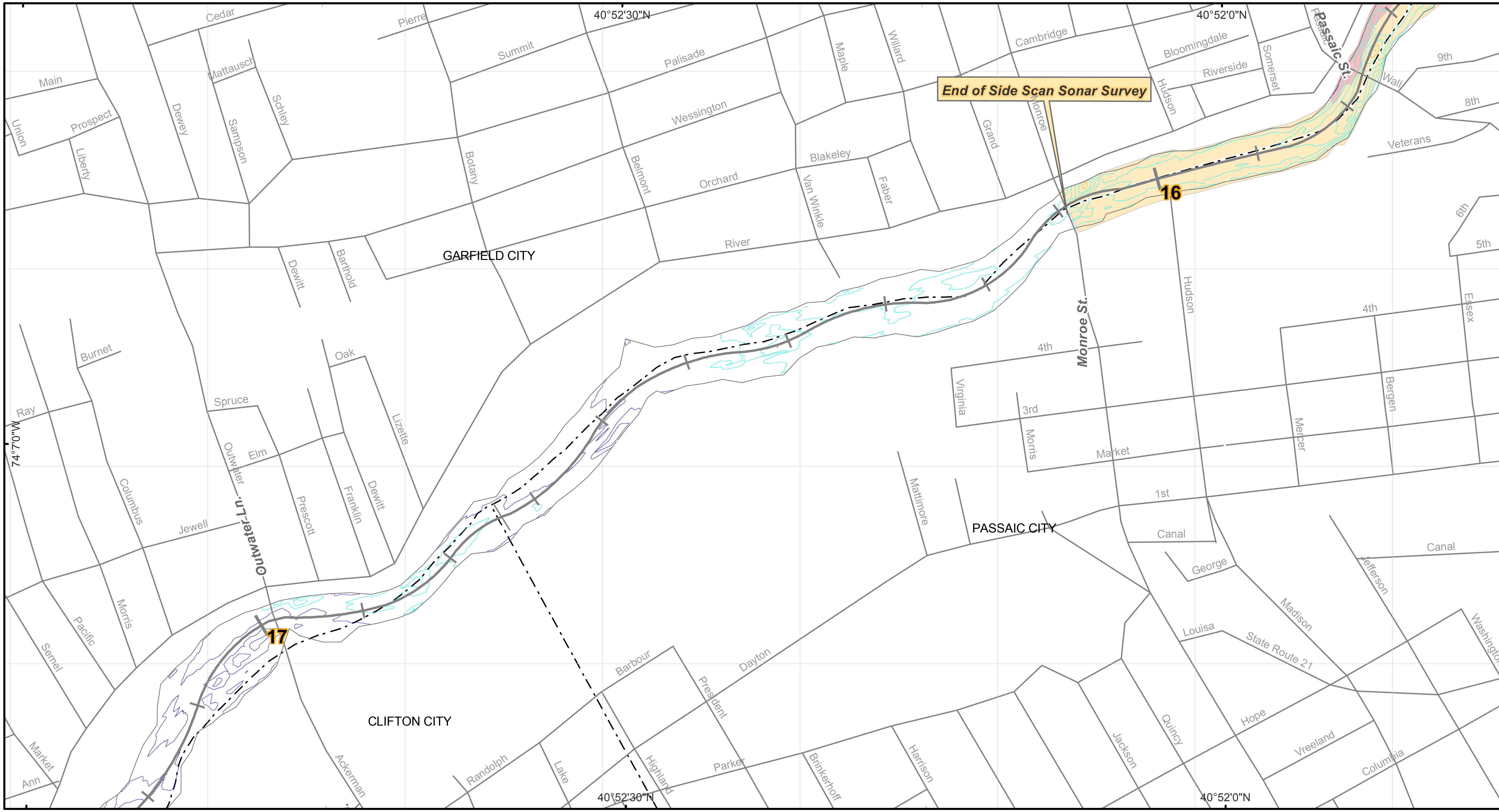

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US Army Corps of Engineers®

Sediment Texture Map

Lower Passaic River Restoration Project

February 2007

Legend

- Rock and Coarse Gravel
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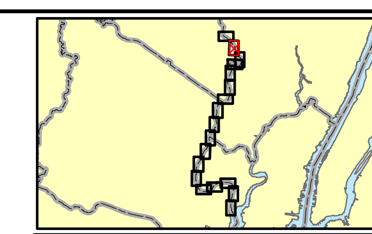

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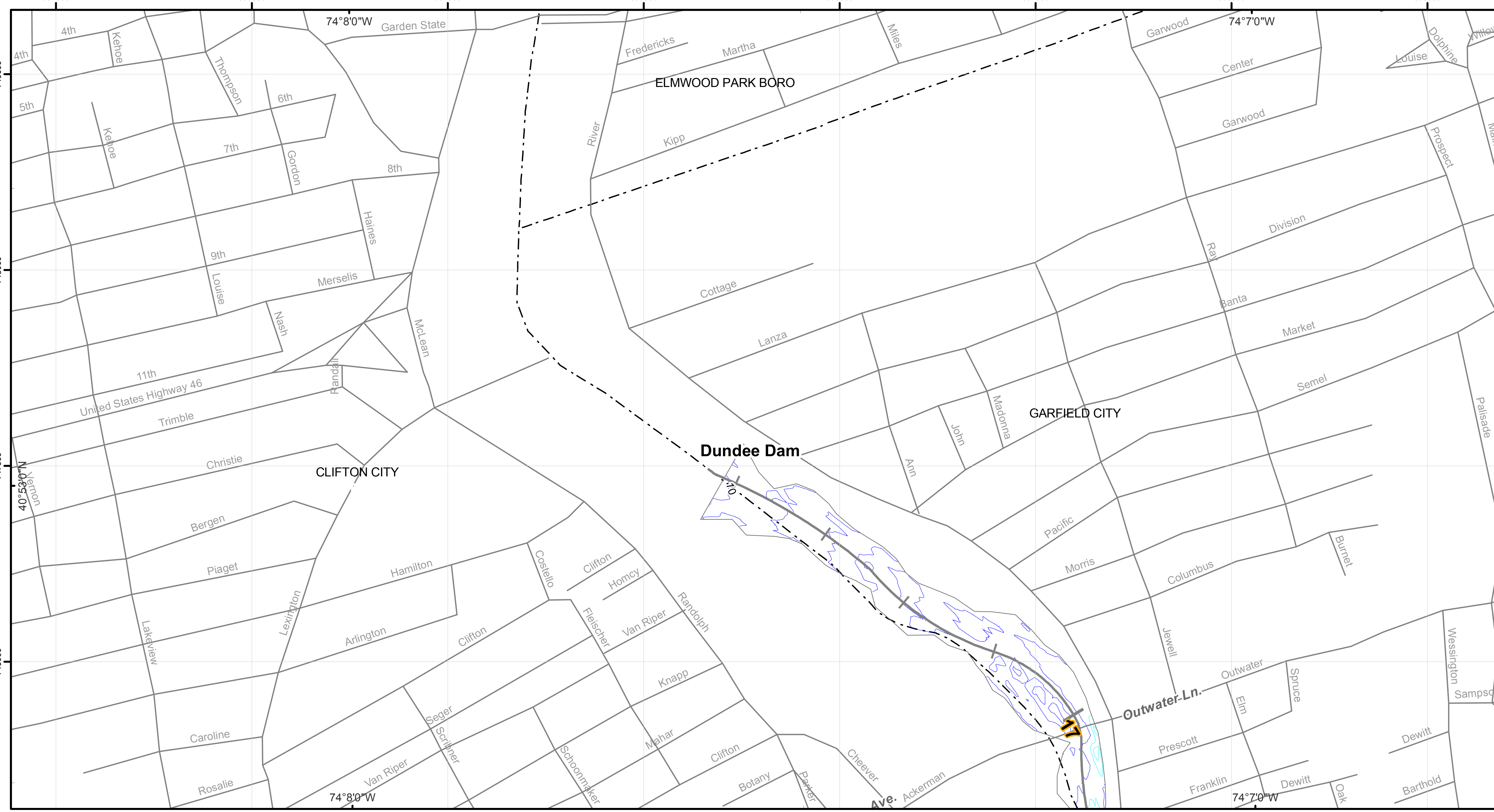

Sediment Texture Map

Lower Passaic River Restoration Project

February 2007

Legend

- Rock and Coarse Gravel
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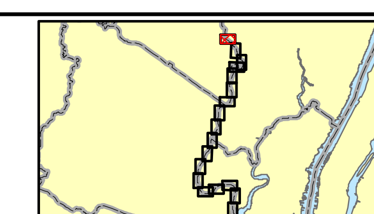

Mile 17 to Dundee Dam

US Army Corps of Engineers®

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Attachment B

Calculation of Groundwater Contribution

LOWER PASAIC RIVER RESTORATION PROJECT
CALCULATION OF GROUNDWATER CONTRIBUTION

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CALCULATION OF GROUNDWATER CONTRIBUTION

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CALCULATION OF GROUNDWATER CONTRIBUTION

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1.0 BASEFLOW ESTIMATION

1.1 RIVER HYDROLOGY

The flow in the Lower Passaic River consists of 3 components: surface water runoff, artificial outfalls, and groundwater seepage. Figure B-1 shows an idealized cross-section of the Lower Passaic River (or any other river in a similar environment). When the rain falls to the ground, some of it escapes as runoff, some infiltrates to recharge the groundwater table, and some evaporates or is used by plants (evapotranspiration). All of the surface runoff within a given watershed will eventually flow to the river. The infiltrating water will also reach the river, but it will travel underground. This portion of the river is called “baseflow” because it is generally present even when it is not raining. Since more resistance exists to flow underground than above ground, the groundwater arrival will be delayed and damped out. Changes in groundwater heads around the river (caused by season or drought conditions) can result in some variation in baseflow. However, these variations are small compared to the variations in surface run off (which can have large daily variations). For this application, an average baseflow was calculated and was assumed to be constant.

The magnitude of the baseflow is dependent on the volume of infiltration within the river’s watershed. Although baseflow is a volume of water added to the river over a given time period, it is often divided by the watershed area, to produce units similar to precipitation (depth per time). When expressed in this fashion, baseflow is independent of the size of the watershed and it can be applied to any other watershed with identical meteorological, hydrologic and geologic conditions.

One way to determine the baseflow in a river is to subtract the run off and artificial discharges from the total flow in a river. The run-off can be subtracted by looking for a dry period in the stream flow dataset when none of the flow in the river can be attributed to surface run off. When flow information is available, it is simple to add up the artificial discharges and subtract them from the total flow.

1.2 SELECTION OF A COMPARABLE WATERSHED

Ideally, the groundwater component to stream flow would be estimated by analyzing one or more stream flow gauges on the river of interest. However, because there is no stream flow gauge station in the Lower Passaic River, and because the river is tidal (the tidal influence would add an additional component to the flow), the analysis could not be performed using data from the Lower Passaic River. Instead, Malcolm Pirnie, Inc. searched for one or more nearby watersheds with similar precipitation, soil type, geology, land use, and vegetation. The resulting recharge value was divided by the watershed area and then applied to the Lower Passaic River watershed.

Several nearby drainage areas were considered. The Little Falls station [United States Geological Survey (USGS) 01389500] is located about 12 miles upriver of Dundee Dam on the Passaic River. However, the drainage area for Little Falls is very large (762 square miles). Although the size does not preclude its usefulness in this application, this particular watershed extends far to the north and west of the station, where land uses and geologic settings vary significantly from conditions in the drainage area of the Lower Passaic River. (Refer to Figure B-2 for the locations and stations for each watershed.) In addition, the watershed above the Little Falls gauge includes over 300 New Jersey Pollutant Discharge Elimination System (NJPDES) permits [New Jersey Department of Environmental Protection (NJDEP), 2005], only about one-third of which have flow data available online from the NJDEP website (NJDEP, 2006).

The drainage areas of three tributaries on the Lower Passaic River were also considered (Figure B-2). Saddle River has two stream flow stations, which are not very useful for this analysis because the drainage areas for these stations extend far to the north where geology, soil types, and land use vary significantly. The other two tributaries (Second River and Third River) have the right geologic characteristics, but are only marginally useful because the periods of record on these stream gauges are fairly short (about 25 and 20 years, respectively) and do not contain recent data. The baseflow for these two drainage areas was also computed (refer to Section 1.5 “Comparison to Second and Third

Rivers"), but Malcolm Pirnie, Inc. also wanted to find a nearby watershed with a longer period of record for comparison.

The Elizabeth River basin with a station at Ursino Lake (USGS 01393450) is nearby and has over 80 years in the data record. This watershed is small (16.9 square miles) and covers an urban area much like the Lower Passaic River. The underlying geology is the same geologic formation as is found under the Lower Passaic drainage area (the Triassic-aged Brunswick Formation). Elizabeth River empties into the Arthur Kill about six miles southwest of the mouth of the Passaic River. (Refer to Figure B-2 and Figure B-3 for the relative locations of the Lower Passaic River, Second River, Third River, and Elizabeth River). Because of the similarities between these three drainage areas and the Lower Passaic Drainage area, the recharge per unit area of the watershed to the Elizabeth River can be calculated and applied to the Lower Passaic River. The recharge per unit area to the Second and Third Rivers was also calculated for comparison.

1.3 ANALYSIS OF PERMITTED DISCHARGES

There are 18 NJPDES permits in the drainage area for the Elizabeth River stream gauge (Figure B-4). Discharge information is available for about half of them at NJDEP's Open Public Records Act (OPRA) website (NJDEP, 2006). For each of the permits within the drainage area, the greatest flow measurement over the most recent year of data is listed in Table 2-1. The OPRA website provided data for only about half of the permits, but none of the facilities are expected to have large outflows with respect to the flow in the Elizabeth River (there are no permitted municipal wastewater treatment plants on the river above the gauge). The total flow of the known locations is less than 0.3 cubic feet per second (cfs), which is a small flow compared to the flow over the Dundee Dam (more than 1,100 cfs).

Table 2-1: Summary of NJPDES Permit Information for Elizabeth River Drainage

NJPDES Identification	NJPDES Facility Name	Flow (million gallons/day)	Flow (cfs)
NJ0060194.001A	American Aluminum Casting	unk	
NJ0107204.001A	Ardell Industries – ASRC	unk	
NJ0080071.001A	Ardell Industries (ECRA)	0.00043	0.001
NJ0069515.001A	Ariston Div - Graphic Design Tech	unk	
NJ0070696.001A	Atlantic Metal Products	0.0178	0.028
NJ0035980.001A	Atlas Tool Co Inc	0.0312	0.049
NJ0027871.001A	Coastal Oil Company	unk	
NJ0031186.002A	ECD Inc	0.0005	0.001
NJG0105082.001A	Exxon S/S 3-0065	0.0034	0.005
NJG0109835.001A	Exxon S/S 3-0209	unk	
NJ0131407.001A	Exxon S/S 3-1799	unk	
NJG0109592.001A	Jersey Plastic Molders	unk	
NJG0108626.001A	Merit Oil of NJ - Merit S/S	0.009	0.014
NJ0105813.001A	Peter A Droback Co	unk	
NJG0068802.001A	Ronald Mark Associates	0.078	0.123
NJ0002291.001A	Schering Corp	unk	
NJ0104001.001A	Star Enterprise	unk	
NJ0087882.001A	Sunoco S/S 6-9096	unk	
NJ0034266.001A	Tuscan Dairy Farms Inc	0.027	0.043
	Sum	**0.167**	**0.264**

unk = unknown value

1.4 DETERMINATION OF BASEFLOW IN ELIZABETH RIVER

The USGS website (USGS, 2007) provides daily average flow rates for the stream gauge on Elizabeth River from June 1922 through September 2005. To determine the baseflow, various years were analyzed separately. For example, Figure B-5 shows the flow data for the randomly selected year 1983, which is representative of the other years in the record. The low points between the storm events are considered to be baseflow.

The information from the stream gauge shown in Figure B-5 was analyzed by calculating the 7-day minimum flow for each day of the year. (The seven days included the three previous days and the three subsequent days.) The point was considered to represent baseflow if the measurement for that day was within 1 cfs of the 7-day minimum. Figure B-6 shows the same stream flow data as Figure B-5 but with the estimated baseflow values connected with a red line. The red line in Figure B-6 probably shows more baseflow variation than reality. Some low points may be below baseflow because of evapotranspiration. Some instances when the baseflow seems to be high may indicate times when closely spaced storms prevented the river from returning to steady baseflow conditions.

Figure B-6 shows that for the year 1983, the baseflow varied between 4 and 19 cfs with an average of about 8 cfs. This analysis was repeated for the rest of the years in the record (Figure B-7). With the exception of the first 10 or 20 years of the record, there is not a lot of variation in the average baseflow value. At the same time, there is a perceptible increase in the minimum baseflow value and a marked decrease in the maximum value. The range of variability generally decreases over the last century, probably due to more engineering in the water system.

The average baseflow over the entire record was calculated by averaging each of the annual averages. The result was about 8.2 cfs. When Malcolm Pirnie, Inc. subtracted out 0.3 cfs for the NJPDES permits and divided the flow by the basin area (16.9 square miles), the recharge per unit area for the Elizabeth River basin was calculated to be 6.3 inches/year. This means that about 6.3 inches of the annual rainfall in the Elizabeth River drainage area infiltrates to the water table and makes its way to the river, where it seeps through the bottom sediments and joins the river water.

1.5 COMPARISON TO SECOND AND THIRD RIVERS

We applied the process described in Section 1.3 “Analysis of Permitted Discharges” and Section 1.4 “Determination of Baseflow in Elizabeth River” to the drainage areas for the Second and Third Rivers for a check of the results. Table 2-2 shows the NJPDES permit information for each of these basins.

Table 2-2: NJPDES Information for Second and Third River Drainage Basin

Second River Drainage Basin			
NJPDES Identification	Facility Name	Flow (Million gallons/day)	Flow (cfs)
NJ0034185.001A	Hoffmann-La Roche Inc	unk	
NJ0107654.001A	Hobart Brothers Co	0.011	0.016
NJ0052078.001A	ABB Lummus Global	0.002	0.003
NJ0002909.001A	Montclair State University	unk	
NJG0156426.001A	Grove St Pumping Station	unk	
	Total	0.01	0.02
Third River Drainage Basin			
NJPDES Identification	Facility Name	Flow (Million gallons/day)	Flow (cfs)
NJ0029335.001A	Peerless Tube Company	unk	
NJ0032280.007A	Clara Maass Hospital	0.042	0.065
NJ0066516.001A	Chevron USA Inc	unk	
NJ0100048.001A	McGraw-Edison Worthington	unk	
NJ0108502.001B	Viacom Incorporated	0.0001	0.0002
NJG0029327.001A	Peerless Tube Company	1.67	2.59
NJG0075221.001A	Exxon S/S 3-1062	unk	
NJG0108758.001A	Newark City	unk	
NJG0127710.001A	Gulf S/S - Frank & Rick's Inc	unk	
	Total	**1.72**	**2.65**

unk = unknown value

As with Elizabeth River, the OPRA website did not provide data for some of the permits. The totals for the Second River watershed result in a very small, negligible flow rate. However, the total artificial flow for the Third River watershed is significant.

The same process detailed in Section 1.4 “Determination of Baseflow in Elizabeth River” was used to separate out the baseflow for all the years of data in the Second and Third River stations. The NJPDES permitted flows were subtracted from the result, and then both flow rates were divided by the basin areas to determine a recharge value in inches/year. Figure B-8 compares the calculated baseflow for each of the 3 drainage basins (after subtracting out NJPDES permitted flows) and shows a good correlation.

Results for all the years of each of the three records were averaged to calculate a single recharge value for each basin. The results, along with an average recharge value are shown in Table 2-3.

Table 2-3: Calculated Recharge for 3 Basins Near the Lower Passaic River

Basin	Average Estimated Low Flow (cfs)	Total NJPDES Flow (cfs)	Baseflow (cfs)	Drainage Area (square mile)	Recharge (inch/year)
Elizabeth River	8.2	0.3	7.9	16.9	6.3
Second River	7.8	2.7	5.1	11.6	6.0
Third River	8.8	0.0	8.8	11.8	10.1
Average					**7.5**

As these three basins are near the Lower Passaic River and have similar geologic settings and land use, the recharge from these smaller basins can be applied to the Lower Passaic River. The Lower Passaic River has a drainage area of 39.5 square miles below Dundee Dam when the basins for Saddle River, Third River, and Second River are removed (Figure B-3). When the recharge is applied to this larger basin, the baseflow to the Lower Passaic River is calculated to be 22 cfs (or about 14 million gallons/day). This value is the amount of flow that infiltrates to the groundwater table after a rain event and slowly makes its way to the river, where it enters by flowing through the bottom sediments.

1.6 CALCULATING SURFACE WATER FLOWS

The nearest streamflow gauge on the Lower Passaic River is the Little Falls Station, about 12 miles above Dundee Dam. The average flow at Little Falls was determined by using the USGS website (USGS, 2007) to extract average yearly flows for each complete year of the record. For the Little Falls Station, this included 107 years between 1898 and 2005. These yearly averages were then averaged to obtain a single flow value for the whole record. This value was found to be about 7 percent higher than the average over the last 50 years. For this reason the average used in the analysis was based only on the last 50 years of the record (1996-2005). The average river flow at Little Falls USGS gauging station from 1956 to 2005 was calculated as 1,050 cfs, or 247 billion gallons/year. The flow from the Little Falls gauge must be adjusted by approximately 10 percent[1] to account for the additional watershed area between Little Falls and the Dundee Dam, yielding an average river flow at the Dundee Dam of 1,160 cfs.

There are three major inflows to the Lower Passaic River: Saddle River, Second River, and Third River. Each has (or had) a USGS station near the intersection with the Lower Passaic River. The watersheds and station locations are shown in Figure B-3. The USGS website was used to obtain yearly average flow rates for each station. Although the differences between the average over the entire record and that over the last 10 years of the record were small (less than 5 percent), each average was based on the last 10 years for uniformity (Table 2-4).

Table 2-4: Surface Flow Sources to the Lower Passaic River

Location	Average Flow over Last 10 Years of each Record (cfs)	Source/Record
Dundee Dam	1,160	10 percent higher than Little Falls (1042 cfs) Record: 1898-2005
Saddle River at Lodi (USGS 01391500)	106	Record: 1924-2005
Third River at Passaic (USGS 01392210)	19	Record: 1978-1997
Second River at Belleville (USGS 01392500)	20	Record: 1938-1964

Figure B-3 shows that the three tributary stations are slightly upstream from the confluence points in each case. This means that the groundwater component between the station and the confluence should be added to the station measured flow. Malcolm Pirnie, Inc. also needs to add in any NJPDES permitted flows between the station and the confluence. Following with this method, we can estimate the total surface flow entering the Lower Passaic River from each tributary.

[1] River flow at Dundee Dam is based on a July 18, 2005 electronic message from Emad Sidhom (Senior Project Engineer at United Water and the New Jersey District Water Supply Commission) to F. Chris Purkiss (Malcolm Pirnie, Inc.). Mr. Sidhom indicated that the flow measurements at Dundee Dam were approximately 10 percent greater than the flows measured at the Little Falls gauging station.

The Saddle River calculation is simple since the station falls on the boundary of a hydrologic unit as defined by the NJDEP (Figure B-3). The area of the drainage basin for that lowest section of the Saddle River is 3,162 acres. When the 7.5 inch/year of recharge (Table 2-3) is applied to this area, the groundwater component in the lowest section of the Saddle River is calculated to be 2.7 cfs. In addition, there are several NJPDES outflow locations within this drainage area (Figure B-4 and Table 2-5) resulting in an additional 2.1 cfs. When these flows are added to the station average flow, the Saddle River surface water addition to the Lower Passaic River becomes 108 cfs.

Table 2-5: NJPDES Permits Below the Lodi Station

NJPDES Identification	Facility Name	Flow (million gallons/day)	Flow (cfs)
NJ0003182.001A	Stepan Company	1.4	2.1
NJ0033511.001A	Farmland Dairies	unk	
NJ0035262.002A	Bergen Cable Technologies	unk	
NJ0104591.020A	Novus Fine Chemicals LLC	unk	
NJ0131032.001A	Former Inmont Division	unk	
NJ0145378.001A	Hexcel Corp	0.003	0.005
NJG0157163.001A	BP S/S 1557	unk	
	Total	**1.4**	**2.1**

unk = unknown value

The Second River and Third River components are calculated differently because the hydrologic unit coverage does not separate the zone above the station. The recharge area below the station can be calculated by comparing the USGS reported drainage area (which includes only the area that contributes to the station flow) to the hydrologic unit area in the NJDEP coverage (which extends to the confluence with the Passaic River). For Third River, USGS reports a drainage area of 11.8 square miles for the station. The NJDEP hydrologic unit area is 12.5 square miles. Subtracting these two areas yields a drainage area of 0.7 square miles for the river reach below the station. When the 7.5 inch/yr (Table 2-3) of recharge is applied, the groundwater component between the station and the confluence is calculated to be 0.4 cfs. In addition, there are a few NJPDES permits downstream of the station but inside the drainage area for Third River (Figure B-4). The information for these permits is listed in Table 2-6. When the groundwater component (0.4 cfs) and the artificial flows (0.2 cfs) are added to the station average flow, the surface water addition from Third River into the Lower Passaic River is calculated to be 19 cfs.

Table 2-6: NJPDES Permits on Third River Below the Station Location

NJPDES Identification	Facility Name	Flow (million gallons/day)	Flow (cfs)
NJG0020214.001A	ITT Avionics Division	0.11	0.17
NJ0105490.001A	ADT Security System Mfg	0.02	0.03
NJ0020435.001A	ITT Aerospace Communications	Unk	
	Total	**0.12**	**0.19**

The Second River calculation is the same as that for Third River. The USGS reported drainage area is 11.6 square miles while the NJDEP hydrologic unit area is 9,315 acres. The calculation increases the Second River component from 20 cfs to 22 cfs. There are no NJPDES permit sites within the drainage area and below this station (Figure B-4). Finally, all the NJPDES permitted flows for the Lower Passaic River were added to the surface water flow. The permit information is listed in Table 2-7 while Table 2-8 summarizes the final flow data.

Table 2-7: NJPDES Permits on the Lower Passaic River

NJPDES Identification	NJDES Facility Name	Flow (million gallons/day)	Flow (cfs)
NJ0000035.001A	National Standard Company	Unk	
NJ0000124.001A	Kalama Chemical Inc	Unk	
NJ0000566.001A	PSE&G Harrison Plant	Unk	
NJ0000639.343A	PSE&G - Essex G S	Unk	
NJ0001431.001A	Amerada Hess Corp - Newark Term	Unk	
NJ0002160.001A	Motiva-Newark Sales Terminal	0.007	0.01
NJ0002194.001A	SparTech Compound	0.043	0.07
NJ0002232.001A	J L Prescott Company	Unk	
NJ0002283.001A	General Chemical-Newark Works	17	26
NJ0002615.21AA	Okonite Company	Unk	
NJ0002771.001A	Sun Refining and Manufacturing	Unk	
NJ0003573.001A	Finetex Inc	0.06	0.09
NJ0003841.001A	Sun Chemical Corp	Unk	
NJ0020478.001A	Pantasote Polymers Inc.	Unk	
NJ0022161.001A	Kearny STP	Unk	
NJ0026034.001A	Getty Terminals Corp	0.005	0.01
NJ0027758.001A	US Postal Service	Unk	
NJ0029505.001A	969 Newark Turnpike Inc	Unk	
NJ0030376.001A	L & M Laplace	0.000	0.00
NJ0031313.001A	Kleer Kast Inc	Unk	

Table 2-7 Continued			
NJ0031992.002A	NJ Transit – Meadows Maint	Unk	
NJ0033146.001A	Custom Chemical Co	0.081	0.12
NJ0034193.001A	Mansol Industries Inc	Unk	
NJ0034223.001A	Mansol Industries Inc	Unk	
NJ0034959.001A	NJDOT- Interstate 280	Unk	
NJ0034983.001A	V H Swenson Co Inc	Unk	
NJ0053783.001A	Toc Terminal Inc	0.073	0.11
NJ0055247.001A	American Ref – Fuel Co	Unk	
NJ0055808.001A	Flexon Industries Corp	Unk	
NJ0063738.001A	Reichhold Chemicals Inc	0.12	0.19
NJ0072109.001A	Getty S/S 56924	Unk	
NJ0076058.001A	Amerada Hess Newark Terminal	Unk	
NJ0076431.001A	Mobil S/S 15-JQ2	Unk	
NJ0078221.001A	Motiva Enterprises LLC	Unk	
NJ0078344.001A	Mobil S/S 15-LAE	Unk	
NJ0081248.001A	Penco of Lyndhurst Inc	Unk	
NJ0083259.001A	Motiva Enterprises LLC	Unk	
NJ0100196.001A	Material Recovery Facility	Unk	
NJ0100714.001A	US Postal Service	Unk	
NJ0102636.001A	Amoco S/S 0925	Unk	
NJ0104167.001A	SpectraServ	Unk	
NJ0106798.001A	Recycle Fibers	Unk	
NJ0107000.001A	Newark Boxboard Co	Unk	
NJ0107395.001A	Nimco Shredding Co	Unk	
NJ0107646.001A	Pramar Realty Co LP	Unk	
NJ0108367.002A	US Postal Service	0.0069	0.01
NJ0108499.001A	Deleet Merchandising Corp	Unk	
NJ0116068.001A	Clayton Block Co LlC	Unk	
NJ0117846.001A	East Newark Borough Of	Unk	
NJ0127272.001A	Parkway Iron & Metal Co Inc	Unk	
NJ0128261.001A	S & W Waste Inc	Unk	
NJ0128287.001A	Transplastic Inc	Unk	
NJ0129046.001A	Newark Asphalt Corp	Unk	
NJ0130508.001A	Spartech Polycom	Unk	
NJ0131814.001A	Presto Lock Inc	0.16	0.25
NJ0132390.001A	Stanley Tools Facility (former)	Unk	
NJ0133396.001A	Mobil S/S 15-JQ2	Unk	
NJ0136727.001D	Getty S/S 56868	Unk	
NJ0137545.001A	Route 21 Associates Site	Unk	
NJ0137774.001A	Joashlin Construction (former River Oil)	Unk	
NJG0020214	ITT Avionics Division	0.066	0.10

Table 2-7 continued			
NJG0029815.001A	Duro Test Corporation	Unk	
NJG0033430.001A	Fairmount Chemical Co	0.040	0.06
NJG0064220.001A	Exxon S/S 3-2138	Unk	
NJG0073741.001A	Honeyware Inc	0.22	0.33
NJG0086720.001A	Getty S/S 56844	Unk	
NJG0103071.001A	Styertowne Mall	0.0054	0.01
NJG0104256.002A	Sun Company Inc (Newark Term)	0.0079	0.01
NJG0108758.002A	Newark City	Unk	
NJG0108871.007A	Harrison Town	Unk	
NJG0111244.002A	Kearny Town	Unk	
NJG0128317.001A	Clifton Fire House 6	Unk	
NJG0146714.001A	General Hospital Center (Passaic)	0.023	0.04
NJG0158658.001A	Branch Brook Park	Unk	
NJG0160741.001A	Chemaid Laboratories Inc	Unk	
	Total	**18**	**27**

unk = unknown value

Table 2-8: Flow Components in the Lower Passaic River

Source	Flow rate (cfs)	Notes
Dundee Dam	1,160	Value from Table 2-4
Saddle River	108	Value from Table 2-4
Third River	19	Value from Table 2-4
Second River	22	Value from Table 2-4
NJPDES Flows	27	Permitted flows on Lower Passaic River. Value from Table 2-7
Total Surface Water Component	**1,322**	
Groundwater Component	22	From baseflow separation analysis (Section 1.4 and Section 1.5)
Total Flow in River	**1,344**	

2.0 ACRONYMS

cfs	Cubic feet per second
NJDEP	New Jersey Department of Environmental Protection
NJPDES	New Jersey Pollutant Discharge Elimination System
OPRA	Open Public Records Act
USGS	United States Geological Survey

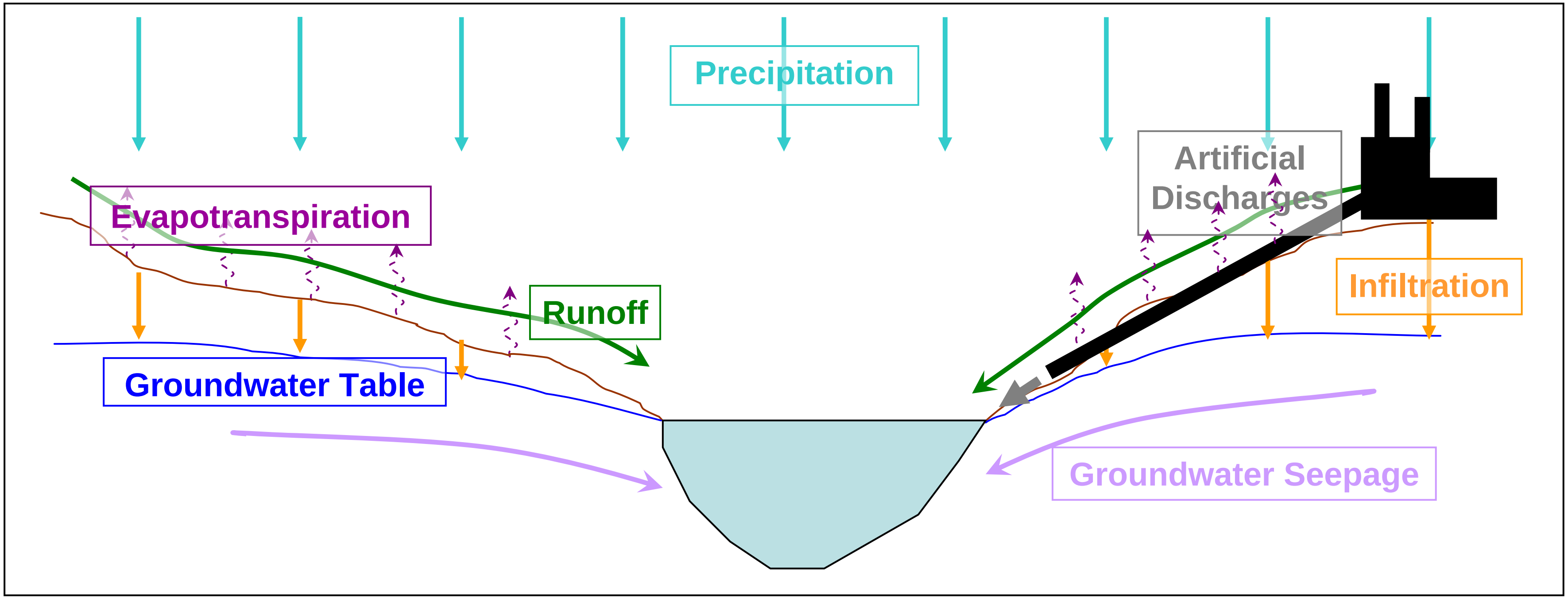
3.0 REFERENCES

NJDEP, 2006. New Jersey Department of Environmental Protection: Open Public Records Act. “DEP Data Miner.” Last modified on 19 September 2006. Last accessed on 10 January 2007. http://datamine.state.nj.us/dep/DEP_OPRA/index2.html.

NJDEP, 2005. New Jersey Department of Environmental Protection: Division of Water Quality. “njpdes related GIS downloads.” Last modified on 29 March 2005. Last accessed on 10 January 2007. http://www.state.nj.us/dep/dwq/njpdes_gis.htm.

USGS, 2007. “USGS Surface – Water Data for the Nation”. Last accessed on 10 January 2007. http://waterdata.usgs.gov/nwis/sw.

United Water New Jersey. 2005. Personal communication between F.Chris Purkiss (Malcolm Pirnie, Inc.) and Emad Sidhom. July 18, 2005.

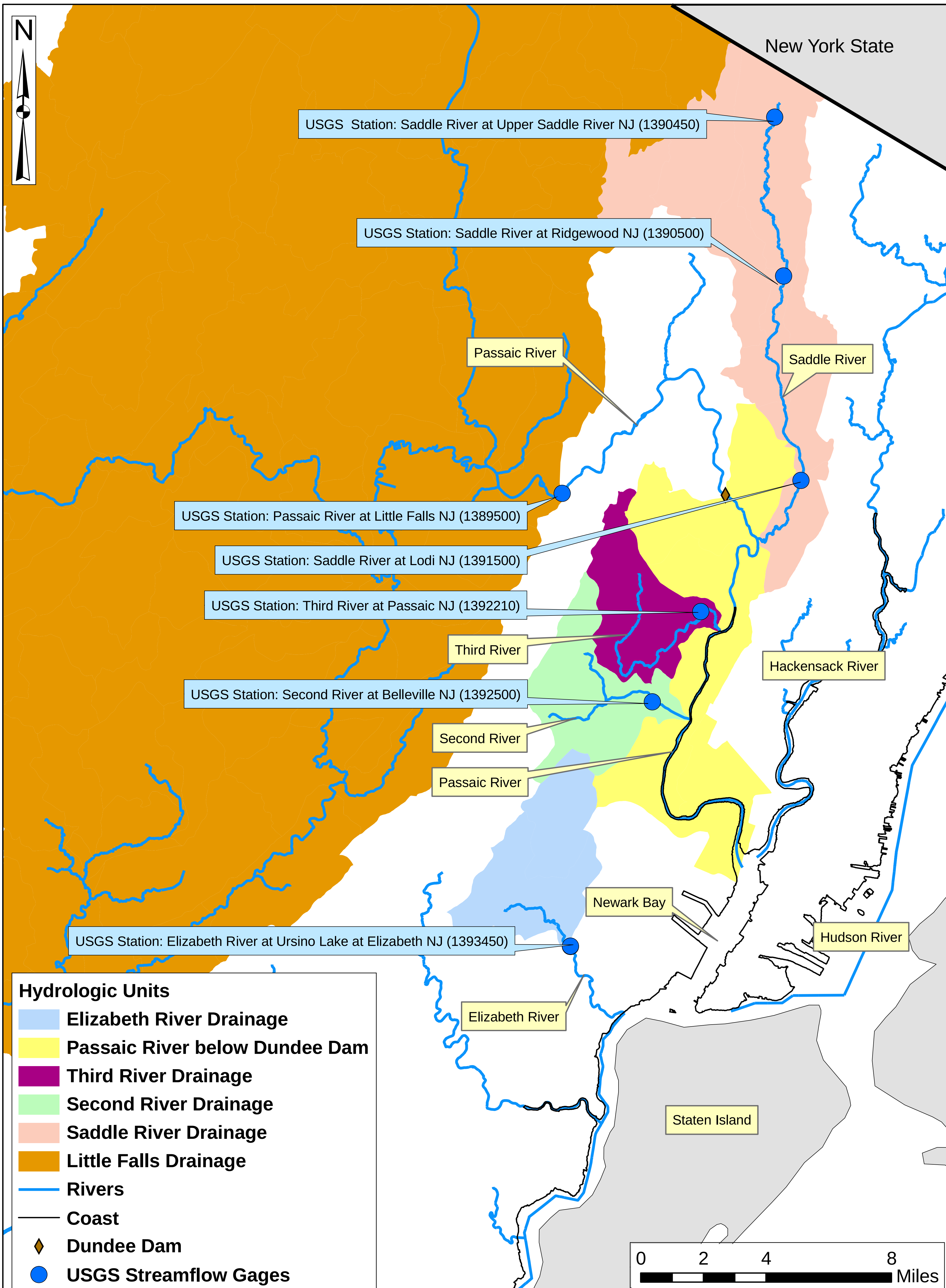


Idealized Cross-Section of the Lower Passaic River

Lower Passaic River Restoration Project

Figure B-1

February 2007



Sources:
Drainage Areas developed from the Hydrologic Unit Coverage from www.state.nj.us/dep/gis/digidownload/zips/statewide/dephuc14.zip.
Rivers coverage from www.state.nj.us/dep/gis/digidownload/zips/statewide/stateriv.zip. Only Level 1 and 2 rivers are shown. (Second River, which is not Level 1 or 2, was digitized from USGS quad map.)
Coastline coverage from www.state.nj.us/dep/gis/digidownload/zips/statewide/coast.zip.
USGS station locations from USGS National Water Information System: waterdata.usgs.gov/nwis/sw. (Stations plotted show current or existing locations.)

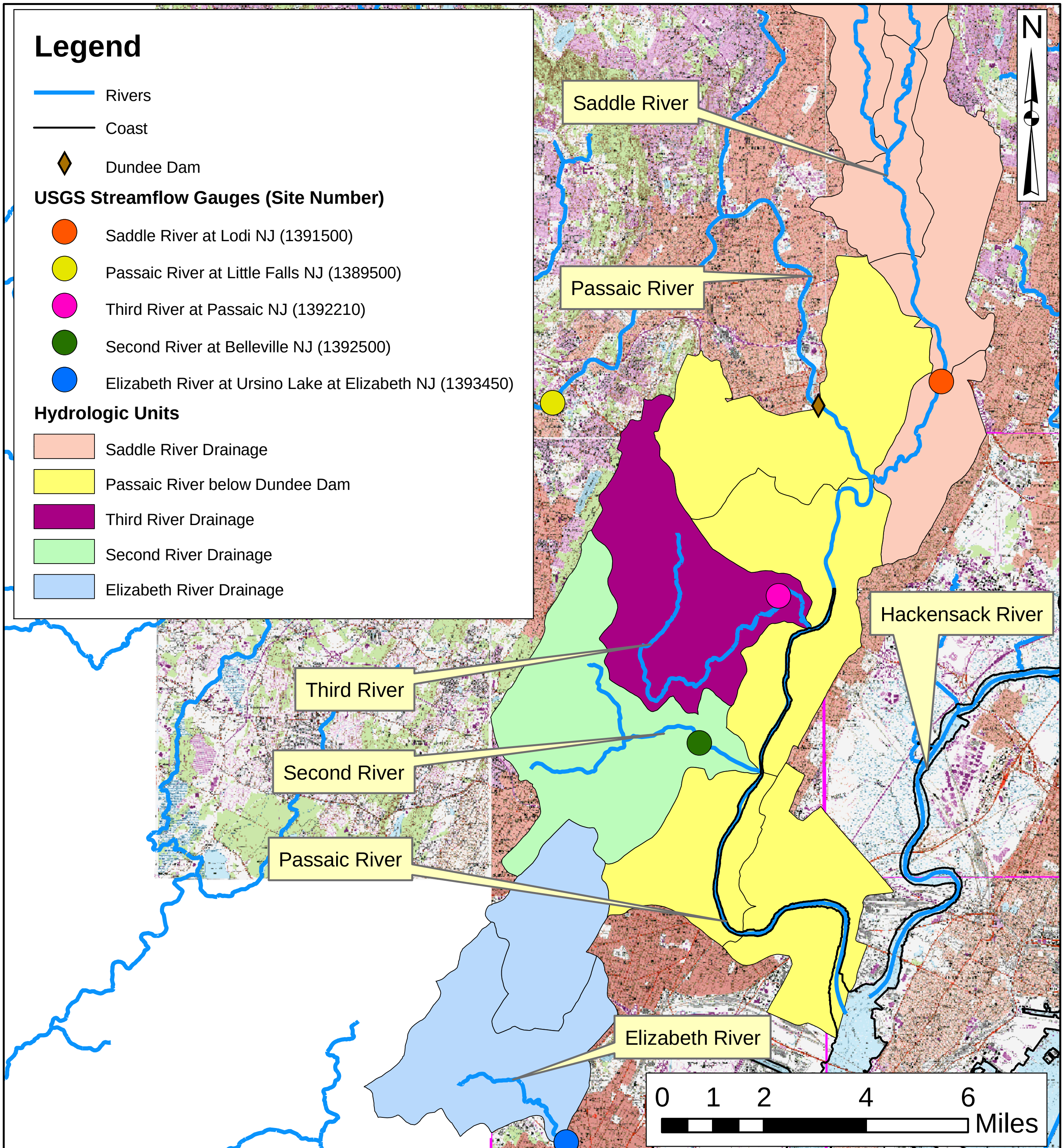
Notes: Although this map stops at the New Jersey/New York border, the drainage area for the Little Falls and Saddle River Stations extend north into the state of New York. The USGS Stations are labeled on the map with the Site Name and Number.

Drainage Areas and USGS Streamflow Gauges
Near the Lower Passaic River

Lower Passaic River Restoration Project

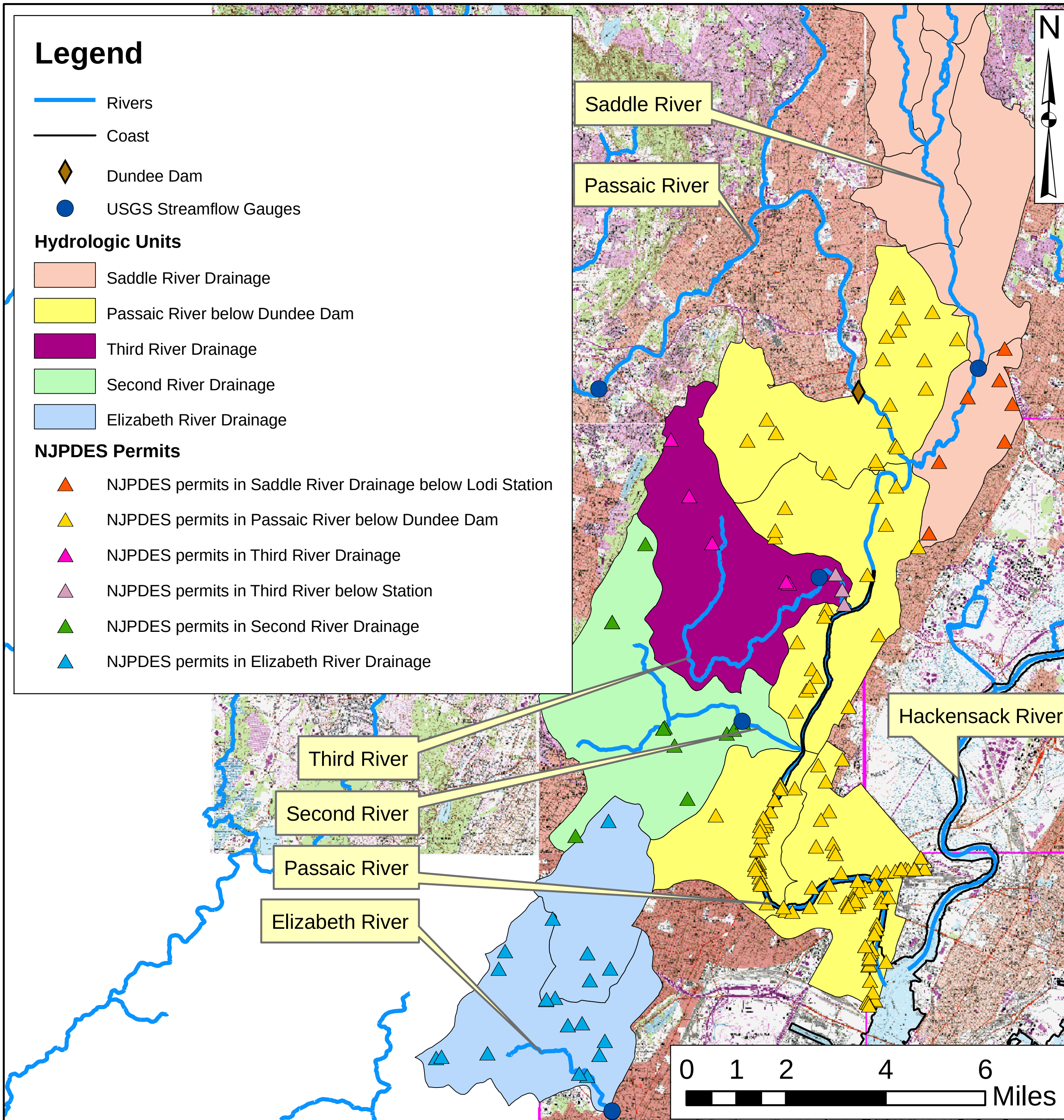
Figure B-2

February 2007



Sources:
Background Maps from USGS quad maps.
Drainage Areas developed from the Hydrologic Unit Coverage: www.state.nj.us/dep/gis/digidownload/zips/statewide/dephuc14.zip.
Rivers coverage from www.state.nj.us/dep/gis/digidownload/zips/statewide/stateriv.zip. (Second River digitized from USGS quad map.)
Coastline coverage from www.state.nj.us/dep/gis/digidownload/zips/statewide/coast.zip.
USGS station locations (with Site Numbers) from USGS National Water Information System: waterdata.usgs.gov/nwis/sw.

US Army Corp of Engineers	Drainage Areas and USGS Streamflow Gauges for Calculating Baseflow	Figure B-3
	Lower Passaic River Restoration Project	February 2007



Sources:
Background Maps from USGS quad maps.
Drainage Areas developed from the Hydrologic Unit Coverage: www.state.nj.us/dep/gis/digidownload/zips/statewide/dephuc14.zip.
Rivers coverage from www.state.nj.us/dep/gis/digidownload/zips/statewide/stateriv.zip. (Second River digitized from USGS quad map.)
Coastline coverage from www.state.nj.us/dep/gis/digidownload/zips/statewide/coast.zip.
USGS station locations from USGS National Water Information System: waterdata.usgs.gov/nwis/sw.
Hydrologic Unit Code coverage from www.state.nj.us/dep/gis/digidownload/zips/statewide/dephuc14.zip.
NJPDES Permit Locations from www.state.nj.us/dep/dwq/njpdes_gis.htm.

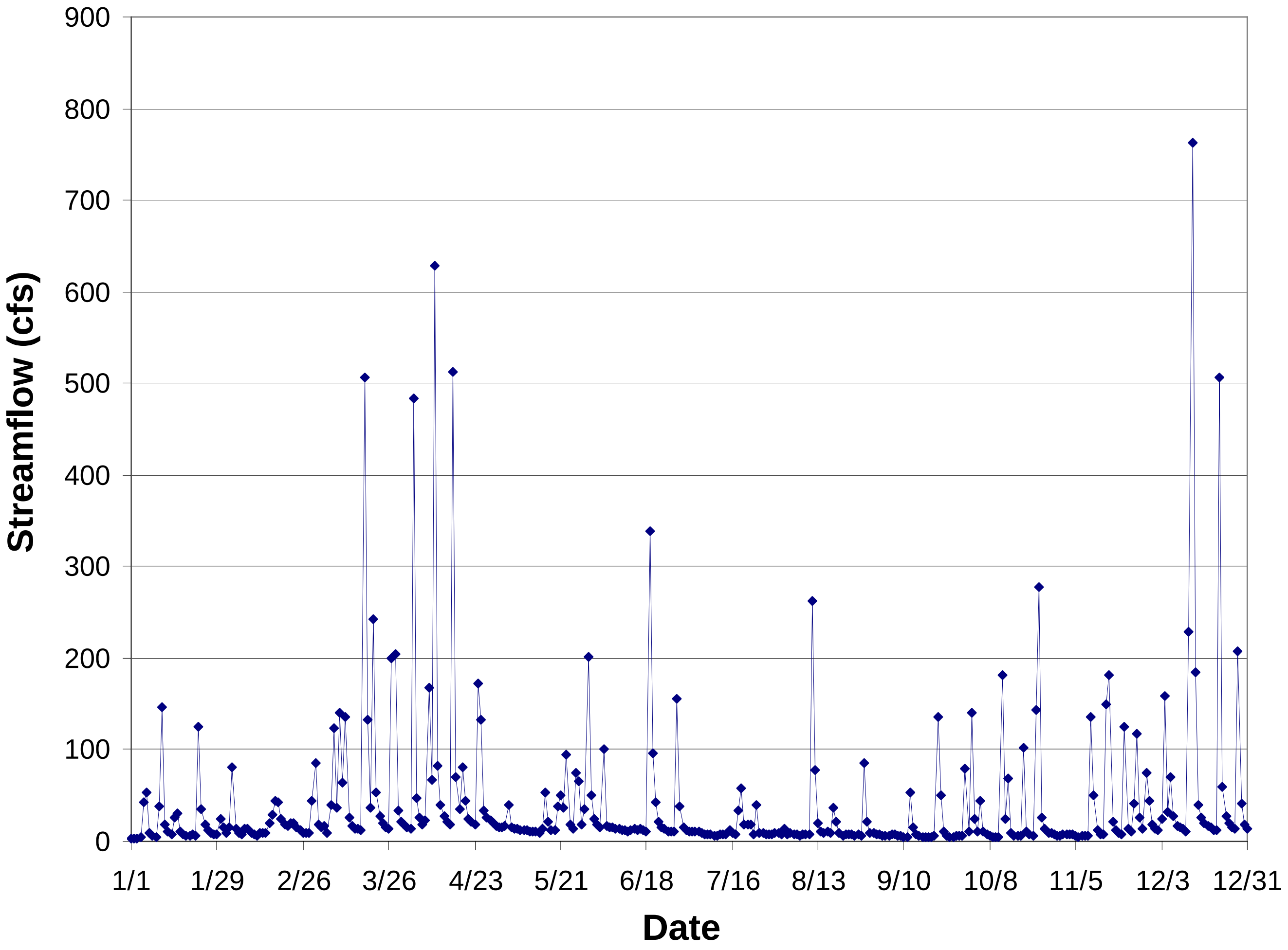
US Army Corps of Engineers

NJPDES Permitted Locations

Lower Passaic River Restoration Project

Figure B-4

February 2007



Notes

Average Daily Streamflow data from USGS: http://waterdata.usgs.gov/nwis/sw.

Station: Elizabeth River Station at Ursino Lake (USGS 1393450)

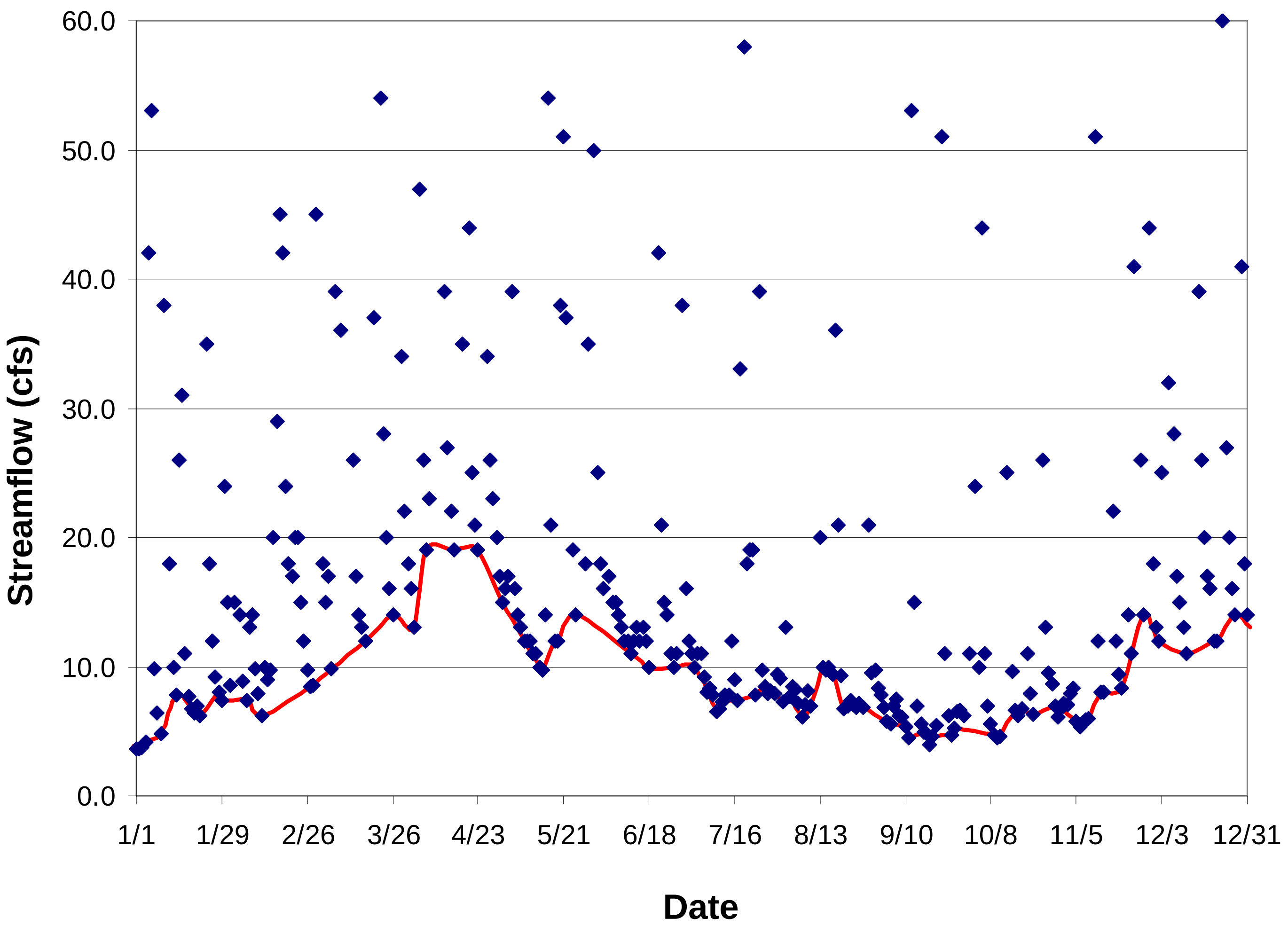
US Army Corps of Engineers

Elizabeth River Average Daily Streamflow - 1983

Lower Passaic River Restoration Project

Figure B-5

February 2007



Legend

Measured Average Daily Streamflow at Elizabeth River

Estimated Baseflow

Notes

Average Daily Streamflow data from USGS: http://waterdata.usgs.gov/nwis/sw.

Station: Elizabeth River Station at Ursino Lake (USGS 1393450)

For clarity, only streamflows below 60 cfs are shown.

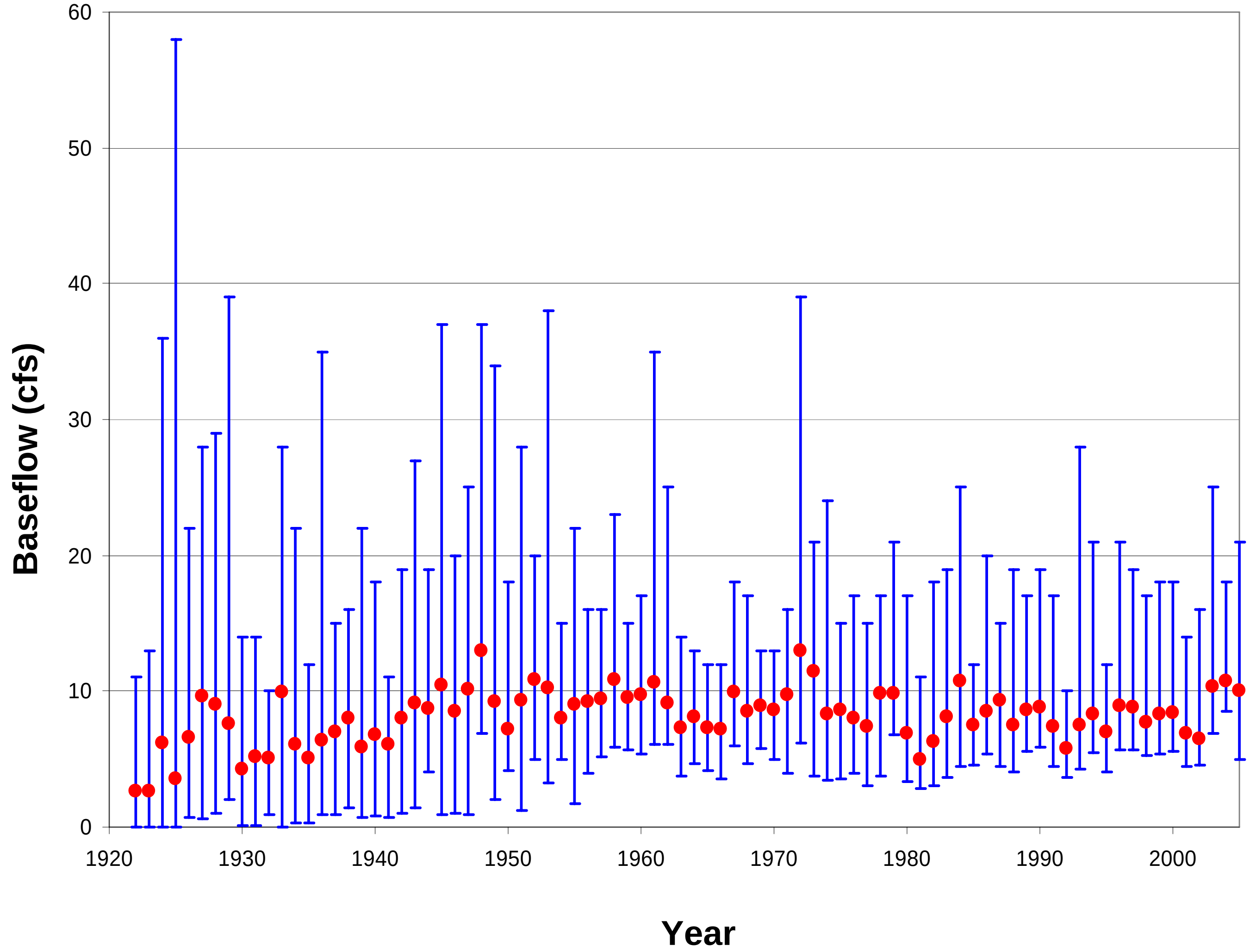
Baseflow estimated by connecting any points within 1 cfs of the 7-day minimum flow.

Elizabeth River Average Daily Streamflow with Estimated Baseflow - 1983

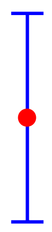
Lower Passaic River Restoration Project

Figure B-6

February 2007



Legend



Notes

Baseflow estimates based on USGS Streamflow data for Elizabeth River at Ursino Lake (USGS 1393450) available at http://waterdata.usgs.gov/nwis/sw.

Data points were considered to represent baseflow if the measured flow was within 1 cfs of the 7-day minimum flow (comprising the three previous days, the current day and the three subsequent days).

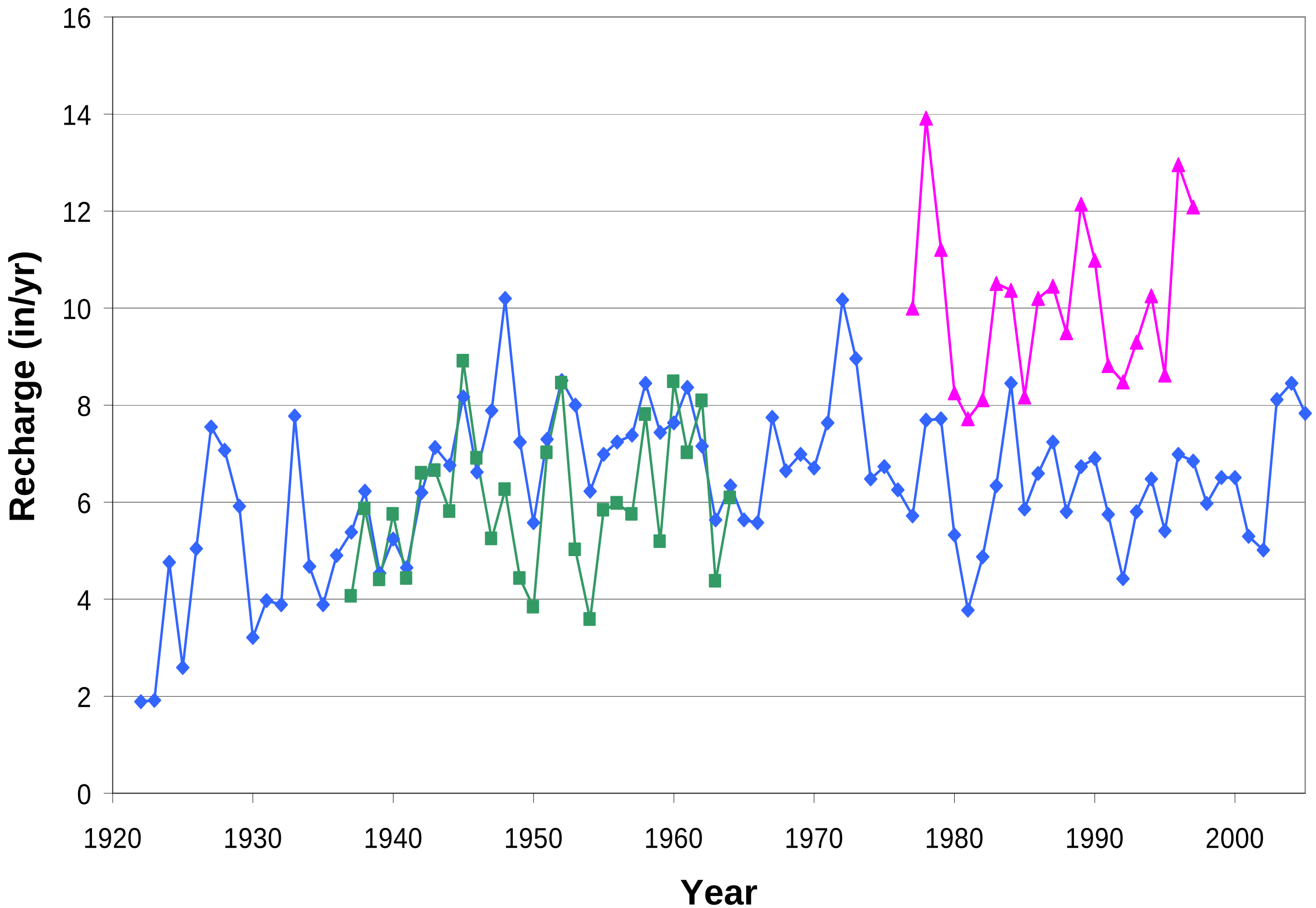
The maximum, minimum and average baseflows represent the statistics on the list of measurements representing baseflow for each year.

Minimum, Average and Maximum Estimated Baseflow for Elizabeth River 1922-2005

Lower Passaic River Restoration Project

Figure B-7

February 2007



Legend

- Elizabeth River
- Second River
- Third River

Notes

USGS Stations: Elizabeth River at Ursino Lake (USGS 1393450), Second River at Belleville (USGS 1392500), and Third River at Passaic (USGS 1392210).

The recharge was estimated using the baseflow separation techniques discussed in the text.

Comparison of Average Estimated Recharge to Elizabeth River, Second River and Third River

Lower Passaic River Restoration Project

Figure B-8

February 2007

Attachment C

Bathymetric Data Analysis

LOWER PASSAIC RIVER RESTORATION PROJECT
BATHYMETRIC DATA ANALYSIS

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LOWER PASSAIC RIVER RESTORATION PROJECT
BATHYMETRIC DATA ANALYSIS

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1.0 BATHYMETRIC DATA ANALYSIS

Historical Tierra Solutions, Inc. (TSI) bathymetric data (surveyed by Ocean Surveys, Inc.) include bathymetric surveys conducted from 1995 to 2001 and extending from river mile (RM) 0.9 to RM7.[1] These data were examined in two separate evaluations to delineate net erosional and net depositional areas in the Lower Passaic River. The TSI surveys were selected because the bathymetric surveying tracks are well aligned, reducing the uncertainty in direct measurement-to-measurement comparisons. The evaluations presented here build on the bathymetric surfaces previously created for the *Draft Geochemical Evaluation (Step 2)* [Malcolm Pirnie, Inc. (2006); refer to Section 2.1 "Sedimentation Rates and Annual Accumulation" for more detail]. All analyses were conducted using Environmental Systems Research Institute, Inc. (ESRI) ArcGIS software and the Spatial Analyst extension. Aerial coverage (*e.g.*, total acreage or percent area) was calculated using the XTools Pro function in ArcGIS. Input and results are in the form of raster (*i.e.*, grid) datasets. A raster dataset is a spatial data model consisting of rows and columns to form grid cells, where each cell contains an attribute value and location coordinates (Kennedy, 2001).

1.1. INITIAL SCREENING TO IDENTIFY APPARENTLY NET EROSIONAL AND NET DEPOSITIONAL AREAS

For the initial screening of the data, consecutive bathymetric surveys were compared to identify areas of the Lower Passaic River that experienced frequent intense erosional or depositional events (gain or loss of 2 inches/year or more). The four year-to-year comparisons include: 1995-1996, 1996-1997, 1997-1999, and 1999-2001. For each comparison, a separate grid was generated, and for each grid cell, the annual sedimentation rate was calculated as the change in depth between the two examined bathymetric surveys divided by the number of years covered by the two surveys (units

[1] The surveying area common to all five bathymetric surveys includes RM0.9 to RM7, which encompasses 94 percent of the total bank-to-bank area based on the shoreline delineated by the New Jersey Department of Environmental Protection Shoreline Type Geographic Information System data.

converted to inches/year). The sedimentation values for each grid cell were then scored and classified as defined in Table 1-1.

Table 1-1: Criteria for Scoring and Classifying Sedimentation Rates in the Year-to-Year Analysis

Sedimentation Rates	Score	Classification
Greater than +2 inches/year	+1	Apparently Net Depositional
Between +2 and -2 inches/year	0	Bathymetrically Neutral Area
Less than -2 inches/year	-1	Apparently Net Erosional

The criteria of +2 inches/year or -2 inches/year used in this scoring process were based on previous annual solids load calculations, which suggested that the largest sediment transport events are roughly equivalent to 2 inches or more of loss or gain of sediment [refer to Section 3.0 "Sediment Transport" of the *Draft Geochemical Evaluation (Step 2)* (Malcolm Pirnie, Inc., 2006)]. Hence, areas experiencing more than 2 inches/year of net deposition or net erosion can be identified as "apparently depositional" or "apparently erosional," respectively.

The scoring process resulted in four grids (one grid for each year-to-year comparison) with grid cells assigned values of +1, 0, or -1 (refer to Table 1-1 for designations). The four grids were then added using the Spatial Analyst Raster Calculator, resulting in a single grid, where each grid cell had integer values ranging from -4 to +4. These integrated values represent the following cases:

- Score -4: Apparently net erosional in all 4 comparison periods.
- Score -3: Apparently net erosional in 3 periods and bathymetrically neutral in 1 period.
- Score -2: Either apparently net erosional in 3 periods and apparently net depositional in 1 period; OR apparently net erosional in 2 periods and bathymetrically neutral in 2 periods.
- Score -1: Either apparently net erosional in 2 periods, apparently net depositional in 1 period, and bathymetrically neutral in 1 period; OR net erosional in 1 period and bathymetrically neutral in 3 periods.

- Score 0: Either apparently net erosional in 2 periods and apparently net depositional in 2 periods; OR apparently net erosional in 1 period, bathymetrically neutral in 2 periods, and apparently net depositional in 1 period; OR bathymetrically neutral in all 4 periods.
- Score +1: Either apparently net depositional in 2 periods, apparently net erosional in 1 period, and bathymetrically neutral in 1 period; OR apparently net depositional in 1 period and bathymetrically neutral in 3 periods.
- Score +2: Either apparently net depositional in 3 periods and apparently net erosional in 1 period; OR apparently net depositional in 2 periods and bathymetrically neutral in 2 periods.
- Score +3: Apparently net depositional in 3 periods and bathymetrically neutral in 1 period.
- Score +4: Apparently net depositional in all 4 comparison periods.

Areas scored with values of -3 or -4 were judged to be apparently net erosional between 1995 and 2001. Similarly, areas scored with values of +3 or +4 were judged to be net apparently depositional during this same time period. In the remaining areas, both erosion and deposition may have occurred, or the area may have been effectively bathymetrically neutral (*i.e.*, change in depth is not significant relative to the potential uncertainty in the bathymetric data).

1.2. DELINEATING ADDITIONAL NET EROSIONAL AND NET DEPOSITIONAL AREAS

In a second screening of the data, longer time periods were examined to minimize the uncertainty in comparing yearly bathymetric surveys. The same scoring process was applied to delineate additional net erosional and net depositional areas that may have been overlooked in the first screening method. Three comparisons were completed using the historical TSI bathymetric data, including 1995 to 2001 (6-year time period), 1996 to 2001 (5-year time period), and 1995 to 1999 (4-year time period).

Following a similar scoring process as described above in Section 1.1 "Initial Screening to Identify Apparently Net Erosional and Net Depositional Areas," sedimentation rates were calculated for each time period. Then, the sedimentation rates were scored based on criteria (*i.e.*, score of +1 represents "potentially net depositional," score of 0 represents "bathymetrically neutral area," and score of -1 represents "potentially net erosional"). The criteria were then adjusted for each time period compared (Table 1-2) to account for uncertainty in bathymetric measurements. The expected accuracy for the type of equipment used for these surveys is ±3 inches assuming good horizontal and navigational control of the boat for repetitive work (*i.e.*, re-occupying the same transects for subsequent surveys). If the water is calm, then the accuracy can often be improved further.[2]

Table 1-2: Criteria for Scoring and Classifying Sedimentation Rates in the Longer-Time Period Analysis

Score and Classification	1995-2001 Criteria	1996-2001 Criteria	1999-2001 Criteria
Score = +1, Potentially Net Depositional	Greater than +0.5 inch/year [a]	Greater than +0.6 inch/year [b]	Greater than +0.75 inch/year [c]
Score = 0,Bathymetrically Neutral Area	Between +0.5 inch/year and -0.5 inch/year	Between +0.6 inch/year and -0.6 inch/year	Between +0.75 inch/year and -0.75 inch/year
Score = -1, Potentially Net Erosional	Less than -0.5 inch/year	Less than -0.6 inch/year	Less than -0.75 inch/year

a: 3 inch uncertainty divided by 6-year time period yields a criterion of 0.5 inch/year
b: 3 inch uncertainty divided by 5-year time period yields a criterion of 0.6 inch/year
c: 3 inch uncertainty divided by 4-year time period equals a criterion of 0.75 inch/year

This scoring process resulted in three separate grids (one for each longer time period comparison) with grid cells assigned values of +1, 0, or -1. The grids were then added using the Spatial Analyst Raster Calculator, resulting in a single grid where each grid cell contains an integer value ranging from -3 to +3. These integrated values represent the following cases:

[2] According to Ocean Surveys, Inc. (2006), a well-respected contractor experienced in conducting bathymetric surveys can achieve this level of accuracy (personal communication, June 7, 2006).

- Score -3: Potentially net erosional in all 3 comparisons.
- Score -2: Potentially net erosional in 2 comparisons and bathymetrically neutral in 1 comparison.
- Score -1: Either potentially net erosional in 2 comparisons and potentially net depositional in 1 comparison; OR potentially net erosional in 1 comparison and bathymetrically neutral in 2 comparisons.
- Score 0: Potentially net erosional in 1 comparison, potentially net depositional in 1 comparison, and bathymetrically neutral in 1 comparison; OR bathymetrically neutral in all 3 comparisons.
- Score +1: Either potentially net depositional in 2 comparisons and potentially net erosional in 1 comparison; OR potentially net depositional in 1 comparison and bathymetrically neutral in 2 comparisons.
- Score +2: Potentially net depositional in 2 comparisons and bathymetrically neutral in 1 comparison.
- Score +3: Potentially net depositional in all 3 comparisons.

Areas scored with values of -3 or -2 were judged to be potentially net erosional between 1995 and 2001. Similarly, areas scored with values of +3 or +2 were judged to be potentially net depositional during this same time period. In the remaining areas, both erosion and deposition may have occurred, or the changes may not be discernable due to the uncertainty in the bathymetric measurements.

1.3. NET EROSIONAL AND NET DEPOSITIONAL AREAS

Delineated net erosional areas and net depositional areas based on the 1995 through 2001 bathymetric data are displayed in Figure C-1 and Figure C-2, respectively. The red areas marked in Figure C-1 represent grid cells that scored either -4 or -3 (or apparently net erosional areas) in the first delineation, which evaluated successive year-to-year comparisons.[3] These red areas account for 0.43 percent of the total area (345 acres) between RM0.9 and RM7 and highlight the areas of the Lower Passaic River that have apparently experienced frequent erosional events of greater than 2 inches/year. Surrounding these red areas are "halos" representing additional likely net erosional areas. These additional areas were delineated using the second delineation method, which considered longer surveying intervals: score of -3 (orange area), score of -2 (yellow area), and score of -1 (light green area). Of these three color schemes, the orange area (accounting for 2.8 percent of the total area between RM0.9 and RM7) highlights areas that have consistently experienced erosion over a 4 to 6-year time period (note that the sedimentation rate in these areas varied from -0.75 to -0.5 inches/year, depending on the respective criteria for the longer term comparisons). Other erosional areas account for an additional 23.9 percent of the total area between RM0.9 and RM7.

The sparsely spaced erosional areas between RM0.9 and RM7.0 of the Lower Passaic River are anticipated since in this area the river tends to experience net deposition (Malcolm Pirnie, Inc., 2006). The large spatial extent of net depositional areas in RM0.9 to RM7.0 is displayed in Figure C-2, which is organized similarly to Figure C-1. The dark blue areas in Figure C-2 represent grid cells that scored either +4 or +3 in the first delineation, which identifies areas that apparently consistently experienced more than 2 inches/year of sediment deposition. These dark blue areas account for 6.3 percent of the total area while other depositional areas account for an additional 67 percent of the total area between RM0.9 and RM7.

To account for the two delineations and to prioritize the various scores, five categories were defined for the sedimentation processes in the Lower Passaic River: "consistently erosional," "occasionally erosional," "bathymetrically neutral area" (experiencing both erosion and deposition), "occasionally depositional," and "consistently depositional." The categories encompass the combined areas corresponding to the scores from the two

---

[3] Scores of -2 and -1 denoting other potential erosional areas are not displayed on Figure C-1 to simplify the graphic display of the figure. Likewise, scores of +2 and +1 denoting other potential depositional areas are not displayed on Figure C-2.

delineations (Table 1-3) and are displayed in Figure 5-1 in the Conceptual Site Model text.

Table 1-3: Categories to Define Erosional and Depositional Areas

Category	Score from First Delineation [a]	Score from Second Delineation [b]
Consistently Erosional	-4 -3	 -3
Occasionally Erosional	-2	-2
Bathymetrically Neutral Area	-1 0 +1	-1 0 +1
Occasionally Depositional	+2	+2
Consistently Depositional	+3 +4	+3

a: Yearly comparison of surveys
b: Comparison of surveys over 4 to 6-year periods

A score of 0 in either delineation method may suggest that the sediment beds experienced no changes in elevation during the time periods examined. However, a score of 0 may also suggest that an area experienced both erosion and deposition, since a combination of positive and negative scores can yield a zero result. Likewise, a score of -1 or +1 in either delineation method may suggest that the sediment beds experienced periods of both net erosion and net deposition. Consequently, the “bathymetrically neutral area” category (including scores of -1, 0, and +1) may encompass areas that have commonly experienced both net erosion and net deposition.

2.0 ACRONYMS

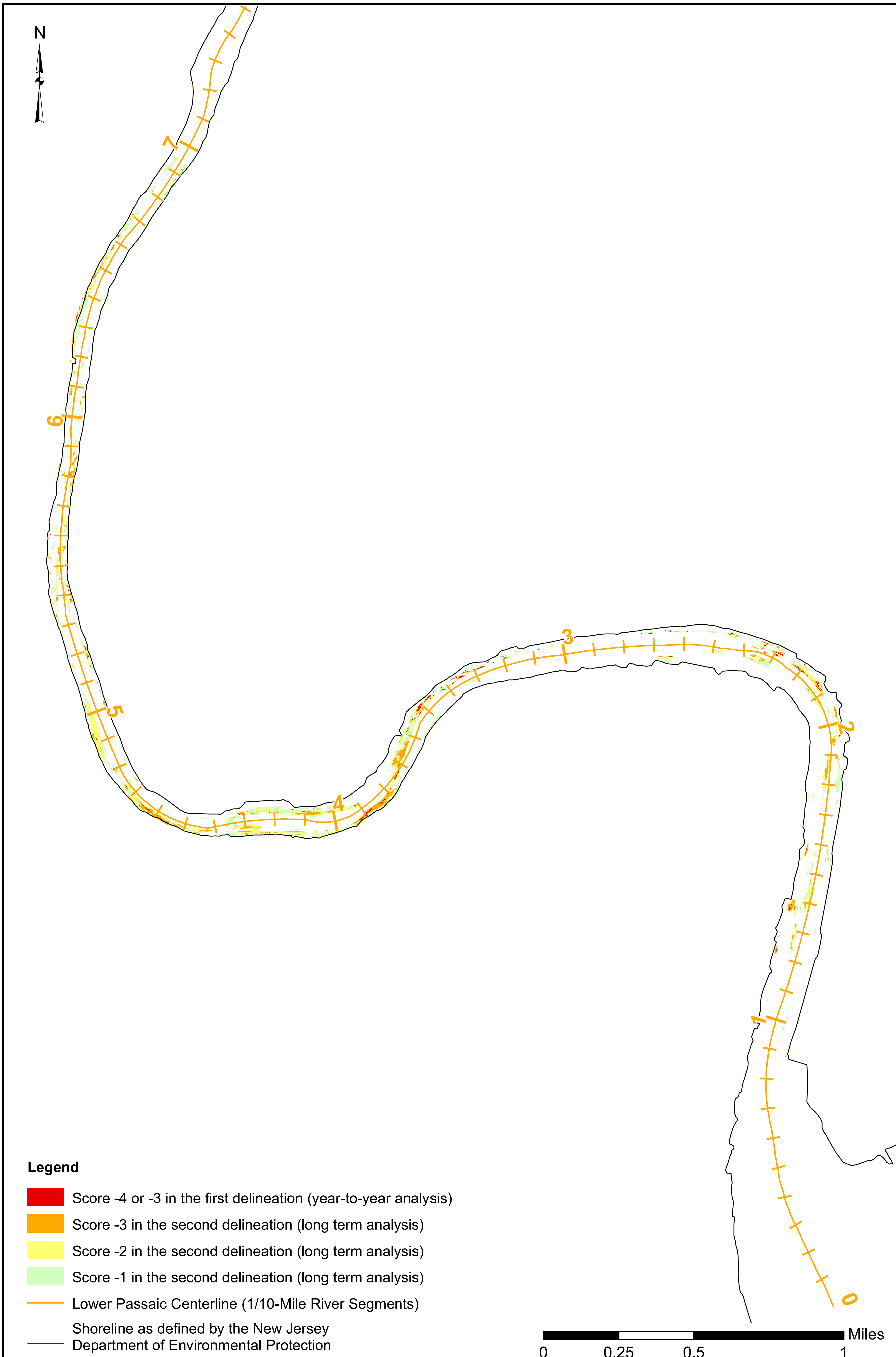
ESRI	Environmental Systems Research Institute, Inc.
RM	River Mile
TSI	Tierra Solutions, Inc.

3.0 REFERENCES

Kennedy H. 2001. Dictionary of GIS Terminology. ESRI Press. (Redlands, California.)

Malcolm Pirnie, Inc., 2006. “Draft Geochemical Evaluation (Step 2).” Lower Passaic River Restoration Project. March 2006.

Ocean Surveys, Inc., 2006. Personal communication between Bruce Fidler (Malcolm Pirnie, Inc.) and Steve Bartlett. June 7, 2006.



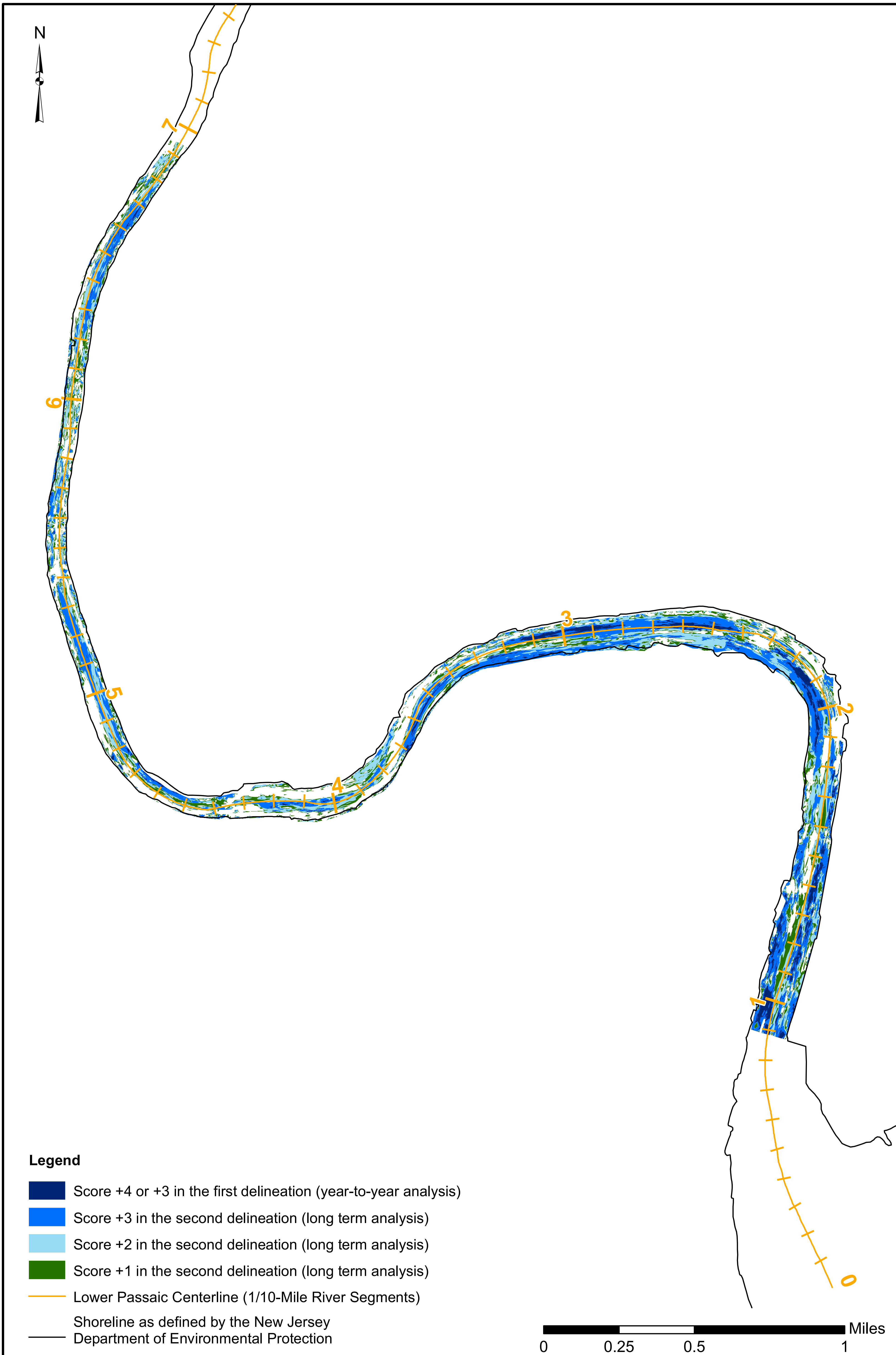
Delineating Net Potential Erosional Areas

Lower Passaic River Restoration Project

Data Sources : Tierra Solutions Inc., Bathymetric Surveys for 1995,1996,1997,1999 and 2001

FIGURE C-1

February 2007



Delineating Net Potential Depositional Areas

Lower Passaic River Restoration Project

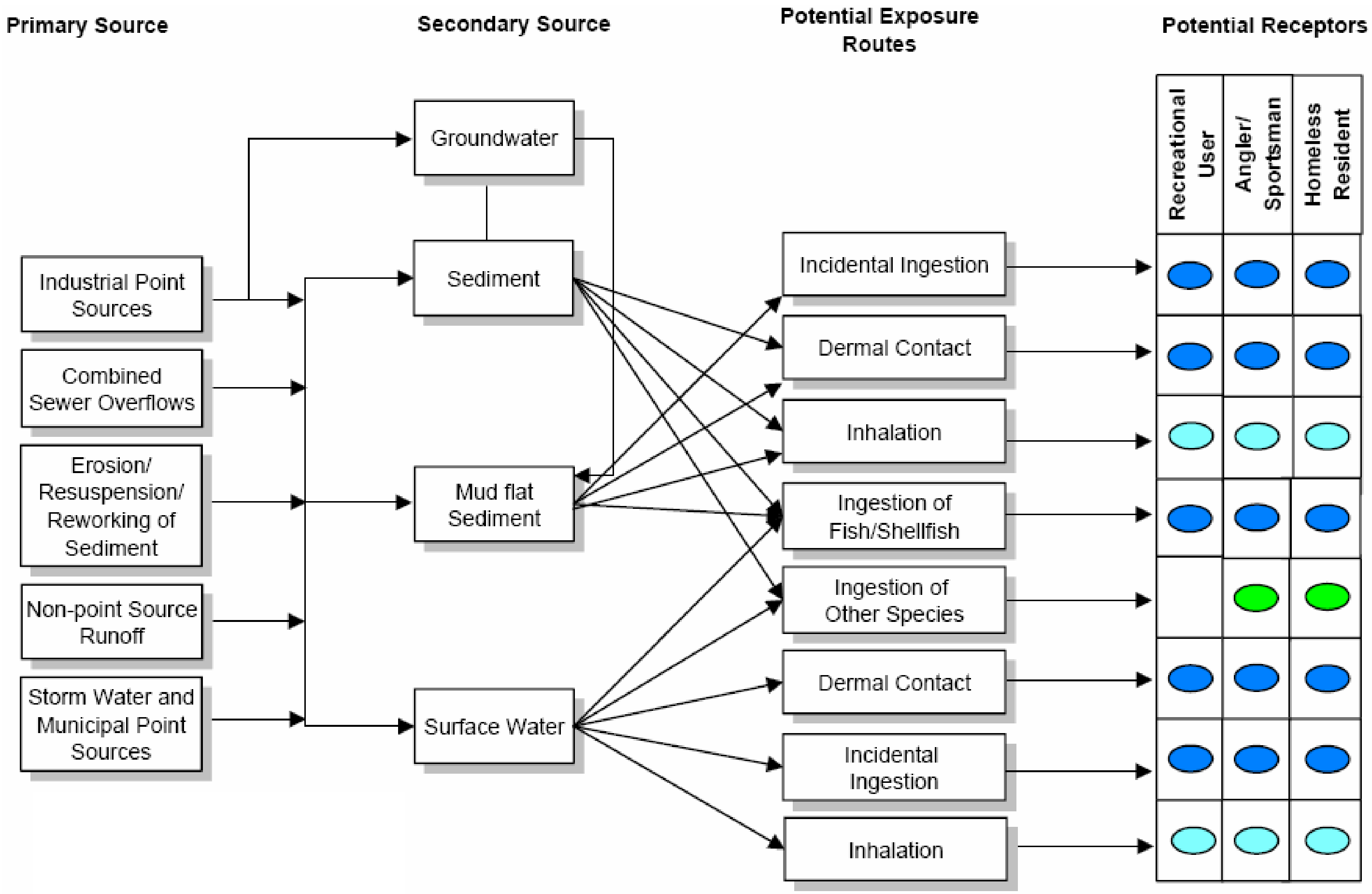
Data Sources : Tierra Solutions Inc., Bathymetric Surveys for 1995,1996,1997,1999 and 2001

FIGURE C-2

February 2007

Attachment D

Exposure Pathways and Receptors Figures



Legend

- Complete, Quantitative Pathway
- Complete, Qualitative Pathway
- Potentially Complete Pathway

Notes

Taken from Battelle, 2005. "Pathways Analysis Report." Lower Passaic River Restoration Project. July 2005.

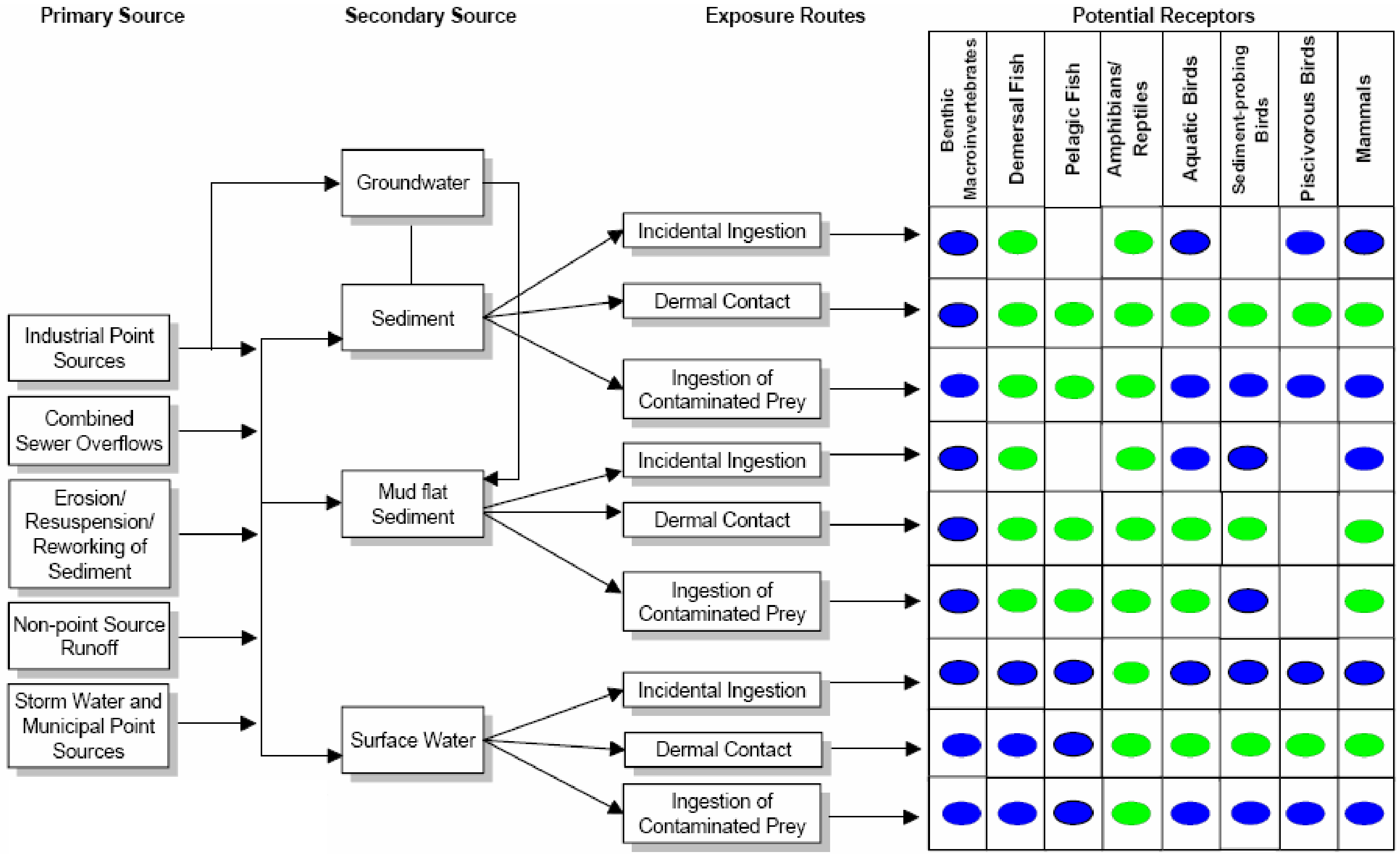
Figure revised by Battelle, January 2007.

Human Health Conceptual Site Model

Lower Passaic River Restoration Project

Figure D-1

February 2007



Legend

Complete, Quantitative Pathway

Complete, Qualitative Pathway

Notes

Taken from Battelle, 2005. “Pathways Analysis Report.” Lower Passaic River Restoration Project. July 2005.

Figure revised by Battelle, January 2007.

Ecological Conceptual Site Model

Lower Passaic River Restoration Project

Figure D-2

February 2007