Delaware Estuary
Regional Sediment Management Plan
White Paper

Appendix A:
SEDIMENT QUANTITY AND DYNAMICS

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Table of Contents

List of Tables

List of Figures

Acronyms and Abbreviations

BC	Blackbird Creek
BH	Bombay Hook
C&D Canal	Chesapeake and Delaware Canal
CEAP	Conservation Effects Assessment Project
DMB	Delaware Memorial Bridge
ETM	Estuarine Turbidity Maximum
LRSDS	Long Range Spoil Disposal Study
NC	New Castle
NRI	National Resource Inventory
RSM	Regional Sediment Management
SSC	suspended sediment concentration
UD	University of Delaware
USGS	U.S. Geological Survey
WHG	Woods Hole Group

Introduction

Sediment is an integral and natural component of the Delaware estuary. It is one element of a complex estuarine system that includes processes associated with biology, biochemistry, geology, geochemistry, hydrology, tidal hydraulics, and meteorology. The processes interact within a continuum of spatial and temporal scales to influence the behavior and "health" of the ecosystem. Sediment as bottom/riverbed substrate supports a wide variety of habitats and ecosystems that extend from the fresh water zone in the tidal river above Philadelphia to the sandy, saline environment at the Capes. (Figure 1) Sediment accumulates in channels and harbors of the estuary, interferes with safe and efficient navigation, and necessitates dredging and ultimately disposal. Suspended sediments play a role in the transport of nutrients and adsorb dissolved toxic substances such as trace metals, pesticides, and PCBs. Suspended sediment creates turbidity, which limits penetration of light into the water column and affects photosynthesis.

The goal of regional sediment management (RSM) is to consider sediment as a resource critical to the economic and environmental vitality of the region. Sediment is often regarded as a localized waste product or pollutant to be disposed of as cost effectively as possible. When sediment is removed for navigation purposes, it is desirable to maximize the beneficial uses of the dredged material. Until the Delaware Estuary RSM program was initiated in 2009, there was no systematic, collaborative approach to dealing with the challenges and opportunities associated with sediment in the estuary. To date, all attempts at beneficial use of dredged sediments have been accomplished on an ad hoc, project-specific basis. The present RSM initiative is intended to broaden local knowledge about how, where, and when to manage parts of the sediment system differently and more beneficially than has been previously practiced. The overall goal of this paper is to help identify the "how, where, and when" of sediment management for the estuary by first developing an understanding of how the *sediment system* functions. The specific goals are to:

1. Identify what is known about the major sediment sources and sinks in the estuary
2. Describe, and quantify where possible, the principal sediment transport mechanisms and pathways
3. Identify deficiencies in the present understanding of the sediment system and improve awareness of ecological processes so as to implement workable, successful applications of RSM within the Delaware estuary.

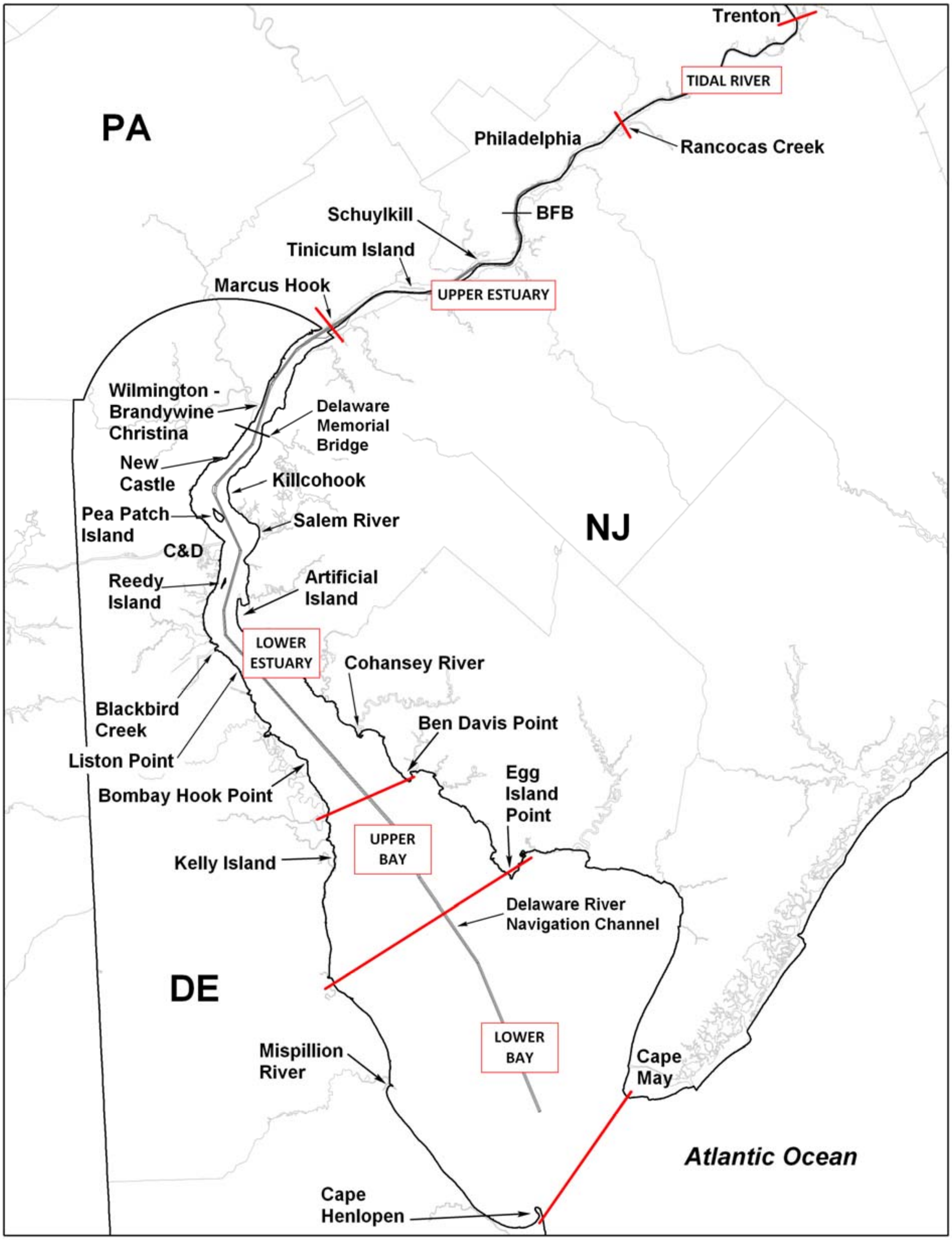

Figure 1: Location Map

The Delaware Estuary Sediment System

Shorelines and Channels

Estuaries trap sediment, most of which originates from erosion of land in the upper reaches of the watershed. As sea levels rose at the end of the last glacial period (about 18,000 years ago), the ancestral Delaware River valley was inundated by water. The approximate boundaries of the estuary were established within the past several thousand years (Fletcher et al, 1990). The current Delaware estuary sediment system is highly altered compared to what existed as recently as one or two centuries ago. Extensive portions of once natural estuarine and river shoreline have been modified by construction of bulkheads, seawalls, piers, and wharves to serve the needs of urban and industrial development. Dredged fill was often used to create new land adjacent to the waterway. Since about 1890, waterborne commerce has necessitated dredging and maintaining progressively deeper channels of the estuary. Most of the sediment dredged from the estuarine system has been placed in upland dredged material disposal sites. A number of these sites were constructed along the shoreline in shallow, sub-tidal areas of the estuary.

Upland Sediment Supply

Upland sediment sources, either from the stream channel or surrounding basin, vary given the relative location within a watershed, nature of the runoff response, maturity of the watershed, and other conditions. In many watersheds, steeper headwater streams may obtain the bulk of their sediment by erosion of the area within and adjacent to the stream channel. Larger-order streams farther downstream primarily store and transport this material with less channel erosion (in terms of incision or streambed erosion). Many landscape evolution models support this concept including the very earliest created by William Morris Davis in 1909 (Cinotto, 2006).

Meade (1982), Trimble (1999), Phillips (1991), and others have found that approximately 80-90 percent of all sediment eroded within a watershed is stored, and only about 10-20 percent is directly removed from the basin. Of the stored sediment, approximately 70-80 percent is stored on hill slopes and floodplains and about 20-30 percent is temporarily stored in the stream channel. What this means to water resource managers is that even if the existing sources of sediment are completely cut off, reductions in sediment loads may not be measurable for many years due to a long residence time.

The Delaware differs from most other large rivers in that there are no dams on the main stem to interrupt the natural downstream transport of fluvial sediment toward the estuary. In fact, it is the longest un-dammed river east of the Mississippi, extending 530 kilometers (330 miles) from the confluence of its east and west branches at Hancock, NY to the mouth of the Delaware Bay.

There is some evidence that mill dams on tributaries to the Delaware may play a significant role in preventing downstream sedimentation. Historic data indicate that at least a third of the tributaries in the Delaware River basin had an average mill spacing of between 1.6 and 15 kilometers (Merritts et al., 2006). Renwick et al. (2005) estimated that 21 percent of the coterminous U.S. drainage area, which represents 25 percent of the total sheet and rill erosion nationally, is captured by small impoundments. Since 2000, there have been 140 planned dam removals in Pennsylvania and 20 in New Jersey. The total sedimentation in the impoundments is large in relation to upland erosion. There has been no known mill pond inventory of the Delaware River basin.

To a degree, the lack of dams on the main stem of the Delaware River has minimized the disruption to the estuarine sediment system since there is no sediment impounded by dams. The annual series of suspended sediment discharged to the estuary from 1950 through 2009 is plotted in Figure 2 (Section 3f describes ongoing work by the U.S. Army Corps of Engineers (USACE) on suspended sediment discharge). Data are presented for the Delaware River at Trenton (red), the Schuylkill at Philadelphia (green), and the Brandywine at Wilmington (blue), which together represent approximately 80% of the total freshwater and sediment discharge to the estuary. The graph shows the large annual variability in sediment discharge, which is highly correlated with freshwater discharge, particularly peak flow events. The drought period of the mid-1960s has relatively low sediment discharge, whereas 2004 through 2006 had several large flood events in and shows relatively higher sediment discharge.

The mean annual sediment discharge over the past six decades at these three locations is 1.26 million metric tons. There is no apparent net increase or decrease in sediment discharge over the period of record. [Note: metric (SI) units are the default system used in this paper. Where useful for purposes of comparison, the corresponding measure in English (Imperial) units will be included.] Mansue and Commings (1974) analyzed suspended sediment input into Delaware Estuary. Their data show an average annual input from the Delaware, Schuylkill, and Brandywine Rivers equivalent to 1.0 million metric tons per year, with a total suspended solids input from all sources of 1.3 million metric tons annually.

Piedmont watersheds contribute unusually high suspended sediment loads to the Chesapeake Bay (Gellis et al 2004), despite low relief and low, long-term erosion rates (Reuter, 2005). The commonly held view since the 1930s is that modern agriculture is the primary source of suspended sediment through upland slope wash, rilling, and gullying (Panel, 2004). Merritts et al. (2006) proposed that sediment yields remain high, despite 20th century best management practices, because of bank erosion and remobilization of stored sediment along tens of thousands of kilometers of incised stream corridors. They estimate that in Lancaster County, bank erosion of legacy sediments could account for 50-80 percent of suspended sediment loads to downstream waterways, including the impaired Chesapeake Bay (Merritts et al., 2004). The various land use/cover types in the Delaware River Basin are shown in Table 1.

Table 1: Land Use/Cover in the Delaware River Basin

Land Use	Sq KM	Square Miles	Acres	Percent of River Basin
Agriculture	8,611	3,325	2,127,808	24.4
Barren	144	56	35,584	0.4
Developed	4,819	1,861	1,190,912	13.8
Forest	16,286	6,288	4,024,256	46.1
Water	2,645	1,021	653,568	7.5
Wetland	2,747	1,061	678,848	7.8
TOTAL	**35,252**	**13,611**	**8,710,976**	**100**

Agricultural cultivated cropland use, a portion of overall agricultural land use shown in Table 1, includes an estimated 343,000 hectares (847,500 acres) or 9.7 percent of the entire Basin (U.S. Department of Agriculture – Natural Resources Conservation Service [USDA NRCS], 2010). Large amounts of cropland in the Basin have been converted from agricultural use to urban/suburban and other uses. The 2007 National Resource Inventory (NRI), which provides nationally consistent data for the 25 year period 1982 through 2007, shows a decreasing area of cropland both nationally and in the Northeast (which includes DE, NY, NJ, and PA) farm production region (USDA, 2009). In addition, soil erosion rates on cropland have decreased from 8.1 to 6.0 metric tons/hectare/year (Table 2).

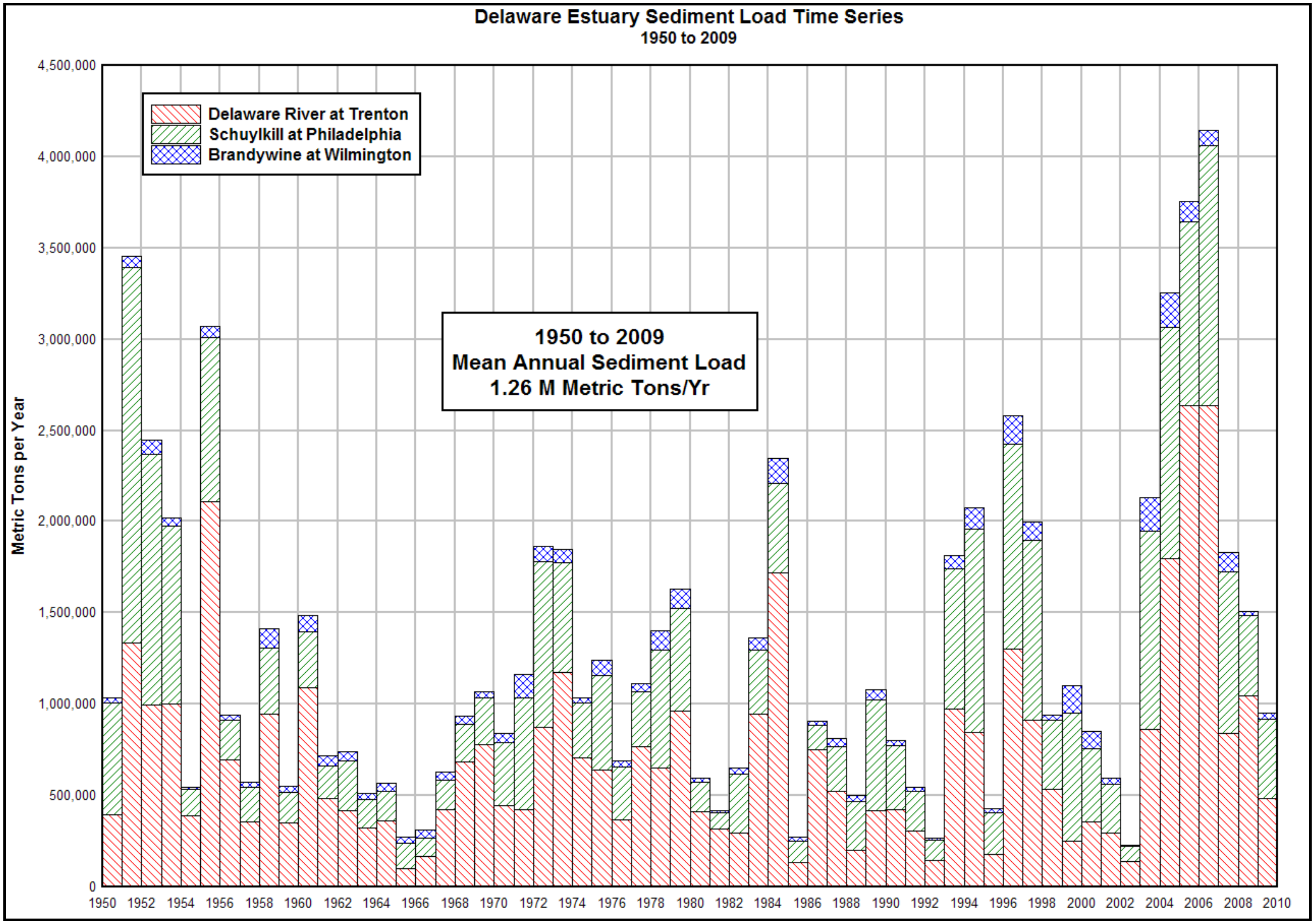

Figure 2: Annual Suspended Load Time Series

Table 2: Northeast Region Cropland Erosion Rates (1982-2007)

Year	Soil Loss (Metric Tons Per Hectare Per Year)	Soil Loss (Tons Per Acre Per Year)
1982	8.1	3.6
1987	8.5	3.8
1992	7.2	3.2
1997	6.5	2.9
2002	6.5	2.9
2007	6.0	2.7

Sheet and rill erosion is the detachment and movement of soil particles within a field during rainfall events. Controlling sheet and rill erosion is important for sustaining soil productivity and preventing soil from leaving the field. Sediment loss is the sediment transported beyond the edge of the field. The average sediment loss for cropped areas in the Delaware River basin is 5.8 metric tons per hectare (2.6 tons per acre) per year (USDA, 2010). On an annual basis, sediment loss can vary considerably. Annual sediment loss is below 4.5 metric tons per hectare (2 tons per acre) for about 50 percent of the cropped area under all conditions, including years with high precipitation. In contrast, sediment loss exceeds 27 metric tons per hectare (12 tons per acre) in one or more years on about 20 percent of the cropped area. Conservation practices in the Delaware River basin have reduced average annual sediment loss by 50 percent for cropped areas. Without conservation practices, 44 percent of the area would have less than 4.5 metric tons per hectare (2 tons per acre) per year of sediment loss, while 65 percent of the cropped areas would have sediment losses of less than 4.5 metric tons per hectare with conservation practices (USDA, 2010).

A study of two relatively undeveloped Delaware River tributary watersheds (USDA, 2007) found the primary sediment sources were streambanks, roadways and agricultural cropland (Table 3). A growing body of evidence in agricultural areas shows that the locus of sediment erosion has shifted from fields and uplands to channels (Simon & Limetz, 2008). The Conservation Effects Assessment Project (CEAP) in the Delaware River Basin consists of 186 sample points representing 342,200 cropped hectares (845,600 acres). This study of CEAP benchmark watersheds revealed that channel contributions are a significant source of sediment. Town Brook, a CEAP benchmark watershed that is tributary to Cannonsville Reservoir and the West Branch Delaware River, had sediment yields of 290 and 105 percent of the reference watersheds for the ecoregion. In both cases, channel erosion, particularly streambank erosion, was important (Simon and Limetz, 2008).

Table 3: Relative Erosion Rates and Delivery Ratios for Sediment Delivery in the Lockatong and Wickecheoke Creek Watersheds

Sediment Source	Relative Soil Erosion Rate	Sediment Delivery Ratio (Percent)
Agricultural Cropland	Low	33
Forestland	Low	33
Roadways	High	80
Streambanks	High	100

Regional radionuclide studies in nearby river basins have determined that much of current stream sediment represents eroded agricultural soil from the 19th century (Nagle et al, 2007; Phillips, 1991). These legacy sediments from prior agricultural uses move through the system during severe weather events. Sun, Natter and Lacombe (2008) have found that suspended sediment concentrations in the Delaware River basin are high during March and April when snow melt combines with rainstorm runoff and lower during the summer when the river discharge is low.

Sediment Budget

To plan and implement rational, efficient, and effective RSM actions within the Delaware estuary requires at least a basic understanding of how the sediment system operates. One way to view the estuarine sediment system is to schematize the principal sources, sinks, pathways, and processes in the form of a sediment budget. In an ideal budget, all sediment sources and sinks are identified and quantified, and all processes that add, transport, and remove sediment are identified and quantified. However, because sediment transport processes are highly variable in time and space, quantifying source and sink terms involves a level of temporal and spatial averaging. Since an estuary may exhibit long-term net accumulation of sediment, or long-term net loss, it is not necessarily expected that the system is at steady state and that the source and sink terms will balance to zero. This paper will demonstrate that we have a good qualitative understanding, and even acceptable quantitative knowledge, of some portions of the Delaware estuary sediment system. However, other aspects of the overall estuary sediment budget, such as sediment sources from urban and suburban sites, are not as well understood.

Sediment Classification and Distribution

This paper considers sediment in two broad classes based on the size of the sediment particles. One component is termed bedload or “non-cohesive” sediment and consists principally of coarse-grained components (sand and gravel). These particles are considered non-cohesive because they exhibit essentially no inter-particle attraction. Bedload refers to the transportation of the sand and gravel at, or close to the bed of the estuary or river rather than suspended in the water column. The other component is broadly classified as “cohesive” or fine-grained sediment and consists of silt and clay mineral aggregates known as flocs (e.g., Gibbs et al, 1981). In general, inorganic suspended particles less than 10 microns in diameter are transported as flocs whereas larger particles move as single grains. Suspended sediment is composed predominately of silt and clay flocs, particulate organic matter such as plant debris, and biological particles such as phytoplankton. By definition, mud is a mixture of silt- and clay-sized grains less than 63 microns in diameter. Clays have larger surface area-to-volume ratios so they have much higher adsorption capacities. Clays exhibit strong inter-particle forces due to their surface ionic charges, which can also bind chemicals. As a result, contaminant testing is frequently required for estuarine mud, but not for sand and gravel. The small grain size of silt and clay results in low intrinsic settling velocities, but flocculation significantly increases the size and effective settling velocities of small particles. Nonetheless, mud flocs can stay suspended in the water column for much longer periods than sand and gravel, and can be transported by the ambient flow over long distances before they settle to the bed.

Depending on the sediment classification scheme, the size difference between sand and mud is in the range of 50 to 74 microns (0.050 to 0.074 mm) mean particle diameter. There are significant differences between the spatial distribution of the two classes within the estuary, as well as physical and chemical processes that govern fate and transport. The distribution of bottom sediment types is depicted in Figure 3 (Biggs and Church, 1984). In the segment from Wilmington to Liston Point, the dominant bottom sediment is mud whereas downstream of Liston Point, the bottom is dominated by mixtures of sand and gravel.

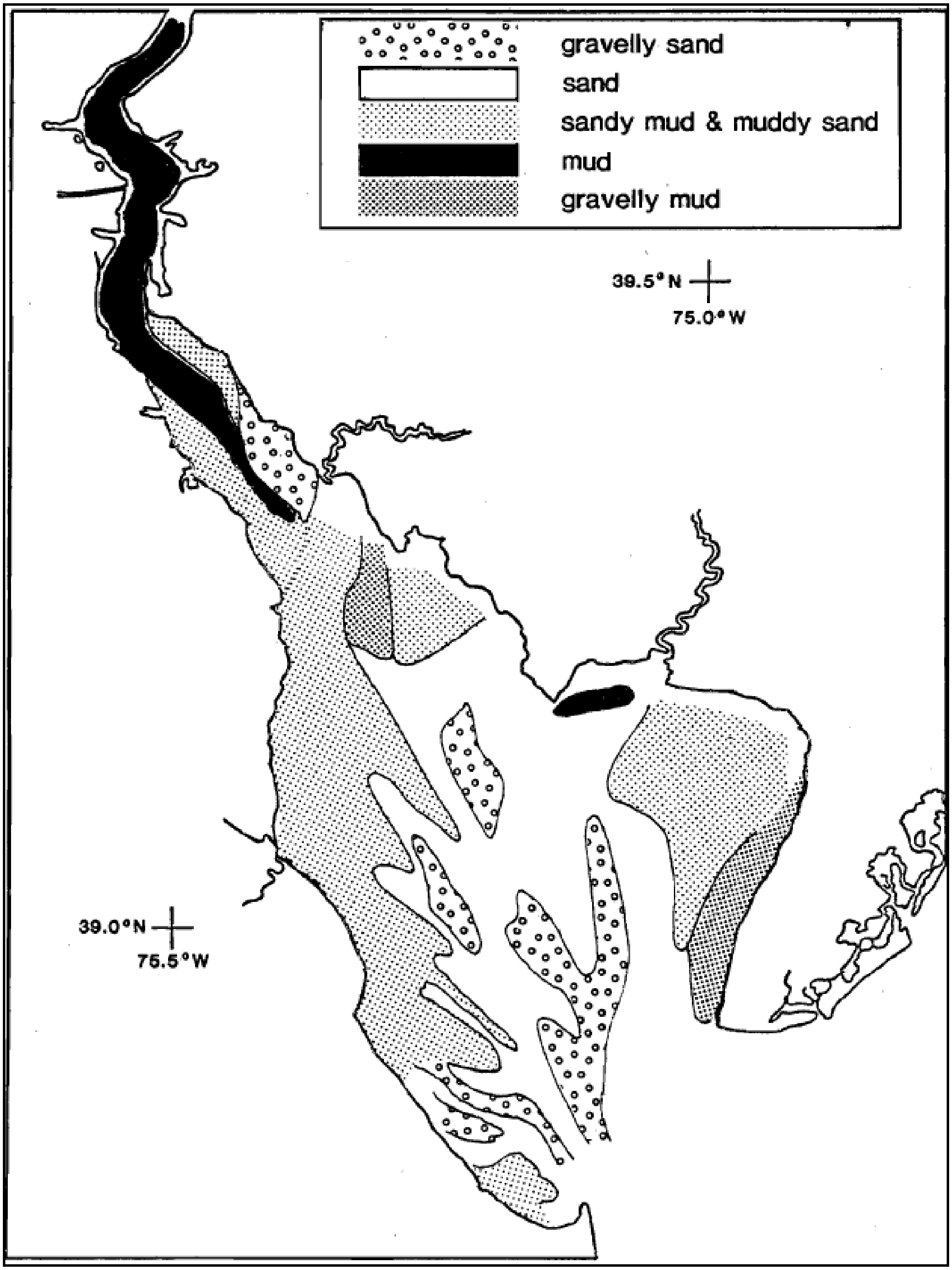

Figure 3: Bottom Sediment Distribution (Biggs and Church, 1984)

The zone of dominant muddy bottom corresponds to the Estuary Turbidity Maximum (ETM), which results from the complex interaction of freshwater inflows from upstream sources with denser, more saline water from the Atlantic Ocean.

In the last decade, research by the Delaware Department of Natural Resources and Environmental Control and the University of Delaware (Sommerfield and Madsen, 2003; Wilson, 2007) has identified and mapped benthic habitats and bottom sediments of Delaware River and Bay. This effort has significantly improved our knowledge of the spatial heterogeneity of bottom sediments in the estuary. The bottom sediment distribution determined through earlier work and depicted in Figure 3 is representative of the estuary and is considered valid for purposes of this paper.

Delaware Estuary Sediment Budget – Quantities and Transport Mechanisms

Sources and Sinks

The earliest attempts to quantify the sediment budget of the Delaware estuary date to the early 1970's (e.g., Oostdam, 1971; Wicker, 1973). More recently, there has been significant work on this topic, principally at UD under the leadership of Dr. Christopher Sommerfield (Sommerfield and Madsen, 2003; Walsh, 2004; Cook, Sommerfield and Wong, 2006; Sommerfield and Wong, 2011). Research has included analysis of historic bathymetric surveys of the estuary to determine the location and rate of change in the sedimentation and scour of the estuary floor. The recent UD research includes direct measurement of currents, salinity, and suspended sediment concentration at multiple locations in order to track the transport of suspended sediments within the system, assess the relative magnitudes of the different transport processes, and determine sediment mass fluxes.

The most recent quantitative sediment budget for the estuary is summarized in Table 4 (Walsh, 2004). The USACE Philadelphia District is working with Woods Hole Group (WHG) and Dr. Sommerfield to update this budget. The in-progress findings of the sediment budget reevaluation are presented in Section (3f) of this paper.

Table 4: 1950-1985 Estuary Sediment Mass Balance

SOURCES		SINKS	
Bottom erosion	3.4	Dredging	2.8
Rivers	1.3	Marshes	2.1
Phytoplankton	0.23	Subtidal shoals	0.63
Waste/industrial	0.17		
TOTAL SOURCES	**5.1**	**TOTAL SINKS**	**5.5**
Note: Sources and sinks shown in millions of metric tons per year			

Table 4 illustrates a number of salient points. First, although the source and sink term do not balance in an absolute sense, they are sufficiently close given the uncertainty of the calculations and measurements involved that they balance to a first order of accuracy. In the list of sources, the largest category is bottom erosion. This indicates that scour of the bed of the estuary was the largest source of sediment available to the system. It was larger by a factor of 2.6 than the average annual input of new sediment . In the list of sinks, the largest contributor is dredging, followed by sediment accumulation in marshes.

This implies that despite the large lateral retreat of the fringing marshes of Delaware Bay documented during the 20th Century, tidal marshes may accumulate more sediment mass than they lose to lateral retreat. This component of the estuary sediment budget is part of the ongoing work described in Section (3f).

Some of the terms in the table can be directly derived with relatively little uncertainty. For example, the contribution from rivers is calculated as the product of suspended sediment concentration (SSC) times river discharge. The dry sediment mass for dredging (sink) and bottom erosion (source) is calculated indirectly by comparing hydrographic surveys from different dates, which results in an in situ (i.e., wet) sediment volume change measurement. Conversion from units of in situ volume (measured at the bed of the estuary) to units of dry mass of sediment requires a volume-to-mass conversion factor. There is a wide range of empirically measured in situ volume to dry sediment mass ratios. For work performed in the UD sediment budget analyses, the investigators adopted the value of 753 kg of dry sediment solids per cubic meter of in situ sediment (Walsh, 2004). This value, equivalent to a sediment porosity of 68 percent assuming a mineral grain density of 2650 kg/m^3, will be used as the default conversion factor for this paper and is viewed as a reasonable approximation based on empirical data on Delaware estuary sediments from the past several decades.

Dynamic Factors – Estuarine Turbidity Maximum (ETM) and Principal Transport Mechanisms

Nomenclature

For purposes of consistent reference to various segments of the estuary, the following geographic naming conventions are applied. The distances in kilometers above the mouth at the Capes are listed for the upstream and downstream boundaries of each zone. The locations listed in Table 5 are shown on Figure 1.

Table 5: Delaware Estuary Zones

Zone	U/S & D/S Bounds	KM Above Capes	Zone Length (KM)	Zone Area (%)	Zone Volume (%)
	Trenton	215			
Tidal River			35	TBD	2
	Rancocas Creek	180			
Upper Estuary			50	TBD	4
	Marcus Hook	130			
Lower Estuary			75	TBD	31
	Ben Davis Point	55			
Upper Bay			30	TBD	29
	Egg Island Point	25			
Lower Bay			25	TBD	34
	The Capes	0			

Estuary Turbidity Maximum (ETM) Overview

The ETM is a zone of elevated suspended-sediment concentration maintained by a combination of: (1) continuous, but unsteady input of sediment from fluvial sources; (2) tidal resuspension of sediment at the bed of the estuary; (3) non-tidal gravitational circulation driven by density differences between upstream fresh and downstream salt water; and (4) tide-induced residual transport (tidal pumping). Understanding the genesis and behavior of the ETM is critical to our ability to formulate effective regional sediment management measures for the fine-grained sediments. Of all the source and sink terms in the estuary sediment budget, dredging and disposal offer the greatest opportunity for alternate management methods in an effort to influence the estuary sediment system. The ETM is the zone with the greatest mass of mobile sediment, the most active and complex sediment transport mechanisms, and includes several navigation channel segments in which most maintenance dredging is performed.

Bed shear stress, generated by reversing tidal currents, provides the immediate source of energy to suspend and then maintain fine-grained sediment in suspension. However, gravitational circulation and tidal pumping produce residual currents that control the along-estuary position of the ETM, and influence the lateral distribution of sediment in the lower estuary and bay. Each of these mechanisms is discussed in greater detail in subsequent sections of this paper.

The location of the suspended load within the ETM varies based on tidal and seasonal time scales. At times, more than one ETM is present, but the ETM is typically centered about 80 - 100 km above the bay mouth, between Artificial Island and New Castle, DE. UD research cruises (Sharp et al, 2009) along the length of the estuary between 1978 and 2003 obtained suspended sediments samples that were analyzed for total SSC. The SSC data from over 1600 of these samples show that the lower estuary, from Marcus Hook downstream to Ben Davis Point, NJ is the zone of greatest SSC (Figure 4).

The zones upstream and downstream of the lower estuary display a gradual reduction in typical SSC values. When mean SSC values are applied to the volume of water in each of the five zones identified in Table 5, approximately 66% of the total mass of suspended sediment is found in the lower estuary, with 30% in the upper and lower bay, and 4% in the upper estuary and tidal river together.

Fluvial Transport

The discharge of freshwater by the Delaware River and its tributaries leads to a net seaward flux of water into the estuary. Fluvial transport of sediment from the watershed above the head of tide into the estuary is unidirectional (downstream), and can be highly variable from year to year due to variations in fresh water discharge (Figure 2). Once sediment crosses the head of tide on a river or stream, it enters the estuarine system and is subject to a number of other transport processes of greater or lesser significance depending on location along the longitudinal axis of the estuary.

Tidal Transport

Delaware Estuary is by definition tidal from the Atlantic Ocean at the Capes upstream about 215 km (133 miles) to the head of tide at Trenton. This zone experiences the periodic rise and fall of water level driven by the semi-diurnal tidal regime of the Atlantic Ocean, with a mean period of 12.4 hours. The tidal wave propagates up the estuary with characteristics of a progressive, shallow water wave, such that the time of high (or low) water at any location is dependent on its distance from the mouth. High tide (low tide) occurs in Philadelphia an average of about 5 hours (6.5 hours) later than at the mouth, and at Trenton, about 7 hours (9 hours) later than at the mouth. The flood (upstream directed) and ebb (downstream) phases of a tidal current cycle are separated by a brief period of slack water in which flow velocities fall to zero, followed by the reverse tidal flow. In addition to the progressive temporal nature of the tidal wave, there is also a spatial trend in tidal range, which is the difference between high tide and low tide height at

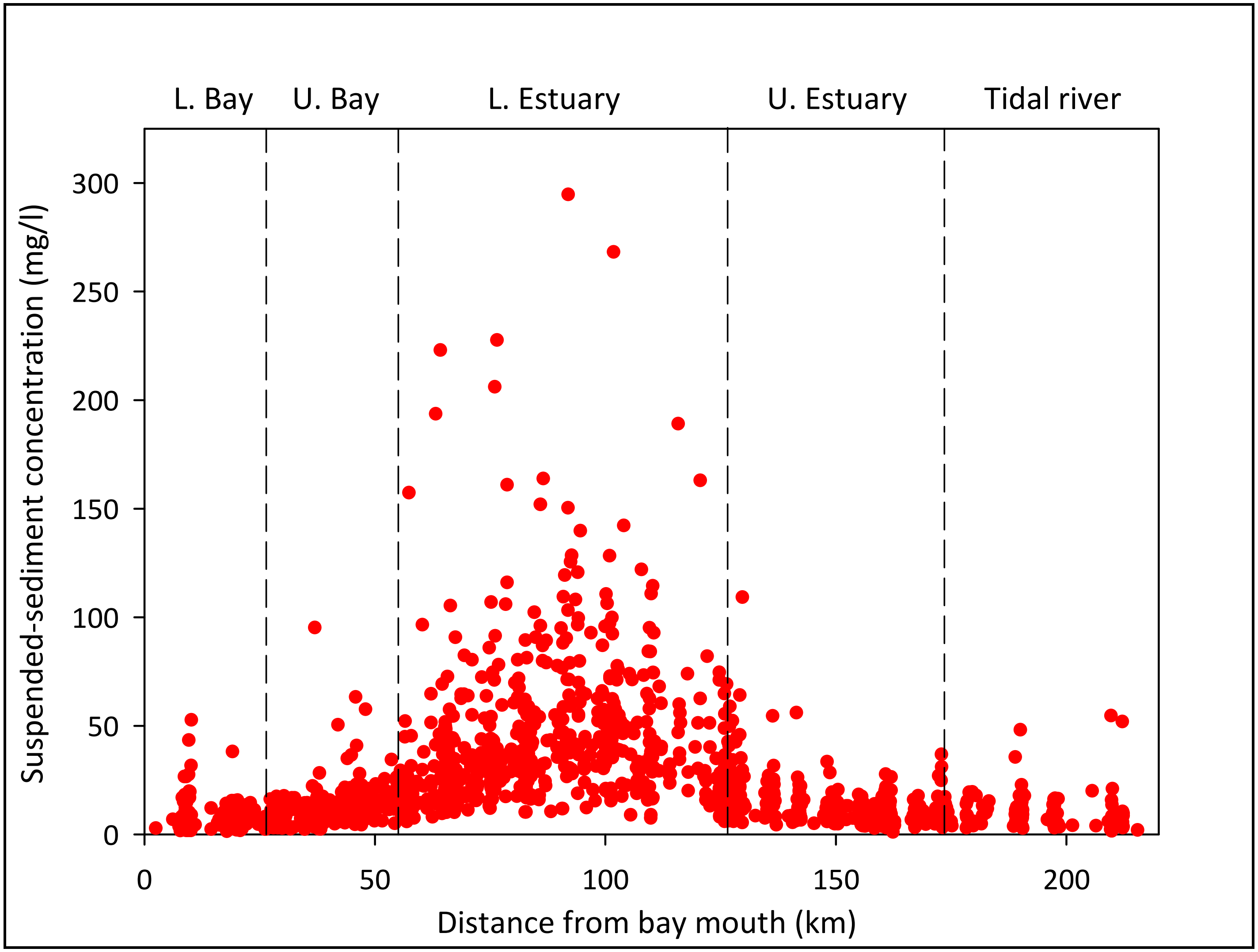

Figure 4: Suspended Sediment Distribution

any location. The mean tidal range at the mouth is 1.2 m (4.1 ft); at Philadelphia it is 1.9 m (6.1 ft); and at the head of tide in Trenton, 2.5 m (8.2 ft). In tidal flow, as in fluvial flow, circulation driven solely by the gradient in water surface elevation is termed barotropic.

There is an important 14-day variation in tidal range that leads to spring and neap tidal phases. Spring tides occur during syzygy (new and full moon conditions) and are characterized by a larger tidal range and corresponding greater flood and ebb current velocities. Conversely, neap tides (first and last quarter moon phases) are characterized by smaller tidal range and current velocities. Typical peak spring tide flood and ebb velocities in Delaware estuary can attain or exceed 100 cm/sec (3 ft/sec). Unlike episodic fluvial flood events or storm-driven ocean surges that occur at irregular intervals, the tidal regime operates continuously, 24 hours per day, 365 days per year, and thus constitutes the principal short-term source of energy to suspend and transport sediment within the estuary. Recent evidence from six months of SSC, and current observations by UD (Sommerfield and Wong, 2011), indicates that the spring-neap cycle also leads to systematic changes in location and SSC of the ETM at three transects in the lower estuary. One finding is that neap tides lead to larger *landward* fluxes of suspended sediments, while spring tides produce a *seaward* flux of sediment. A detailed discussion of the neap-spring variability in sediment transport is beyond the scope of this paper.

Gravitational Circulation

A longitudinal salinity gradient is a permanent feature of salt distribution in the Delaware estuary. Along the gradient, salinity is higher at the mouth and downstream end of the system, and decreases in the upstream direction. Unlike fluvial and tidal flows that can be observed by eye and measured in real time, estuarine gravitational circulation is a residual flow best resolved with a sufficiently long time series over multiple tidal cycles during which the vertical distribution of the flow is measured. This is accomplished either with a vertical array of conventional current meters or more recently, by bottom-mounted acoustic Doppler instruments that measure the vertical profile of water velocity in a number of discrete bins, typically on the order of 1 m intervals through the water column. Gravitational circulation is the tidally averaged residual movement of water driven by the seaward-directed flux of the mean river discharge and landward-directed flux that results from the longitudinal salinity gradient. This circulation is also referred to as “baroclinic” flow. In some estuaries, gravitational circulation is the primary, if not exclusive, mechanism that leads to the formation of the ETM, where suspended sediment concentrations in the water column are highest and the estuary bed is primarily comprised of fine-grained sediments (Figure 3).

Tidal Pumping

Tidal pumping is a transport mechanism contributing to the distribution of sediment within estuaries. In the Delaware Estuary, it is driven by asymmetries in tidal velocity and particle settling, and by tidal variations in internal mixing in the stratified lower estuary (Sommerfield and Wong, 2011). Phase differences between water velocity and suspended-sediment concentration produce tide-induced residual fluxes of sediment that contribute to the formation of the ETM. As in many estuaries, gravitational circulation and tidal pumping coexist in the Delaware and influence the intensity of the ETM in ways that depend on location, tidal conditions, and freshwater inflow.

Observations of Sediment Transport and the ETM in the Lower Estuary

Long Range Spoil Disposal Study

The existence of an ETM within the Delaware estuary has been recognized for at least four decades as a critical feature of the estuary sediment transport system. The USACE investigation titled “Long Range Spoil Disposal Study” (LRSDS, Wicker, 1973) evaluated sediment transport mechanisms and quantities to determine the cause of repetitive, problematic high shoaling rates in several locations along the

Delaware River navigation channel, primarily between Marcus Hook and Wilmington. In May and July 1969, the LRSDS obtained two series of single tide cycle synoptic current and SSC measurements at Tinicum Island, Marcus Hook, and the Delaware Memorial Bridge (Figure 1). The report documents instantaneous SSC and current observations and calculates the ebb- and flood-phase total suspended sediment fluxes at the three sites. An expanded summary of the findings of the LRSDS is presented in Appendix A of this paper.

The largest ebb- or flood-phase suspended sediment fluxes measured during the 1969 experiment consisted of approximately 26,000 metric tons of sediment at the Delaware Memorial Bridge (DMB) station. This finding quantified the mass of sediment suspended in the water column and transported up- and downstream by the flood and ebb currents during ordinary conditions of tide and freshwater inflow. The average hourly flux of suspended sediment at the DMB was over 4,000 tons per hour (26,000 tons / 6 hours), as compared to the long-term average rate of sediment input from above the head of tide, about 150 tons per hour (1.3 million tons / 8,760 hours). It is not the absolute value of these rates that is important; rather, it is the relationship between the two, indicating that the very large quantities of primarily fine-grained sediment are stored and available for transport within the ETM of the estuary. The LRSDS provided the following analysis with regard to the navigation channel shoaling/dredging problem:

> *"The estuary serves as a temporary storage reservoir for materials contributed from the watershed. When the rates of these contributions are high, as is the case during floods and freshets, some of the material received by the estuary is deposited in the channel, but a far greater portion is deposited on the much larger bottom areas beyond channel and anchorage limits. Some of the materials deposited beyond the limits of these navigation improvements remains there until greater than normal tidal currents occur in consonance with the widely varying tidal regimen, and they thereupon go into transport. Thus, although the bed of the estuary is the primary supplier of shoaling material, this source must be replenished from time to time by materials from the watershed, supplemented by the locally introduced material and by diatoms."*

UD Observations in 2003

Between March and June 2003, UD (Cook, Sommerfield and Wong, 2006) obtained SSC and a current measurement at two transects: Tinicum Island (upper estuary) and New Castle (lower estuary). The period of measurement included the occurrence of two typical spring freshets that were found to have at least short-term significant impacts on sediment transport. Analysis of the time series of data led to the following four principal conclusions relevant to estuary sediment transport mechanisms (bold italics added for emphasis):

> "(1) In Spring 2003, the Delaware Estuary turbidity maximum migrated axially in association with river peakflows of 1,000 to 2,000 m^3/sec, typical springtime events with a recurrence interval of 1 - 2 years. ***Such flows are capable of displacing the salinity intrusion and suspended sediment trapped within the ETM zone ~20 km to seaward,*** while at the same time increasing salinity stratification and suspended sediment mass in the lower estuary. River-forced excursions of the ETM temporarily decrease SSC in the upper estuary, because pools of easily resuspendable sediment are advected seaward.
>
> (2) Spatial and temporal variation in SSC and flux in the upper Delaware Estuary is highly dependent on the proximity of resuspendable bed deposits, some of which reside in quasistationary depositional zones . . . . ***Throughout the study period the depth-averaged residual current and sediment flux were seaward***, and the flux magnitude increased 3 - 4 fold during river peakflows on account of elevated ebb currents and bottom scour. The seaward residual current . . . appears to be **a significant mechanism of sediment transport to the estuarine turbidity maximum zone**.

> (3) Although subtidal variations of currents and SSC in the upper Delaware Estuary are forced principally by freshwater discharge, ***remote winds during the study period had a measurable influence on residual flow***. Sustained along-shelf winds (50° from North) of speeds ≥10 m/sec increased water levels in the upper estuary by nearly 100 cm and reduced the nontidal drift. . . .
>
> (4) Sediment mass balance suggests that ***the upper estuary channel is a quantitatively important repository of sediment on inter-annual timescales***. During the 80-day observational period, the estimated sediment load delivered by tributaries to the study area was 5 X 10^8 kg [0.5 million metric tons]. By comparison, the sectionally averaged sediment flux at Tinicum Island was 4 X 10^8 kg, and 11 X 10^8 kg was measured at New Castle. The flux imbalance (~7 X 10^8 kg) implies that ***deposits remobilized from storage within the intervening channel were a significant source of sediment delivered to the lower estuary***. In view of these results, and given the persistence of sediment deposition in the upper estuary (as evinced by dredging records), we speculate that ***suspended sediment becomes entrapped by up-estuary tidal pumping and deposition during periods of low riverflow***."

UD Observations in 2005

The most recent series of SSC and current observations obtained by UD took place between March and October 2005 (Sommerfield and Wong, 2011). The principal purpose of these observations was "to identify mechanisms of suspended-sediment flux and turbidity maintenance in the Delaware River estuary." Three transects within the lower estuary were monitored, New Castle (NC), Blackbird Creek (BC), and Bombay Hook (BH, Figure 5).

The period of measurement captured the large freshwater flood event that peaked on 4 April 2005, when inflow at Trenton reached 6776 m^3/sec, the third highest peak flow observed since 1898. Inflows remained at elevated levels for approximately the next 20 days, during which an estimated 2.6 million metric tons of sediment were discharged to the estuary. This 20-day total exceeds the *mean annual discharge* of sediment by a factor of 2, demonstrating the episodic nature of new sediment input to the estuary from the watershed. Later in the observational period, freshwater inflows returned to typical seasonal low flow values. This data provides the most spatially and temporally comprehensive synoptic view of circulation and sediment transport phenomena obtained to date in the Delaware estuary. The observations covered an extended period with large variations in hydrologic conditions and provide important new insights into the workings of the estuary sediment transport system.

Much of the analysis and discussion in Sommerfield and Wong (2011) pertains to identifying the relative role and magnitude of the transport mechanisms outlined earlier in sections. The following conclusions from Sommerfield and Wong are considered significant and are quoted here:

> "The estuarine channel is a strongly advective transport environment with **residual sediment fluxes driven mostly by gravitational circulation**.
>
> **Tidal pumping is a contributing process of residual sediment flux** in the channel near the estuarine null point and turbidity maximum, though the magnitude and direction of pumping vary with river flow and resident sediment inventory in the upper estuary.
>
> **Sediment pumping in the channel is driven by tidal asymmetries** in velocity and particle settling, and perhaps by tidal variations in internal mixing in the stratified lower estuary.
>
> In contrast to the estuarine channel, **residual sediment fluxes over the subtidal flats are weak** and dominated by tidal pumping.

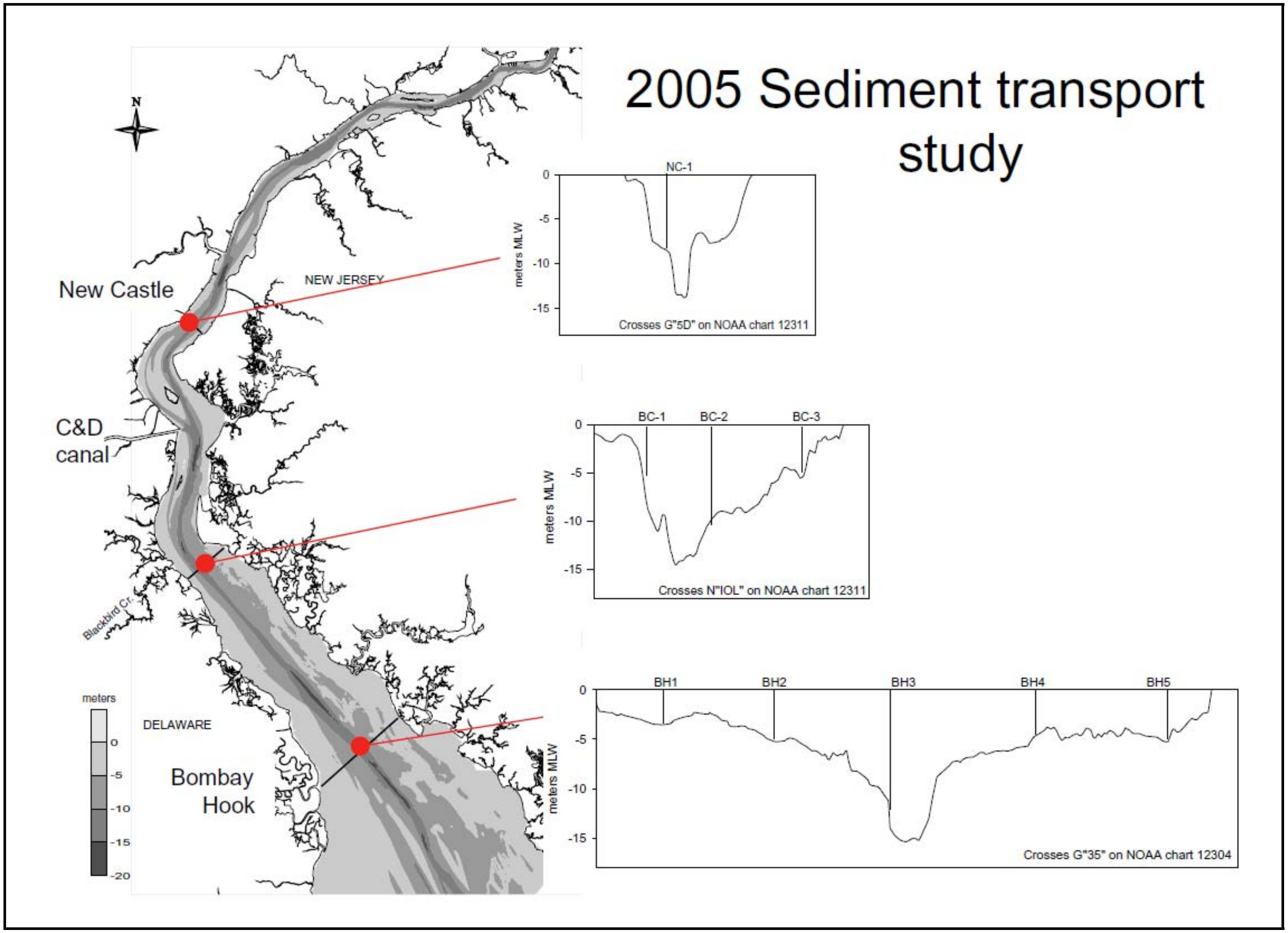

Figure 5: Location Map for UD 2005 Observations (Sommerfield, "Understanding Turbidity in the Delaware Estuary", 2007 Delaware Estuary Science Conference)

> **Landward advective fluxes of sediment in bottom waters of the lower estuarine channel are strongest during neap tides**; during large spring tides sediment is mixed high in the water column and the **advective flux reverses** to seaward under the residual surface outflow.
>
> Despite these transient seaward fluxes, **the estuary has an enormous capacity to buffer extreme freshwater discharges and suppress export of suspended sediment to Delaware Bay**.
>
> **Gravitational circulation in the axial channel of Delaware Estuary is a fundamental mechanism of sediment entrapment within the ETM zone**, but . . . tidal trapping over the shallow subtidal flats is involved in the permanent sequestration of sediment delivered to the estuary as whole. This implies lateral circulation and sediment transport between the estuarine channel and subtidal flats, the nature of which will require further research to characterize."

These observations unambiguously confirm previous notions as to the importance of gravitational estuarine circulation in the creation and maintenance of a permanent ETM in the lower estuary. In effect, a large portion of all new sediment added from fluvial sources is trapped within the lower estuary, consistent with the uniform and nearly continuous mud bottom mapped by Biggs and Church (1984, Figure 3). This also explains the fact that four localized navigation channel hot spots, which lie in a 30 km reach from the Chesapeake and Delaware Canal (C&D Canal) upstream to Marcus Hook, together require about 80% of the maintenance dredging (by volume) within the entire estuary. Presumably the hydraulic geometry in these high shoaling rate areas causes the highly localized nature of their shoaling/dredging characteristics despite the much greater longitudinal extent of the ETM (Figure 6).

Maintenance Dredging Trends

Annual maintenance dredging quantities have been compiled in a number of USACE reports since major navigation improvements began in the estuary around 1900. A 1937 report (USACE, 1937) states "maintenance dredging amounting to about ten million cubic yards annually" was required over the preceding 25 years. Subsequent USACE reports (USACE 1967, USACE 1984) also present estimated annual navigation project dredging in the estuary. For this paper, maintenance dredging quantities from 2000 to 2009 were compiled for the major federal navigation projects in the estuary. Figure 7 presents the annual dredging rates from these four dates (1937, 1967, 1984, and 2009).

Maintenance dredging rates are shown in Figure 7. The quantities are displayed in terms of cubic yards per year on the left axis and are converted to their corresponding sediment mass values of metric tons per year (right axis) using the relationship of 753 kg/m^3 adopted by UD investigators (see Section 3c above). The quantities display the trend of reduced maintenance dredging over the past several decades, but are not directly applied in this paper for purposes of a quantitative sediment budget for the estuary.

The cumulative maintenance dredging from all federal navigation projects in the Delaware Estuary for the period 1997 through 2009 is presented in Figure 8, and illustrates the relative portion of total estuary dredging associated with each project.

Sediment Transport in Delaware Bay

In contrast to the recent intensive research into sediment transport processes in the lower estuary (Figure 3), less rigorous research has been done on transport processes in the upper and lower bay. In terms of an overall estuary sediment budget, the upper and lower bay are significant in that they constitute about 80% of the total estuary surface area and 63% of the estuary's volume. The zone from Trenton to Philadelphia includes approximately 2% of the estuary surface area and volume and from Philadelphia to

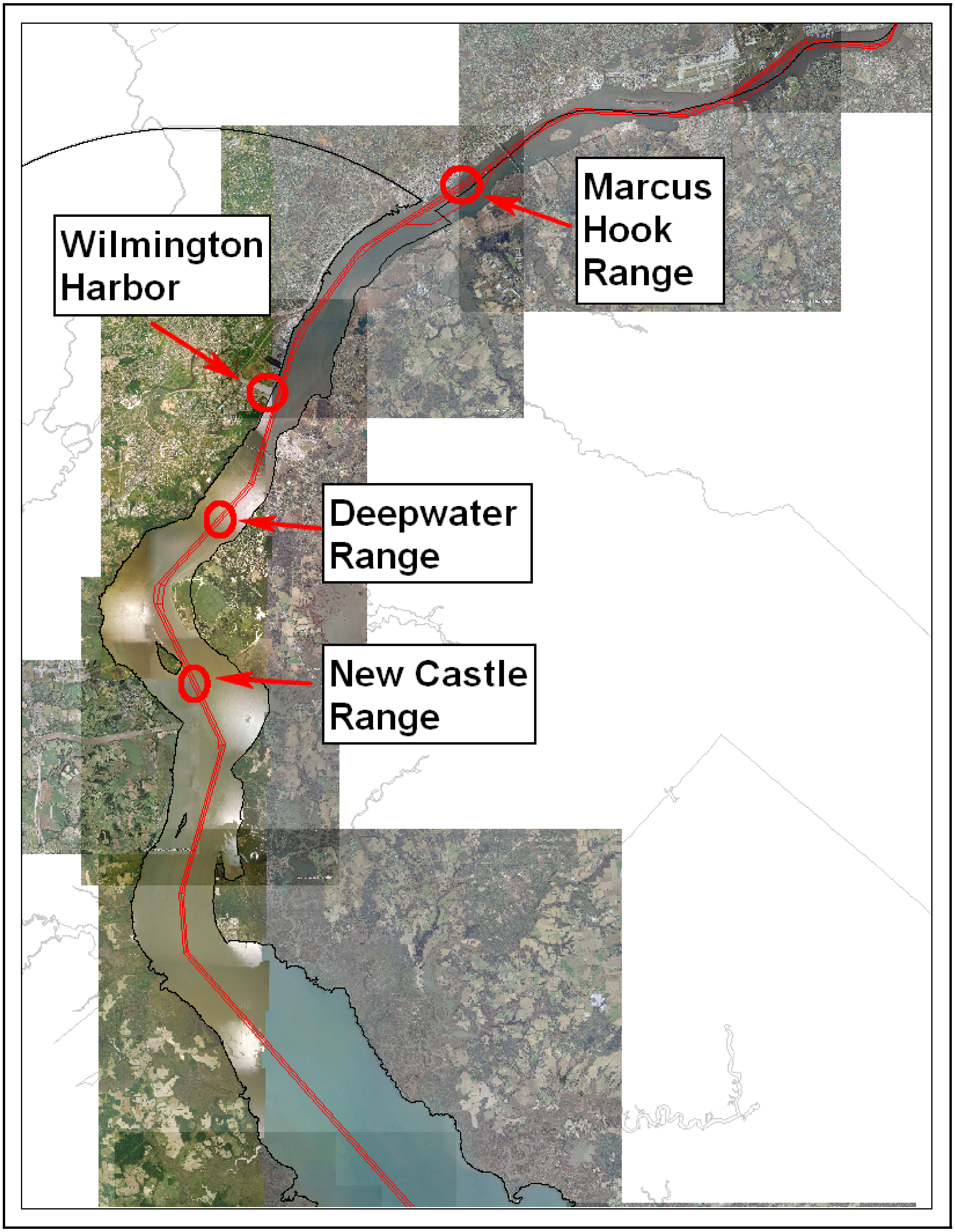

Figure 6: High Maintenance Dredging Areas

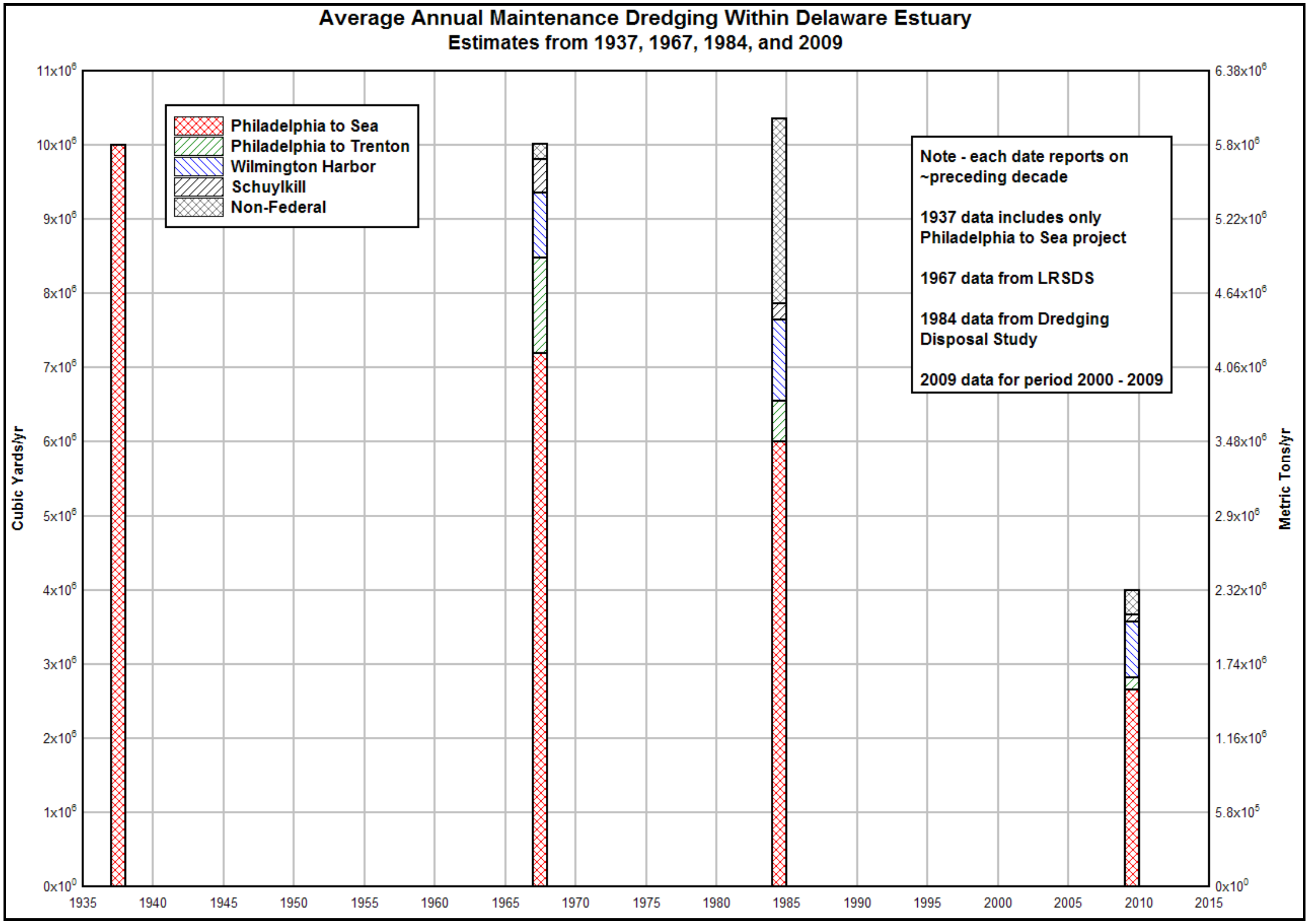

Figure 7: Maintenance Dredging Rates

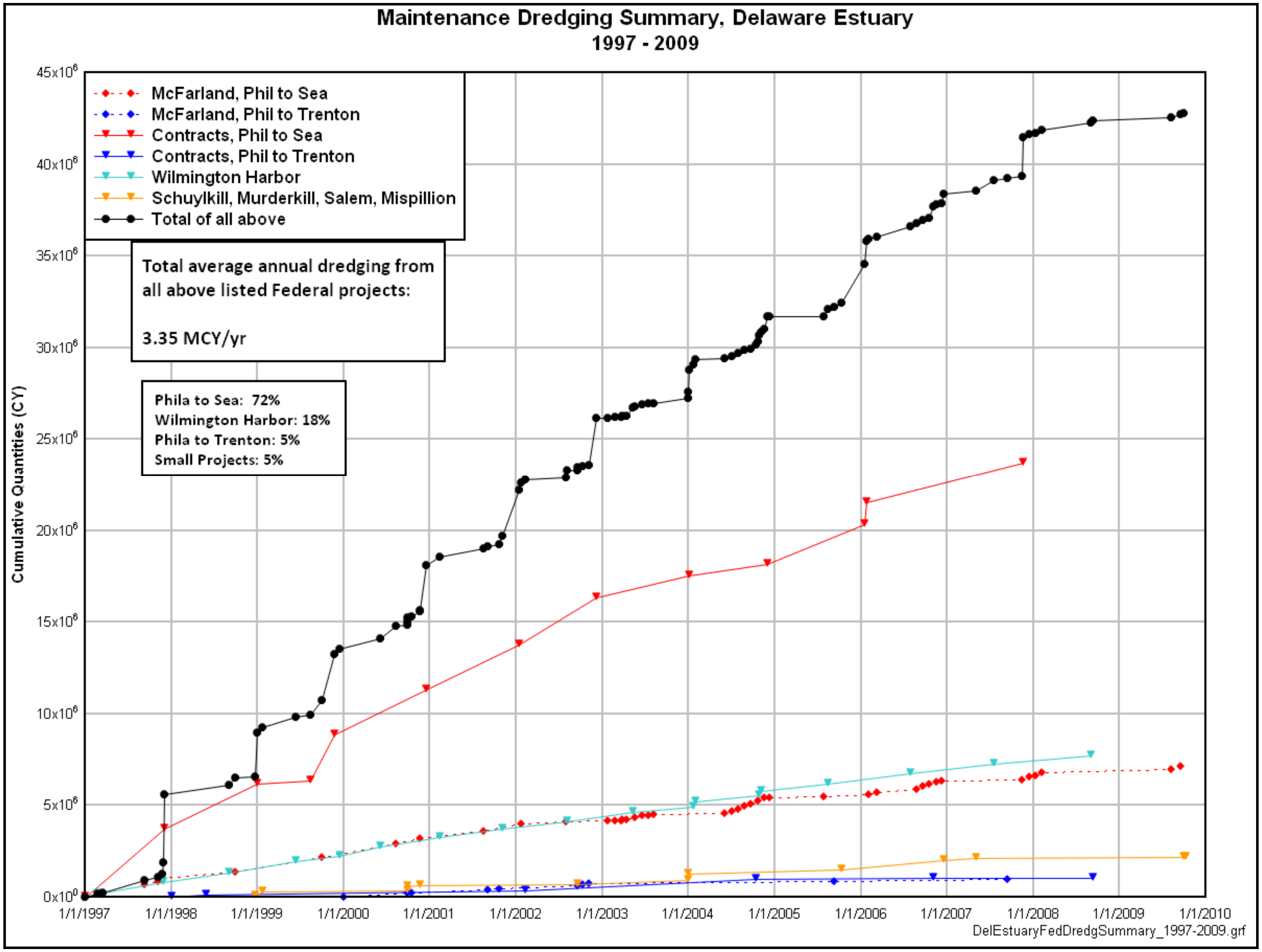

Figure 8: Cumulative Maintenance Dredging, Federal Navigation Projects in Delaware Estuary, 1997 - 2009

Bombay Hook, approximately 16% of the total estuary surface area, and 35% of the estuary volume. From an estuary-wide perspective, the upper and lower bay are ecologically important in that they include most of the critical oyster and horseshoe crab, as well as a significant fraction of fringing tidal marsh.

Oostdam (1971) reported on current and SSC observations at the mouth of the estuary on multiple dates between 1967 and 1970. By extrapolating the net transport measured over many non-continuous tide cycles across the mouth, Oostdam calculated that Delaware Bay exports between 2.9 and 10.1 X 10^9 kg (2.9 to 10.1 million metric tons) of suspended sediment annually. However, he qualifies the calculated range of net transport values as likely overestimates due to lack of data from the bottom 0.6 m (reported as “2 feet”) of the water column. The author also computed Lower Bay bathymetric changes between 1842 and 1968 and found large localized changes, with bottom erosion dominant on the east side, and shoaling dominant on the west side. Overall, he concluded the lower bay exhibited a dynamic equilibrium between relative sea level rise and a small net deposition of sediment from 1842 to 1968.

Wong and Moses-Hall (1998) examined the three-dimensional flow and salinity regime across the 18 km-wide mouth of the estuary, using data obtained in April 1984. Their principal finding was that there are “two branches of buoyant outflow in the shallow areas along the shores separated by a more saline inflow concentrating in the deep channel and the central portion of the bay”. The results are consistent with the overall importance of gravitational circulation causing a net inflow of more saline water along the deeper center of the estuary and its influence on maintaining the ETM in the lower estuary zone.

Knebel (1989) utilized side-scan sonar data from Delaware Bay and found that the lower bay acted as a sink for coarse-grained sediments that enter the bay on flood tide at Cape May and Cape Henlopen, and found evidence of upstream-directed sediment transport along the deeper channels, driven by flood-tide currents. Knebel also found evidence of fine-grained sediment accumulation in the shallow nearshore region northwest of Cape May, as far north as Maurice River Cove.

Pizzuto (1986) examined the sediment budget and dynamics of the sandy barrier shoreline along a portion of the western shore of the lower bay, where rates of up to 3 meters per year of retreat were observed in the preceding decades. Pizzuto states: “Eroding marsh or estuarine sediments will remain suspended and will be carried out of the nearshore zone. Only coarser sands or gravels may be carried onshore to the beach. The influence of lithology further implies that the direction of onshore--offshore transport may vary up and down the coast depending on the location of fine or coarse sediments.”

Finally, Kelley (1983) and Hall et al (1987) present evidence that indicates the export of suspended sediment plumes from Delaware Bay. Their findings suggest “resuspension of northeast Delaware Bay bottom sediment, augmented by contributions from the Delaware River, provides most of the fine-grained sediment to the Atlantic coastal marshes of Cape May Peninsula”.

Together these and other research efforts provide insight into aspects of bay sediment transport, but clearly much work remains to be done before we have a full understanding of the dominant processes transporting sediment within (or out of) the Bay, and contributing to a robust budget for sediments in the upper and lower bay zones.

Ongoing Sediment Budget Research

In 2009, the Philadelphia District USACE, contracted with Woods Hole Group (WHG) and Dr. Christopher Sommerfield to identify sediment sources, transport pathways, and sinks in the Delaware Estuary including the development of a regional sediment budget with emphasis on fine-grained (cohesive) sediments. The budget is being developed from the most recent data available from a number government agency and academic sources and is intended to provide a framework for managing sediment and related resources in the estuary. The principal tasks in this contract include:

1. Analysis of sediment loads at the head of tide on the Delaware River at Trenton, Schuylkill River in Philadelphia, and Brandywine River in Wilmington, using data archived by U.S. Geological Service (USGS)
2. Analysis of the suspended sediment inventory in the estuary based on University of Delaware oceanographic surveys
3. Analysis of maintenance dredging records provided by USACE
4. Compilation of bottom sedimentological data (grain size and bulk density)
5. Digital shoreline datasets and analysis of shoreline change for periods of interest
6. Digital bathymetric datasets and analysis of bathymetric change for several periods
7. An analysis of fine sediment accumulation within the fringing tidal marsh of the estuary
8. GIS map layers for the relevant work products (grain size, bathymetry, bathymetric change)
9. An updated regional sediment budget derived from Items 1−8.

To date, a number of these products have been largely completed. The suspended sediment load time series shown in Figure 2 and the suspended sediment distribution in Figure 3 are both products of this work. In addition, Item 7 above has been completed in draft form and indicates that the magnitude of inorganic sediment accumulation in tidal marshes is about 1.1 million metric tons annually, compared to the estimated 2.1 million metric tons in the Walsh (2004) sediment budget shown in Table 4. The shoreline change analysis (Item 5) is in progress and when complete, will provide an estimate on the rate at which erosion of the tidal marsh fringes contributes to the overall estuary sediment budget as a source term. Likewise, the analysis of historic bathymetric datasets (Item 6) will provide further insight into the magnitude of shoaling and scour outside the limits of the main navigation channels. As additional work products become available from the WHG contract, the findings will be incorporated into subsequent versions of this paper.

Principal Conclusions

1. The mean annual contribution of new sediment to the estuary has averaged 1.3 million tons per year over the past six decades. However, the seasonal and year-to-year variability in sediment discharge is large and reflects the underlying variability of the hydrologic regime of the Delaware watershed.
2. The sediment budget is not spatially inclusive of the entire estuary, but it does indicate that erosion of the bottom is the largest source of sediment and that dredging is the largest sink, both of which exceed the mean annual contribution of new sediment from the watershed.
3. The ETM is a permanent feature of the estuarine sediment system. It results from seaward advection of sediment originating above the head of tide on the Delaware River and its tributaries, combined with a landward flux of suspended sediment driven by estuarine gravitational circulation. Gravitational circulation results from the longitudinal salinity gradient between the saline mouth of the estuary and the fresh water zone that typically extends from Marcus Hook to Trenton. At any given time, the total mass of sediment suspended in the water column can approach the mean annual mass of sediment contributed by rivers. Sediments at the bed of the estuary in the ETM are dominantly fine-grained (i.e., mud). The muddy bottom in the ETM constitutes a large reservoir of sediment that is readily suspended and transported in the short term by energetic tidal currents. On a longer-term basis, residual circulation patterns tend to concentrate and retain fine-grained sediment within the ETM. Ultimately, this zone is a trap for the majority of fine-grained sediments, although an unknown fraction of the ETM sediment escapes to the upper and lower bay.

4. The overall pattern of gravitational circulation and sediment transport is modified by a number of factors, including the three-dimensional geometry of the estuary, as well as hydraulic factors such as tidal pumping, neap-spring tidal variations in dominant sediment flux direction, and episodic fluvial flood events. Consequently, there is a complex set of interactions that are not fully understood and quantified, but ultimately control the fate of sediment distribution and transport within the estuary.
5. The single largest component of the estuary sediment budget amenable to change through management measures is maintenance dredging and upland disposal. Other major components in the sediment budget, including fluvial sediment input and bed erosion (sources) and marsh accretion (a sink), are not as amenable to significant change as dredging/disposal. The management problem is to find effective and efficient alternative ways to modify current dredging and disposal practices to best benefit the overall health of the estuary. Given the critical regional economic and social needs to maintain the existing network of navigation channels and harbors (the waterborne commerce transportation network), it is unlikely that a significant reduction in dredging can be achieved. Instead, the principal challenge facing the RSM Workgroup is to find alternatives to permanent impoundment of dredged sediment in confined upland disposal sites.

Remaining Problems/Questions to Address

Sediment Budget

The present estuary sediment budget is spatially incomplete, in that it does not encompass the entire estuary. Evaluation of historic changes in estuary geometry from Philadelphia to the head of tide, and from Bombay Hook to the Capes, is needed to determine the magnitude of the bottom erosion (or bottom accretion) component. A sediment budget has been reasonably well established for the Philadelphia to Bombay Hook reach. However, this reach represents approximately only 20% of the area (30% of the volume) of the estuary. An analysis of the remaining 80% remains to be accomplished; this would include a quantitative assessment of historic dredging for the navigation channel from Philadelphia to Trenton. This channel reach has a substantially higher fraction of coarse-grained sediments that have been dredged and disposed of, compared to the channel from Philadelphia to the sea.

Marsh Sediment Budget

The role of tidal marshes as sink or source terms in the sediment budget requires further analysis. Although we do have a reasonable assessment of vertical sediment accumulation in selected marsh zones (sink term), we do not have a good quantitative measure of the sediment budget impact of fringing marsh erosion in the bay (source term). Fringing marshes along both the NJ and DE bay shorelines have experienced a significant lateral retreat for at least the past century.

Coarse-grained Sediments

Most scientific investigations to date have concentrated on the ETM and fine-grained sediments in the lower estuary. Additional research is needed both upstream and downstream of the lower estuary, where coarse-grained sediments are more prevalent and a different suite of hydraulic and sedimentary processes affect sediment transport.

Dredging

Over the past four or five decades, there has been a progressive decline in the average annual volume of sediment removed from navigation channels by dredging. During this period, there have been no reductions in project depths maintained, nor has there been any significant reduction in the number of federal or non-federal projects requiring maintenance. The cause of this decline has not been investigated to date.

Geochemistry and Biochemistry

Fine-grained sediments are affected by both chemical and biological processes that may play a role in transport, settling rate, and ultimately deposition and stabilization of sediment at the bed of the estuary. Little work has been done to date evaluating the potential for biological and chemical interactions to affect the behavior and fate of suspended sediment.

Fine-grained Sediment Transport in the Bay

The 2005 research by UD (Sommerfield and Wong, 2011) in the lower estuary identified differences in sediment fluxes occurring in the deeper, central portion as compared to shallower marginal areas to the east and west. Additional research is needed to develop a better understanding of the transport mechanisms and fluxes on the marginal shoal areas of the lower estuary and in the Bay.

Mechanisms of Marsh Loss

In addition to the loss of fringing marshes along the Bay shoreline, there are also a number of locations in which portions of interior marsh have reverted to shallow open water. Numerous contributing factors have been proposed for both fringing and interior marsh loss, but the primary causative factors have yet to be identified with certainty.

Sediment Transport Pathways

“Our general understanding of sediment routing from watershed sources to depositional sinks in tidal basins is poor, and research focusing on sediment storage within the tidal freshwater segment of river estuaries is sorely needed” (Sommerfield and Wong, 2011).

Model

There is presently no operational Delaware estuary sediment transport model that could be readily applied to assess alternate sediment management practices. (Note - sediment transport was included in a three-dimensional numerical hydrodynamic model of the Delaware estuary developed as a PhD thesis in 2006: “Simulation of Hydrodynamics and Sediment Transport Patterns in Delaware Bay” by Tevfik Kutay Çelebioğlu, Drexel University).

Given the complexity of the sediment transport system that has become apparent over the past decade, development of such a model would undoubtedly be a lengthy and expensive undertaking, even though our understanding of relevant transport processes has improved significantly through field data collection and analysis.

Lack of a sediment transport model should not be viewed as an intractable obstacle in the search for improved methods to manage sediment resources of the estuary. Certain beneficial use options, such as harvesting sediments from existing confined upland disposal sites, can reasonably be implemented without a model. Sediment in confined disposal areas is already out of the system and harvesting such material would simply (and beneficially) create new disposal capacity. Other types of questions such as, Where was the ETM prior to 1890 when major modifications to the estuary channel and shorelines began? or What are the impacts on the estuary sediment budget from deepening the main navigation channel? are difficult to answer with a reasonable degree of certainty in the absence of a robust model. This is a matter that can only be resolved with time and careful consideration. In the interim, the Delaware Estuary RSM initiative should identify sediment management and beneficial use options that can be implemented with a reasonable expectation of success in the absence of a model to rigorously assess potential impacts of such actions.

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Sediment Quantity and Dynamics White Paper Committee

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Appendix A

Summary - Long Range Spoil Disposal Study, Sub-Study 2 “Nature, Source, and Cause of the Shoal” (USACE, 1973)

Appendix A: Summary - Long Range Spoil Disposal Study, Sub-Study 2 “Nature, Source, and Cause of the Shoal” (USACE, 1973)

This report presents background information on two topics relevant to regional sediment management in the Delaware estuary. The first is the **sediment budget** analysis developed for the estuary; the second is prototype measurements of **suspended sediment transport** obtained in 1969. Summaries of these two topics are presented below.

Sediment Budget (pages 29 - 42)

The goal of the sediment budget analysis was to identify the “nature, source, and cause” of the sedimentation that takes place within the limits of the navigation channels between the head of tide at Trenton and RM 57 in the Reedy Island Range of the Delaware River main channel. The principal shoaling/dredging problem identified in the report is the Marcus Hook Range and Anchorage. The overall magnitude of shoaling/dredging is described as follows (page 1): “The total shoaling of the federally maintained man-made channel and appurtenant anchorages averages 8.2 million cubic yards each year.” Downstream of RM 57 the report states there is no observed channel shoaling and thus no sediment volume or mass calculations were made for the reach between RM 57 and the mouth.

The sediment budget analysis in Sub-Study 2 does not utilize conventional sediment budget terminology, in that it does not explicitly refer to sources and sinks. Instead, the report calculates (a) the mass of sediment contributed to the estuary from all sources and compares this to (b) the mass of sediment that accumulates within the multiple navigation projects of the estuary. In this regard, the mass of sediment identified in part (a) of the analysis effectively corresponds to the term sources as applied in most modern sediment budget references, whereas the mass of sediment identified in part (b) only loosely corresponds to the term sinks as used in most sediment budgets. Shoaling in the navigation channels, which necessitates its removal by dredging, is the only sink term considered in this report. Parts (1a) and (1b) of the analysis are discussed separately below.

Sediment Contributions to the Estuary

The following table is reproduced from Table 16 of the report.

Suspended Solids Inputs to the Delaware Estuary

Source terms	Tons per year
Tributary drainage area	1,402,000
Erosion of bed and banks (outside channel boundaries)	-
Trenton to Philadelphia	1,524,000
Philadelphia to RM 60	760,000
Dredging	385,000
Storm and sanitary sewers	133,000
Industrial pollutants	57,000
Diatoms	1,500,000
Atlantic Ocean	0
Airborne particulates	95,000
Column Total	**5,856,000**
(Metric tons equivalent)	*(5,311,392)*

Note in the above table that the category “Erosion of bed and banks (outside channel boundaries)” was computed from hydrographic survey comparisons between 1961 and 1966. The hydrographic surveys were used to determine volumetric changes; then empirical relationships between in situ sediment volume and sediment dry mass were used to convert volumes to the mass units in the table above. Pages 29 through 37 of the report describe the derivation of the other categories of suspended solids inputs to the estuary.

Sediment Shoaling in Navigation Channels

Hydrographic surveys from 1961-62 were compared with surveys from 1965-66 to determine the sediment volumetric change *within navigation channel limits* over that period. The observed sediment volume change, plus all dredging performed in the period, were summed to obtain the total shoaling volume, and divided by the appropriate number of years to determine average annual volumetric shoaling per 1,000 ft-long segments of the Philadelphia to Trenton and Philadelphia to Sea channels. Dredging and shoaling for the same period were also calculated for other federal and non-federal navigation projects in the estuary. Sediment volumes were adjusted to equivalent dry sediment mass using location-specific conversion factors. Plate 12 on page 39 of the report documents empirical data used to derive the volume-to-mass conversion factors. The calculated shoaling in the principal navigation channels of the estuary is presented in Tables 17 and 18 of the report, and is summarized in the following table.

Shoaling in Delaware Estuary Navigation Channels

Location	Tons per Year, Dry Mass
Philadelphia to Trenton	773,000
Philadelphia to the Sea	3,317,000
Anchorages	501,000
Non-Fed Navigation Facilities	1,660,000
Tributary Channels (Schuylkill, Wilmington Harbor, etc)	594,000
Column Total	**6,845,000**
(Metric tons equivalent)	*(6,208,415)*

The report recognizes the imbalance between the sediment masses calculated in parts (a) and (b) and proposes a number of plausible explanations for the imbalance. The report also concludes that the principal source *external* to the estuary is the watershed above tidewater with regard to sediment that shoals within the navigation channels. However, the immediate short-term source of shoaling within the navigation channels is sediment that originates from the bed of the estuary itself. See page 90:

> “The estuary serves as a temporary storage reservoir for materials contributed from the watershed. When the rates of these contributions are high, as is the case during floods and freshets, some of the material received by the estuary is deposited in the channel, but a far greater portion is deposited on the much larger bottom areas beyond channel and anchorage limits. Some of the materials deposited beyond the limits of these navigation improvements remains there until greater than normal tidal currents occur in consonance with the widely varying tidal regimen, and they thereupon go into transport. Thus, although the bed of the estuary is the primary supplier of shoaling material, this source must be replenished from time to time by materials from the watershed, supplemented by the locally introduced material and by diatoms.”

Suspended Sediment Transport (pages 42 - 87)

Suspended sediment and current measurements were obtained in 1969 at three locations in the Delaware River. The measurement locations were (1) Tinicum Island, Station 90+000; (2) Marcus Hook Range, Station 124+000; and (3) Cherry Island Range, Station 180+000, about 500 ft d/s of the Delaware Memorial Bridge. At each location, three observation points were established, one at the center of the channel, and one each to the east and west outside the navigation channel edges. The dates of measurement were 15 May and 23 July 1969, at which times the estimated freshwater discharge above Marcus Hook was 12,300 cfs and 9,800 cfs, respectively. Observations were made over one tidal cycle on each date, capturing a full flood and ebb sequence. A summary table of the computed flood and ebb phase sediment fluxes is presented below, based on data in Table 22 of the report. In addition to the summary table below, pages 42 - 87 present details of the tide, current, and suspended sediment observations obtained at the three sampling locations on the two dates.

LRSDS - Suspended Sediment Transport During Flood and Ebb Phases, Tons

	15 May 1969		23 July 1969	
Location	**Flood**	**Ebb**	**Flood**	**Ebb**
Tinicum Island (Sta 90+000)	4,176	5,139	2,994	3,313
Marcus Hook (Sta 124+000)	13,653	16,240	9,101	6,354
Cherry Island Range (Sta 180+000)	28,710	28,800	18,211	22,680

Delaware Estuary
Regional Sediment Management Plan
White Paper

Appendix B:
RESTORATION AND BENEFICIAL USE

November 2011

Last Revised: November 23, 2011
Final Draft – September 2012

Table of Contents

List of Figures

Acronyms and Abbreviations

BU	Beneficial Use
CDF	Confined Disposal Facility
DNREC	Delaware Department of Natural Resources and Environmental Conservation
MACWA	Mid-Atlantic Coastal Wetlands Assessment
PADEP	Pennsylvania Department of Environmental Protection
PDE	Partnership for the Delaware Estuary
PDM	processed dredged material
RSMP	Regional Sediment Management Plan
TMDL	Total Maximum Daily Load
TNC	The Nature Conservancy

Introduction

Delaware River Estuary Regional Sediment Management Plan (RSMP) Restoration and Beneficial Use Objective: Support ecological restoration and optimize environmental benefits through the incorporation of an enhanced understanding of sediment-related processes; and to promote the beneficial use of sediment (including dredged material) for a variety of purposes.

The RSMP Team is exploring ways to improve the management of sediments in the Delaware Estuary. This white paper is intended to identify restoration actions that would help natural systems cope with current sediment regimes, outline a broader range of placement and use alternatives for dredged material, and identify specific ways to combine restoration and port maintenance activities to achieve dual purposes.

From an ecological perspective, sediment is a resource and a vital component of estuarine systems. Anthropogenic actions can alter sediment processes on variety of scales, from local to watershed, leading to changes in the quantity or quality of sediment in the environment. Too much or too little sediment in any given location can create problems for the estuary's natural systems. Changes in grain size or contaminant concentration can also create ecological problems. Increased understanding of sediment processes, allow resource agencies to take appropriate action to correct or mitigate problems.

From an economic perspective, the estuary’s function as an international port leads to the traditional view that sediment is a problem for navigation. It accumulates continuously in channels and harbors, and needs to be removed regularly, usually by dredging. In theory, there are a wide variety of options for the placement of dredged material (sediment), but considerations of cost and other practical constraints limit the viability of many of these options. For many years, dredgers in the Delaware Estuary have placed most of the dredged sediment into upland Confined Disposal Facilities (CDFs) located along the shores of the estuary.

This paper describes ecological and economic concerns related to sediment in the Delaware River Estuary and how these concerns are inter-related. The paper is organized into sections entitled Restoration and Beneficial Use. The Restoration section includes a broad discussion of restoration topics that affect sediment-related processes and suggests ways in which dredged materials may be beneficially used as part of restoration. The Beneficial Use section discusses issues related to the use of dredged sediment for a variety of purposes. Figure 1 shows areas of separation and overlap between the sections: Sediment-associated activities considered in this white paper are encompassed within the two large circles.

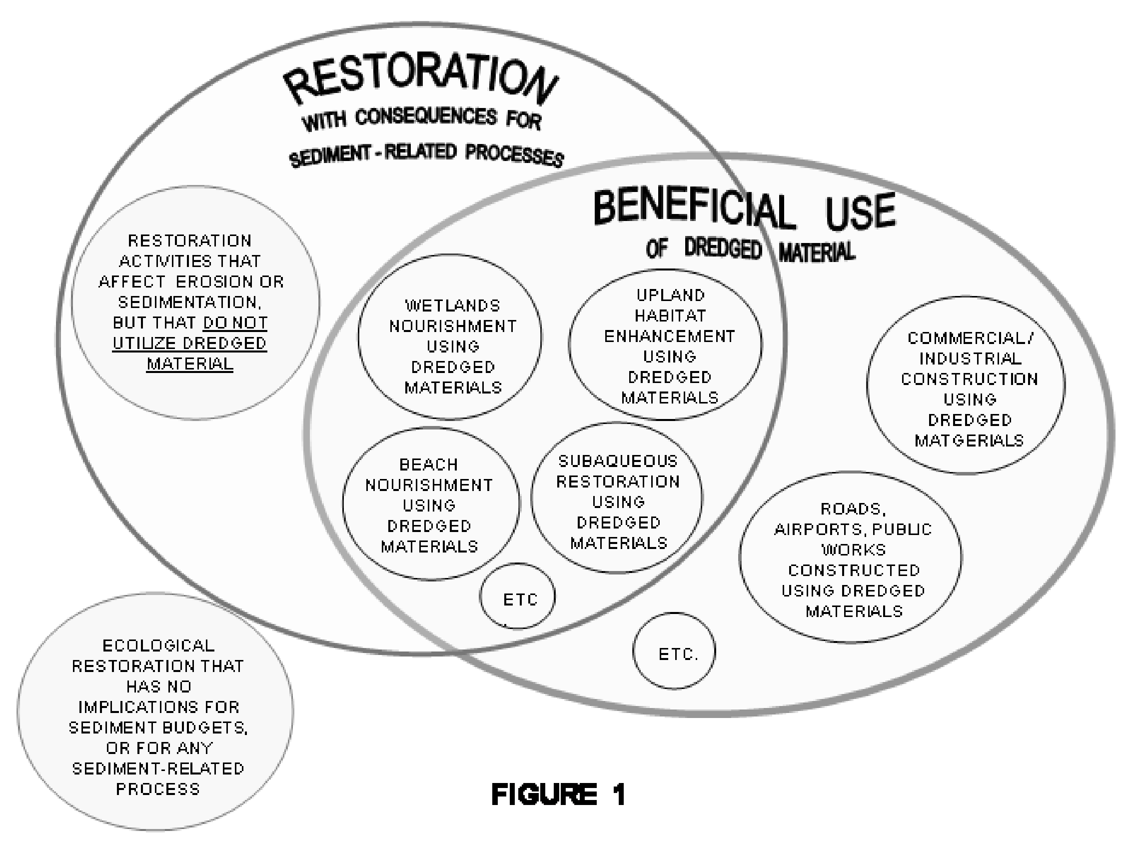

Figure 1: Relationship between Restoration and Beneficial Use

Restoration

Introduction

Restoration, in an ecological context, refers to activities that are designed to undo, or correct for, losses or adverse impacts to natural resources. Because this paper has been prepared as part of a Sediment Management Plan, the discussion of restoration topics will be limited to those that have a bearing on sediments or sediment-related processes.

This paper will consider both active and passive ways of using sediments in restoration. Active use of sediments is the importation and placement of sediment as part of the restoration activity, and represents a kind of beneficial use. Passive use of sediment is an action that causes a change in the sediment dynamics at a restoration site, usually to improve the site's retention of sediment. Passive restoration may slow erosion, enhance natural deposition, or both. It is possible to conceive of restoration actions that are at once both active and passive.

The following natural resource topics have been selected for consideration: sub-aqueous lands, tidal wetlands, shorelines, upland areas, and watersheds.

Subaqueous Lands

Recent efforts by the Delaware Department of Natural Resources and Environmental Conservation (DNREC), the Partnership for the Delaware Estuary (PDE), and others to assess the estuary bottom have shed new light on its tremendous diversity and spatial heterogeneity. Two broad categories of habitat have been described: soft bottom and hard bottom. Soft bottom is composed of loose sediments ranging from fluid mud to sand and gravel. Soft bottom areas are subject to regular deposition and re-suspension of sediments according to fluctuations in the current. Hard bottom areas cover a smaller total area than soft bottoms and include rock or cobble, and reefs formed by the colonial habits of certain aquatic invertebrates, including oysters and tube worms such as *Sabellaria*. The estuary's hard bottoms are considered to have a high ecological value and are used extensively by fish. They also provide additional water quality benefits through filter-feeding by reef-forming organisms.

A hard bottom species of particular interest is the American oyster (*Crassostrea virginica*), which has had an important place in the estuary's natural and human histories. The area covered by healthy oyster colonies was once very large, but is now significantly reduced. Resource managers in New Jersey and Delaware are involved in various activities aimed at restoration of oysters, including the physical importation of material (shell) for the purpose of providing suitable substrate for oyster larvae to attach and grow. In spite of the ecological and economic significance of oysters, the long-term prospects of the Delaware Estuary oyster reefs are uncertain, particularly in light of the changes that may come with rising sea level, salinity, and temperature. Assuming that oyster restoration is an activity that can and should continue, it could be combined with other sub-aqueous or shoreline restoration projects in ways that are discussed below.

Human activities have altered the estuary bottom at places such as borrow pits and abandoned navigation and berthing areas. Such areas often (but not always) have a low ecological value, having been affected by changes in water depth, water chemistry, circulation patterns, and sediment type. In some cases, restoration of such sites may be desirable. This would be accomplished by filling the hole with sediment to bring the bottom back to a more natural grade. The material used in such restoration would need to meet a high standard of quality in order to be approved by regulatory agencies. The restored estuary bottom would need to be comprised of material with an appropriate grain size distribution and low contaminant concentrations.

If the hole to be filled is deep enough, and if dredged material of varying quality is available, it may be possible to place unsuitable (i.e. moderately contaminated, or inappropriate grain size) material into the deepest part of the hole, and then cover it with a layer of clean material. In order for such a layered project to be successful, there would need to be a sufficient thickness of the uncontaminated top layer to ensure that the deeper material is not available to the benthic ecosystem, and also to ensure that erosion will not expose the deeper material over time. Another variant of this kind of restoration is to cover the filled area with coarse material and promote the formation of a hard bottom community.

It is possible that such restoration opportunities exist in the Delaware Estuary, but they are not well known. It would be useful to survey state and federal agencies who maintain navigation and beach nourishment projects, to prepare an inventory of sites. It should be recognized that conditions at former dredging and borrow sites may change over time due to deposition and side slumping.

All underwater restoration proposals would require the review and approval of state agencies, who will consider the advisability of filling the area and the suitability of the material proposed for the fill. Minimizing environmental damage from the restoration activity may require the use of sediment dispersal prevention techniques such a silt curtains, tremie tubes, or diffusers. Seasonal restrictions to protect aquatic wildlife would need to be observed.

Note: Seasonal restrictions on underwater placement of fill are an example of how construction activities in subaqueous and littoral habitats are regulated to protect aquatic life. Seasonal restrictions are commonly referred to as windows (or dredging windows), and there are several of them that apply in the Delaware Estuary, corresponding to the life cycles of different species. The windows close on certain dates to protect wildlife during spawning, migration, or other sensitive life stages; and then open again later in the year to allow dredging and other construction activities to take place. Dredging windows in the Delaware Estuary are established through a cooperative process involving several state and federal agencies, known as the Delaware River Basin Fish and Wildlife Management Cooperative. Additional information about seasonal restrictions appears in the Dredging and Dredged Material Management White Paper.

Tidal Wetlands

Tidal wetlands are some of the most productive natural ecosystems in the world, and are widely recognized for their important ecological functions. The services they provide include flood protection for coastal communities, maintenance of water quality, habitat for hundreds of species of fish and wildlife, and carbon sequestration. Tidal wetlands are a hallmark feature of the Delaware Estuary. They are found in a nearly complete and contiguous band along both shores of the Bay from the capes to the central portion of the estuary near the C&D Canal, and above that point more sporadically to the head of tide at Trenton.

While much of the Estuary's original wetlands have been destroyed by draining or filling, fringing wetlands today encompass more than 150,000 hectares (370,000 acres) (Kreeger at al 2010). Of the areas that remain, many have been altered by human activities such as diking and ditching. Dikes were built beginning in the 1800s to control tidal flows and create salt-hay farms and impoundments for waterfowl. Ditches were built on a huge scale starting in the 1930s to control mosquitoes. These historic activities have had major effects on the exchange of water and waterborne sediment between the Estuary and its wetlands.

Large-scale wetland restoration has been undertaken in the Delaware Estuary, primarily consisting of two kinds of activities: 1) conversion of tidal marsh vegetation from invasive types to more desirable native types, and 2) restoration of tidal flows to sites that were formerly diked for salt hay farming (PSEG). More recently, there has been a growing interest in other kinds of restoration activities, specifically activities that could help wetlands adjust their surface elevation and keep from being drowned as sea level rises.

Many of the Delaware Estuary's wetlands are overrun with non-native vegetation, especially *Phragmites australis*, known as the common reed. The restoration of native wetland vegetation is done primarily to improve ecological conditions for the production of fish and other wildlife. Such projects generally do not involve importation or removal of sediment, but they may have a passive impact on erosion and sedimentation processes in the marsh. The type of vegetation that is dominant in a marsh can affect tidal flows, surface elevation, and topography in the marshes. The re-establishment of native plant cover should restore a more natural exchange of tidal flows and sediment between the marsh and the adjacent waterways. Beginning in the 1990s, thousands of acres in Delaware and New Jersey have been restored in this manner.

Restoration of tidal flows to formerly diked wetlands has been carried out at several large sites in southern New Jersey. Almost 10,000 hectares (24,700 acres) of tidal wetlands was restored using this approach in the 1990s. Sediment was not imported for these projects, although excavated material from the dike breaches and from channel construction was redistributed across the site to create topographic diversity.

Although the large-scale diking and draining of wetlands ended years ago, there have been progressive declines of tidal wetlands documented in recent years across the Delaware Estuary region. Several causal factors have been implicated in this phenomenon including rising sea level and inadequate importation of suspended sediment (Kearney et al 2002; Stedman and Dahl 2008, Cahoon et al 2009). Normally, tidal wetlands can build vertically (accrete) in order to compensate for subsidence and/or sea level rise. This accretion occurs through the accumulation of organic matter (peat) from autochthonous production as well as the importation and trapping of suspended sediments washing in with tidal or storm flows. The importation and deposition of new sediments is essential to the long-term sustainability of coastal wetlands. Marshes that are not keeping pace with sea level rise and sit too low in the tidal prism cannot maintain their vegetation. Once the vegetation is lost, erosion can cause irreversible changes, which often results in the conversion of marsh to shallow open water or unvegetated mud flats.

To enhance a threatened marsh's chances of survival, active restoration could be implemented through importation and placement of sediment. The primary method for this type of restoration is called thin-layer application, which involves spraying sediment slurry under high pressure (Ray, 2007). Developed in Louisiana in the early 1990s, this method has been used at sites in other states, including Maryland and New York, but not in the Delaware Estuary. The practice is not common and should be considered an innovative method. An important limitation of the thin-layer method is the barge-mounted spraying equipment must be within about 90 meters (295 feet) of the restoration site, which limits the area that can be treated by spraying. In most of the thin-layer spray projects undertaken to date, nearby channel bottoms have been used as the source of sediment. However, it is possible that sediment supplies (i.e. dredged material) could be transported to a restoration site by hopper barge or pipeline.

A possible alternative to spraying would be to apply a thin layer of sediment slurry by pipeline. Slocum et al. (2005) studied a marsh site where an accidental spill of dredged material had occurred, and used their observations to speculate on the viability of nourishing tidal wetlands using deliberate applications of dilute sediment slurry. They believe that this method may be used to distribute sediment across a large area. Unlike the spray method, sites deep within the marsh interior could be reached by using standard movable pipes, and by ensuring high water content in the slurry, which should be capable of transporting sediment up to 1,000 meters from the pipe.

The method of application depends on the thickness of material to be applied and the desired final elevation of the wetland surface.. In an early experiment, applying more than 23 cm of material smothered the existing vegetation; but with a thickness of 23 cm or less, native grasses re-established by growing up through the new layer (Reimold 1997). If a project design calls for placement of a thicker layer of new sediment, vegetation could be established in other ways such as from seed if there is a seed source adjacent to the restoration area or transplant (Mendelssohn and Kuhn, 2003). Ongoing scientific research and monitoring of recent restorations around the country are likely to produce additional information that could be used to optimize restoration outcomes. General recommendations for research are outlined in the Recommendations section below.

There is currently no broad consensus in the Delaware Estuary region about the need for, or the appropriateness of, performing wetland nourishment by thin-layer placement. The conditions that govern wetland resilience vary from place to place across the region. Some sites may accrete at a rate sufficient to maintain the marsh as sea level rises, and other sites may not. Any kind of restoration proposal for wetlands would need to be approved by both the landowner and state and federal permitting agencies. Early engagement with these parties is recommended, particularly since the idea of placing sediment in wetlands is contrary to the traditional ideas of wetland protection and stewardship that are held by the regulatory agencies.

Several efforts are currently under way to gather site-specific information about wetland condition across the Delaware estuary region. The USACE is producing a report this year describing conditions at wetlands around the region (see *Sediment Quantity and Dynamics White Paper*). PDE recently launched a collaborative effort to examine the health and function of tidal wetlands. The Mid-Atlantic Coastal Wetlands Assessment (MACWA) includes probabilistic rapid assessments of wetland condition as well as ongoing monitoring at a network of fixed stations. The study may help identify sites where active restoration efforts could help maintain ecological viability. The Nature Conservancy (TNC) is currently undertaking a project to identify priority conservation areas throughout the Delaware River Basin, including the tidal marsh complexes and shoreline of the bay. As part of the project scheduled to be completed June 30, 2011, TNC staff are assessing the ecological condition of the basin. TNC and its partners, including federal and state governments and conservation non-profits, will identify priority areas for protection, restoration, and/or other conservation actions. Ultimately, TNC will use the results to recommend tidal marsh restoration, shoreline restoration, and shellfish restoration projects.

Shorelines

The Delaware Bay shore is characterized by a variety of shoreline types. The upper portions of the tidal river are highly developed with much of the shoreline altered by structures such as bulkheads and revetments. The middle section of the Estuary has a mix of developed shorelines, marsh edges, and narrow sandy beaches. The central and southern section of the Delaware Bay, where wave energy increases, has long stretches of narrow sandy beach, often backed by low lying dunes.

Developed shorelines: Where the shoreline is bulkheaded or otherwise hardened with man-made structures, the ecological value of the shore and nearshore environment is generally poor. In some places, these structures are no longer in use and may be degraded. Advocates of environmental restoration would like to see such areas converted where possible, with unused structures removed and replaced with natural habitat. An ideal restoration project would involve removing the structural shore treatment and changing the topography along the entire slope, starting above the high tide elevation and grading down to the sub-tidal. Often, one of the specific goals of this kind of project is to create a fringe of tidal marsh at the water's edge. Although such restoration sites are intended to function like natural systems, they often require some kind of engineered solution to provide stability. Projects of this kind may affect local erosion and sedimentation processes, but they are not likely to require the active importation of large quantities of sediment.

Shoreline restoration can sometimes involve trade-offs between different kinds of habitats. Some shoreline conversion projects propose changing existing areas of shallow open water to intertidal wetland, or to a gradually sloping shoreline. Such conversion of habitat may not be viewed as beneficial by all environmental resource agencies. The lead agencies for permitting (state environmental agency and USACE Regulatory branch) have the primary responsibility for weighing the environmental costs and benefits of restoration designs, and these agencies customarily consider comments from other state and federal resource agencies when making permitting decisions.

Wetland edges: Wetland edges comprise much of the shoreline in the central part of the Delaware Estuary. Examining maps and satellite images shows large stretches of shoreline where wetland edges are retreating through erosion with loss of wetland acreage. In some places, the shoreline has retreated as much as 1000 meters between 1880 and the present. When wetland edges retreat, wetlands are converted to open water and sediment is deposited in subtidal areas. In the interest of slowing or reversing shoreline recession, PDE and Rutgers University are undertaking a project to test various methods of protecting and restoring marsh edges along the shores of the Maurice River in southern New Jersey. The project, “Delaware Estuary Living Shorelines,” is specifically designed to slow shoreline erosion at wetland edges, and facilitate passive sediment trapping and accretion in the wetland. The project uses a soft-armoring tactic as an alternative to hard approaches such as bulkheads or riprap. Logs made of natural fibers are anchored along the eroding wetland edge and augmented with shell bags and live plants and mussels. The living shoreline is intended to promote the stability of both the wetland behind the shoreline and the subtidal areas in front of it. Field work began in 2007 and a practitioner's guide is being prepared for release in 2011. An estuary-wide planning project is soon to be launched, which will involve a survey of shoreline condition over a large area to assess restoration needs.

For high-energy areas along the open bay, more aggressive tactics may be needed to provide protection from waves. In such places, structures such as breakwaters or nearshore reefs could be placed a short distance offshore to deflect wave energy. This would facilitate the passive trapping of sediments and provide wave protection for the wetland edges. Breakwaters, sills, or reefs could be built using dredged material. Combining active restoration (using sediment to build sills or reefs) with passive restoration (design to facilitate trapping of sediment) would create a "hybrid approach to shoreline restoration.

Beaches: In the lower bay, there are long stretches of narrow sandy beach backed by low-lying dunes. Often there are broad tidal wetlands behind the dunes. The bay beaches are important habitat for a variety of animals, including migratory birds, horseshoe crabs, and terrapins. Small residential communities, typically consisting of one or two rows of homes behind the beach and dune, occur on both sides of the Bay. Beach erosion is an ongoing problem in the developed areas, in part because the natural tendency of the sand to migrate is hindered by the presence of homes and shore protection structures.

Both New Jersey and Delaware use sand for beach nourishment projects along the bayshore. DNREC has estimated the long term and perpetual need for roughly 94,000 cubic yards of sand per year to counteract the effects of coastal erosion at seven bayfront communities in the southern part of the state. Potential sources of sand include offshore borrow areas and navigation channel dredging. Beach nourishment needs in New Jersey are given here not in terms of annual maintenance needs, but in terms of major projects for one-time placement. A number of such projects have been in planning for several years, and they include both developed areas and environmental restoration areas. The cumulative total of sand needs for several projects in three different counties is more than 1.5 million cubic yards.

Appropriate methods need to be used in all beach nourishment projects to ensure that the project does not cause ecological damage, and that the restored sandy beach meets the habitat needs of wildlife. Critical issues include sediment grain size, beach slope, and location of borrow areas. The sediment in most parts of the lower Delaware Bay tends to be coarse-grained (i.e. sand), and low in contaminants. Every proposed beach nourishment project would require site-specific testing of source materials to ensure the material placed on the beach is appropriate for that use. Offshore borrow areas should be selected so as not to disturb important underwater habitats. Seasonal restrictions apply to beach nourishment projects, which are generally not permitted between April 15 and September 15. State environmental agencies have the responsibility of reviewing nourishment projects to ensure that these issues are properly addressed.

From the perspective of Regional Sediment Management, dredged material should be used in beach nourishment whenever possible. There have been several examples of this kind of beneficial use in the Delaware Bay. The beaches of Bowers and South Bowers Beach in Delaware have been nourished through the direct placement of sand dredged from the nearby Murderkill River navigation channel. Likewise, sand dredged from the Mispillion Inlet has been placed on the eroded shoreline north of the Mispillion jetty to repair a breach. These projects demonstrate successful collaboration between the USACE and DNREC.

Uplands

Restoration of upland areas is usually associated with a past disturbance that has interfered with the ability of the land to regenerate a productive natural plant community. Disturbed uplands areas may be poorly vegetated and subject to high rates of erosion. Such sites can be significant sources of sediment and contaminants.

While the means for restoring degraded uplands vary with the nature of the disturbance and the setting, it is common for such projects to involve soil imports or soil amendments to fill depressions, grade the surface topography, and improve the growing conditions for plants. Dredged material can be used for this purpose, either by itself or as a component of a blended material. The Harbison-Walker site (Northwest Magnesite Plant) is a former industrial site located in Cape May, New Jersey. In the 1990s, before restoration, the site's soil was too alkaline to support healthy and diverse vegetation. The desired end use of the property was open space and wildlife habitat. Dredged material was incorporated into the soil to add organic matter and decrease the pH. Native vegetation was planted and established. While this project is a successful example of restoration, it also illustrates a challenge that should be considered when taking dried dredged material from a CDF. Depending on how long it has been in the CDF, dredged material may contain roots and rhizomes of plants that were growing at the CDF site. These plants, including invasive types, may establish opportunistically at the restoration site and should be considered.

Dredged material has been used to reclaim abandoned mine lands in Pennsylvania. Across the state there are hundreds of thousands of acres of land that are impacted by coal mining. The mining activity removed forests and topsoil, leaving many sites physically unstable, or with insufficient soil to support healthy plant cover. The Pennsylvania Department of Environmental Protection (PADEP) has worked for years to carry out restoration activities at former mining lands, and yet much remains to be done. A pilot project to demonstrate the use of dredged material for mine reclamation was carried out at Bark Camp in Clearfield County between the late 1990s and 2002. Over 400,000 cubic yards of dredged material from the New York/New Jersey Harbor was transported to Bark Camp, mixed with coal ash and lime kiln dust, and used to grade and contour the site. The surface of the regraded site was covered with 18 to 20 inches of manufactured topsoil (not containing dredged material), and the site was planted with grasses. Despite the abundance of mine sites needing reclamation, there have been only a small number of other projects completed to date. Some material from USACE's Fort Mifflin CDF in Philadelphia has been transported to former mining sites in northeast Pennsylvania, but the scale of this has been limited. The sheer magnitude of the abandoned mine problem in Pennsylvania makes this beneficial use concept appealing. The challenges, however, include high costs for material transportation and handling, and public concerns regarding the safety of dredged material. Pennsylvania’s experience in the mine reclamation projects shows that beneficial use projects may require public education and outreach to help people understand the ways in which the environmental risks can be managed.

Watersheds

This section provides a general overview of the 12,000 square mile Delaware Estuary watershed and sediment issues in its non-tidal areas. It would be beyond the scope of this paper to attempt a comprehensive explanation of the role that sediments play in physical and ecological processes in watersheds. Instead, we will provide a broad discussion of watershed conditions and restoration. There is a discussion of related issues in the *Sediment Quantity and Dynamics White Paper*. None of the restoration concepts discussed in this section are likely to require the active use of dredged material.

Accelerated stream erosion is one of the most common water quality problems reported in streams of the Delaware watershed. Stream channel instability is widespread. While this problem is not new, a detailed understanding of its causes is still emerging. It is appropriate to consider this on a multi-decadal time scale, and to recognize that the ultimate cause of stream channel instability is often land use change. While streams in undisturbed forested landscapes tend to be reasonably stable, streams in landscapes where forests have been removed tend to be unstable. Development on the land surface generally has the effect of increasing sediment loads in waterways. There are a number of large-scale, long-term efforts under way that address various aspects of this problem.

The earliest efforts to reduce watershed sediment loading were directed at agricultural lands. Beginning in the 1930s, the loss of soil from agricultural areas across the U.S. was the impetus for establishing programs to assist farmers with the implementation of conservation practices. The Natural Resources Conservation Service (formerly the Soil Conservation Service) is the primary organization responsible for this effort. Conservation work in agricultural lands has been under way for many decades now, and it has almost certainly reduced the flux of eroded sediment from farmlands to waterways.

Beginning in the 1970s, as urban and suburban sprawl advanced across the landscape, awareness has grown of the ways in which developed landscapes influence the streams that flow through them. Streams in urban areas tend to suffer from a common set of problems; when land development takes place, construction activities can produce a large temporary flux of sediment to local waterways. As development progresses, increasing the amount of impervious surfaces in a landscape causes erosive flood flows in urban streams, streambank erosion, and downstream transport of sediment. It is generally believed that much of the sediment load in urban areas is derived from the stream channels themselves, as the streams erode and the channels enlarge. In recent decades, there have been increasing regulatory efforts to address these problems using erosion and sediment control practices at construction sites, low-impact development practices, and stormwater management retrofits. A considerable amount of work remains to be done in these areas.

The growing field of stream restoration is a response to the stream channel problems caused by land use changes. Using various techniques (and with varying degrees of success) stream restoration is generally aimed at stabilizing waterways that are actively eroding. Taken altogether, stream restoration efforts in the basin have probably had the effect of reducing the export of sediment to downstream areas. However, compared to the scale of the problem, the amount of restoration that has been completed to date is very small. It may be expected that these efforts will continue for the foreseeable future, but at a rate that will vary according to the availability of funding. federal and state governments generally support such efforts with modest funding through grant programs. Assessment of restoration needs and prioritization of projects has not been carried out on a basin-wide scale in the Delaware River basin.

Total Maximum Daily Load (TMDL) is a regulatory tool that could play a role in the control of sediment from developed areas. Where streams have been determined to be impaired from sediment-related causes, a TMDL implementation plan must be prepared. These plans may force local governments or landowners to implement projects to reduce sediment discharges. Philadelphia's work to reduce sediment in the Wissahickon watershed through stream restoration projects is an example of this effort (Philadelphia Water Department, 2010). The program for addressing sediment impacts using TMDLs is fairly new and not well established. In the future, as more entities undertake TMDL implementation, it may eventually result in further reductions in sediment loading from watersheds across the region.

Historic dams and their legacy represent a special concern within this subsection. From the watershed perspective, dams trap sediment that would otherwise make its way downriver to the estuary. Although the mainstem Delaware River is famously dam-free, tributaries in the Delaware basin have hundreds of dams that were built between 150 and 300 years ago. Some historic dams are still in place, others have been breached, and some have been deliberately removed as a restoration measure. Behind these historic dam sites, the stream channels and floodplains are filled with large volumes of sediment. The volume of material represented by these legacy sediments may be quite significant. When old dams become partially or completely breached, it leads to erosion and downstream transport of the stored sediment. Sites with breached dams and eroding legacy sediments are often very unstable, and can represent significant sediment sources in their watersheds (Walter and Merritts, 2008). Gellis et al. (2009) and Merritts et al. (2010) note the following regarding removal (through streambank erosion) of sediment from storage behind mill dams and on flood plains: 1) occurring today, 2) major source of sediment in the basin, and 3) expected to be a significant source for decades to come. Because of the similarity between the Chesapeake and the Delaware basins in terms of geology, landforms, and history, these conclusions should be of interest for the Delaware basin. However, there has been no large-scale attempt to inventory Delaware basin streams to assess the number of dam sites or the volume of legacy sediments still present in former impoundments behind old dam sites.

The planned removal of historic dams and the restoration of formerly dammed sites are activities that can have important consequences for sediment flows in watersheds. Dam removal has been undertaken for a variety of reasons, the most common one being the desire to re-establish fish passage between stream segments. One of the most significant results of removing a dam is that it allows watershed-derived sediment to move naturally downriver and releases the legacy sediments that have been stored behind the dam for decades (sometimes centuries). Regulatory oversight is typically provided for dam removal projects to ensure that the release of legacy sediments will not severely impact downstream reaches, and that the stream channel remains stable following the demolition of the dam. Even so, some sites where dams have been removed may represent significant ongoing sediment sources despite the best efforts of the parties carrying out the restoration.

Beneficial Use

Introduction

Sediment dredged from underwater areas is called dredged material. Dredged material can be a nuisance, hazard, or valuable commodity, depending on its characteristics and intended use. Dredged material is often simply disposed of in deep water or in a disposal facility. The practice of putting dredged material to a good use is called beneficial use.

In the Delaware Estuary, it has long been common practice to dispose of dredged material by placing it into a Confined Disposal Facility (CDF). Dredged material is pumped into a CDF as liquid slurry, and water is removed by draining and evaporation, while the sediment is retained in the facility. Most large CDFs are used repeatedly, which results in dredged materials from recent projects being placed on top of layers of dredged materials from past projects. Eventually, every CDF will reach capacity and need to be closed. Beneficial use of dredged material is the most effective means of conserving CDF capacity. Beneficial use may involve alternative methods of placement during dredging (that is, bypassing the CDF altogether), or it may involve the removal of dried dredged material from a CDF.

Beneficial use is not new to the Delaware River basin. In the past two decades, over 3.5 million cubic yards of Delaware River dredged material has been used for projects such as land redevelopment, highway construction, and landfill cover. Below is a table showing some examples of beneficial use projects in the Delaware Estuary region, compiled from information provided by USACE, New Jersey Department of Environmental Protection, and Pennsylvania Department of Environmental Protection.

Examples of Beneficial Use in the Delaware Estuary

Project	Location	Year completed	Amount of dredged material used, cubic yards
NJ Turnpike, Exit 1	Deepwater, NJ		180,000
Landfill cap	Burlington Co. RRC, Bordentown, NJ		15,000
Route 29 overpass	Trenton, NJ		2,900
Tweeter Center	Camden, NJ	1995	220,000
Philadelphia International Airport, Runway 8-26 construction	Philadelphia, PA	1997	1,900,000
River Winds Golf Course	West Deptford, NJ	2001	160,000
Strip mine reclamation	Tamaqua, PA	2003	60,000
Landfill closure	Hazleton, PA	2009	800,000
Mispillion Inlet shoreline restoration	Sussex County, DE	2009	25,000 +
Landfill daily cover	Waste Management, Inc, Falls Township, PA	ongoing	150,000 / year
Dream Park Equestrian Center	Gloucester County, NJ	ongoing	150,000 through end 2010
Landfill cap	Harrison Ave Landfill, Camden, NJ	pending	180,000

The amount of material beneficially used to date in the Delaware River region is small in proportion to the total amount of material produced by dredging. There is considerable potential for increasing the quantity of material used beneficially in this region. In the sections to follow, we discuss four categories of beneficial use: landfill uses, site remediation, general construction, and ecological restoration.

There are three fundamental factors related to beneficial use: grain size, chemical composition, and location. Each of these three factors has an important bearing on the viability of a potential beneficial use project.

Grain size: Dredged material is typically a combination of gravel, sand, silt, and/or clay in varying proportions that is mixed with organic matter from decomposed plant and animal material. Understanding potential uses of dredged material requires that the material be characterized by particle size distribution, and organic content. Particle size is mainly what drives the engineering properties of the sediment.

Chemical composition: Sediments tend to bind and hold chemical contaminants. Smaller particle sizes (clay and silt) tend to have higher affinities for contaminants than larger particles such as sand. Higher quantities of organic material also correlate with a higher potential to bind contaminants. Understanding potential uses of a dredged material requires that the material be characterized by contaminant concentrations. Regulatory requirements, usually administered at the state level, set limits on the uses of materials that contain contaminants. The presence of chemical contamination does not necessarily preclude all uses of a material, but knowing the contaminant concentrations is critical to determining which uses are appropriate. The higher the level of contamination, the more restrictive the beneficial use options. Some material may be so contaminated that no beneficial uses are permissible. Such materials should be handled properly to eliminate human health or environmental risks. For a more detailed discussion of sediment contamination, see the *Sediment Quality White Paper*.

Location: Material transportation and handling costs have a major influence on the feasibility of beneficial use project proposals. In general, increasing the distance between the source of the dredged material and the beneficial use location increases the cost of the project. Transportation cost can be sufficient by itself to prevent implementation of an otherwise viable project.

Good planning requires that resource managers have a number of beneficial use tools available. Those considered below are the options that the white paper workgroup members believe are applicable in the Delaware Estuary. This discussion will attend to the simplest applications first, considering both engineering and regulatory perspectives, and progress to more complicated applications.

Landfill Uses

There is a constant need for daily cover on solid waste landfills throughout the greater Delaware River region. Dredged material has the engineering properties appropriate for this use. This use is relatively unrestrictive in terms of contamination, because modern landfills are constructed with controls that make it possible to safely use dredged material that has some degree of contamination.

There is a continuous demand for material to be used at landfills. Waste Management of Pennsylvania has been successfully using dredged material on its landfills in Falls Township, Bucks County, for a number of years. These facilities have the advantage of being located close to a CDF where the USACE and others routinely dispose dredged material. The RSM Workgroup recommends that other landfill operators should consider using dredged material. Naturally, they will need to take into account the distance to a reliable source of material, and the cost of transportation.

Construction Aggregate

The value of sand and gravel for construction is well known. These materials are usually obtained by mining natural deposits, but dried dredged material from a CDF may be used as well. Dredged material can be readily used for infrastructure construction or private development, as long as the material meets the engineering requirements of the user, and does not exceed the state's chemical criteria for the proposed use.

Since CDFs are traditionally managed for disposal, and not for beneficial use, the valuable aggregate (sand and gravel) they contain is sometimes mixed with less desirable fine grained material, and/or with contaminated material. In such cases, the materials in the CDF may need to be sorted or blended prior to use. Such material handling processes will drive up the cost of the project, but depending on the circumstances, the extra cost still may not preclude beneficial use.

If a CDF owner determines that his facility contains valuable aggregates, and that the value of the material exceeds the cost of excavation, processing, and transportation, then it may be possible for him to sell the material to a construction contractor, developer, or broker. In the case of federally-owned CDFs, USACE can put out a bid if there is known interest in material, and the market would determine the cost of removing the material. In some cases, it may be worthwhile for a CDF operator to subsidize the cost of removing sediment in order to create disposal capacity. This idea of a renewable CDF may, in some locations, be an important management tool where new land is either unavailable or too valuable to use for a new CDF. One specific way that a CDF owner could facilitate the marketing of dredged materials for beneficial use would be to conduct sampling and analysis of the materials in his facility. Providing information about the regulatory characteristics of the material would reduce uncertainty for prospective purchasers, and allow a larger number of bidders to consider using it.

The types of projects that can use dredged material are as numerous as there are needs for aggregate. Dredged material has been used as general fill, for airport construction, in highway projects, for construction or repair of berms and levees, for beach replenishment, and for general landscaping. At least one regional company in New Jersey uses dredged material in their concrete formulations, and actually seeks permits to dredge in federal channels to obtain it. While it is possible to discuss these various proven uses, the fact remains that these projects still account for a small percentage of the total production of dredged material in the Delaware Estuary region. Relatively few contractors and developers understand the value of dredged material, or know where such materials can be easily and consistently obtained. Therefore, developing beneficial use opportunities in the construction field will require aggressive marketing. The RSM Workgroup suggests that CDF owners should be responsible for developing marketing plans, with assistance from any stakeholders who have an interest in increasing the rate of beneficial use.

Site Remediation

The long history of industrial activity in the Delaware River region has left a large number of former industrial sites that require some remediation in order to be used. Dredged material has been used in the remediation or redevelopment of several contaminated industrial sites, closed solid waste landfills, and abandoned mines. A wide range of types of dredged material have been used for this purpose, ranging from clean sand to contaminated silt and clay. This kind of project offers multiple benefits, including the opportunity to eliminate an existing source of contaminated sediment by capping or stabilizing the site. Despite the record of successful projects, and despite the multiple benefits that can be achieved, this is a complicated and still somewhat controversial beneficial use strategy.

Dredged material is a soil-like product whose characteristics may be less environmentally harmful than the contaminated soils currently exposed at a remediation site. Dredged material can be used to fill and grade the site to prepare it for redevelopment, and/or to create an impermeable cap over contaminated soils. There is a wide range of conditions at former industrial sites and possible combinations of use of dredged material and engineering controls. State environmental agencies play a significant role by reviewing the proposed remedy and determining if the dredged material ought to be used in such a way. Environmental consultants and contractors should consider using dredged material whenever imported fill is required for a remediation site, or when an impervious cap is needed to sequester contaminated soils.

Dredged material can be blended or otherwise processed to improve its characteristics. The need for processing of dredged material prior to beneficial use depends on the nature of the material and its intended use. Sometimes dredged material requires blending with another aggregate in order to give it the desired engineering properties. Fine grained dredged material (silts and clays) can be blended with pozzolanic additives (such as cement kiln dust or coal ash) for dewatering and providing structure and strength. Dredged material that has been modified in this way is usually referred to as processed dredged material (PDM). Because of its low permeability when compacted in place, PDM can be useful as an impermeable cap or hydraulic barrier. The properties of this engineered product are not identical to those of other fill materials, and its use requires special care. It may be necessary to add a layer of surface soil on top of PDM for use as a growing medium if the site is intended to support plants. The creation and use of PDM is amenable to dredged material that has modest levels of contamination. In some situations, the addition of pozzolans to form PDM can actually reduce the potential for leaching of contaminants from the product after it is placed (Douglas et al, 2005).

Using dredged material at contaminated sites often raises concerns from the public, particularly from people who live near the remediation site. Many people are concerned about the use of dredged materials and uncertain about the implications on the quality of life. Therefore, these projects will often need to involve some public education or outreach component in order to be successful.

Ecological Restoration

Dredged material could be used in a variety of ways to help restore natural habitats in the Delaware Estuary region. Some general issues are addressed below.

On a national level, more dredged material has been used for habitat creation and restoration than for any other beneficial use. This is mostly due to the enormous amounts of clean material dredged annually in remote locations, much of which can be placed in such a way as to create aquatic or avian habitat near the dredging site. In the Delaware Estuary, there have been relatively few projects to date. In this region, the principal challenges of using dredged material for habitat come from chemical composition and location.

In order to use dredged material for habitat projects, contaminant concentrations in the material must be very small. But how small? There is no clear answer to that question. The environmental agencies who oversee aquatic resource permitting programs may seek to apply different sediment quality criteria than the ones used in other beneficial use projects. Instead of using human health-based criteria, as is usually done in construction projects, the permitting agencies may consider applying ecologically-based criteria. Important factors include fate and transport, bioavailability, and bioaccumulation of the particular contaminants present in the material. This issue is technically complex, and is further complicated by the fact that there are few, if any, ecological criteria that are universally applied by all federal and state regulators. Attitudes and approaches toward this subject vary from state to state. Successful implementation of any project will require early and close coordination between the agencies that have relevant expertise and legal jurisdiction.

In the Delaware Estuary, matching up restoration sites with conveniently-located sources of dredged material is a challenge. Creative solutions may be necessary to overcome the technical challenges of transport as well as the problem of cost. In selecting the means of transport, consideration will have to be given to the end use, and whether it is advantageous to deliver the material as water slurry or as dewatered material. In the interest of demonstrating the feasibility of such projects in the near term, it may be wise to keep transportation costs low by matching dredged material sources with restoration locations that happen to be located close by.

Additional Considerations

This white paper is intended to highlight restoration and beneficial use opportunities that may be available in the Delaware Estuary region. We have tried to indicate some of the advantages, and also some of the challenges. We have not attempted to give a cost/benefit profile of each concept. Ultimately the viability of any concept or project depends on a complex set of circumstances, costs, and benefits. Some of these circumstances depend on market conditions, and some depend on regulatory requirements and agency attitudes. Much depends on available funding.

Although restoration is an idea with many proponents, a myriad of challenges often stand in the way of implementation. Opportunities for restoration are sometimes limited, especially in urban areas, so it may take extra effort to find them and to make them work. On the other hand, the value that our society places on natural habitats is increasing, and will likely continue to rise. Our intent with this paper has been to identify restoration opportunities and look to the future and think outside the box as we consider project feasibility.

Traditionally, at the USACE and other agencies, policies and goals for ecological restoration are considered separately from policies and goals for dredged material disposal. For those projects whose purpose is strictly related to the maintenance of navigation channels, the USACE is constrained to choose the least cost method for dredged material disposal, provided that method is environmentally acceptable. (USACE, 2007) As long as this rule, which is informally called the Federal Standard, governs the placement of dredged material, it will be rare to have projects that combine dredging operations with restoration. Usually, dredging disposal needs are linked with restoration only when the added costs of incorporating a restoration element into a navigation project are relatively small; when a non-federal sponsor assumes the incremental cost of placement at a restoration site; or when particular projects are authorized to have multiple purposes, as in some USACE Civil Works projects. For USACE, multi-purpose projects are those that cross-cut multiple business lines, such as Navigation and Ecosystem Restoration. For multi-purpose projects that include ecosystem restoration, cost-benefit analyses would be required, and would include calculation of both the National Economic Development and National Ecosystem Restoration values of various alternative plans. It is hoped that USACE's implementation of multi-purpose projects will increase in future years, to help address the complex challenges described in this paper. The members of the Delaware Estuary Regional Sediment Management team also hope that our efforts can help bring about a new paradigm, where the environmental and economic benefits of the restoration component of a project are considered to offset the (presumably) higher costs of moving dredged material to a restoration site instead of to the nearest CDF.

Restoration and Beneficial Use - Recommendations

Next Steps: Project Framework and Goals

The diverse options for incorporating restoration and beneficial use into sediment management can be categorized and simplified into an implementation strategy. This strategy should establish clear short-term and long-term goals for restoration and beneficial use of sediments, and categorize projects according to those goals within a conceptual framework developed by consensus. A starting point for this conceptual framework is suggested below. The next step should be to convene a working group to develop and implement a restoration and beneficial use sediment strategy.

Project Framework

Project Category	Objective	Example Projects	Example Goals*	
			Short-Term	Long-Term
Non-Tidal Passive	Control sediment loading to estuary	Riparian and in-stream habitat improvements to trap sediments	By 2020: 1) Increase acreage of floodplain wetlands by 10% 2) Replace 10% of dams with natural stream habitat	By 2040: 1) Restore riparian land cover to 1990 acreage; 2) Remove all non-purposed dams and stabilize legacy sediments
Non-Tidal Active	Enhance uplands and stabilize sediment sources	Placement of dredged materials to remediate or cap brownfields, mine lands, etc	By 2020: Re-use 5% of dredged material produced in the estuary for upland enhancement	By 2030: Maximize the re-use of appropriate quality dredged material for uplands restoration
Tidal Passive	Capture sediment along shorelines	Install "Living Shorelines" to prevent shoreline recession, expand intertidal wetlands, and improve nearshore subaqueous habitat	By 2020: Install pilot Living Shoreline projects of at least 500 m at 2 sites in the upper estuary and 2 sites along Delaware Bay (for at least 2 km total)	By 2030: Integrate living shorelines into routine management of sediments and for sea level rise adaptation
Tidal Active	Enhance tidal wetlands and beaches with sediment	Placement of dredged materials to build elevation of tidal wetlands; and nourish eroding bay beaches	By 2020: 1) Protect at least 1,000 acres of tidal wetland from drowning using nourishment 2) Enhance at least 2 km of beaches	By 2030: Maximize the re-use of appropriate quality dredged material for tidal wetlands and beaches

* Example goals in the table are suggested for discussion purposes only and do not represent the viewpoint of any individuals or organizations. Goals to be proposed in the Regional Sediment Management Plan should be science-based and developed by consensus of the participating organizations.

Additional Recommendations

1. Research and planning are needed to advance the concept of **subaqueous restoration**
    a) Inventory Delaware Estuary borrow pits, unused channels, and other areas that were previously dredged that may represent subaqueous restoration opportunities.
    b) Evaluate the feasibility (costs, logistics) and benefits of using dredged material to restore subaqueous habitats.
2. Research, planning, and action are needed to advance the concept and implementation of **tidal wetland restoration** by the active method of thin-layer placement of sediment.
    a) Assess Delaware Estuary tidal wetlands for restoration needs.
        i. Collect and maintain detailed elevation data for Delaware Estuary tidal wetlands.
        ii. Assess the need for intervention, and prioritize on a regional scale.
            (1) Integrate results of assessment projects completed or currently under way (including USACE, The Nature Conservancy, and PDE).

        (2) Assess, rank, and map the tidal wetlands of the Delaware Estuary for elevation capital.
        (3) Assess possible future conditions in Delaware Estuary tidal wetlands in the absence of restoration.
        (4) Identify wetland sites that have sediment sources located nearby, since these may be considered for early implementation.
    b) Engage landowners and regulatory agencies to identify and address barriers to implementation of thin-layer placement, including regulatory impediments.
    c) Evaluate methods of thin-layer placement to understand how to optimize restoration outcomes.
    d) Evaluate where and how sediment (including dredged material) could be obtained for thin-layer placement in wetlands.
    e) Engage stakeholders to develop implementation opportunities, beginning with demonstration-scale project.

3. Research, planning, and action are needed to advance the concept and implementation of **shoreline restoration**.

    a) Assess, prioritize, and map Delaware Estuary shorelines for restoration needs. This includes areas where shoreline restoration would protect or restore adjacent tidal wetlands.
    b) Evaluate living shorelines demonstration projects, and use the results to improve the method.
    c) Continue research on living shoreline techniques, including hybrid techniques that involve construction of subaqueous sills or reefs.
    d) Engage stakeholders to develop additional implementation projects for living shorelines and hybrid projects.
    e) Promote engagement between USACE and states to implement the placement of dredged sand for beach nourishment, to meet the sand needs that have been identified by the states.

4. Understanding and controlling the **watershed sediment** load. [Also see Project Framework above.]

    a) Advocates of reducing watershed sediment loads should become familiar with the existing sediment reduction programs that are operating in particular watersheds. These may include regulatory or outreach programs in agriculture, land development, stormwater management, stream restoration, or dam removal.
    b) To follow on recent findings reported for the Chesapeake basin (Gellis et.al. 2008, Merritts et.al. 2010), detailed research about sediment storage behind historic dam sites in the Delaware basin may be warranted.
    c) Watershed planning should engage all stakeholders. Multiple purposes can often be achieved through cooperation between partners.

5. Beneficial Use (BU) of dredged materials for all categories of activity

    a) **Dredgers** may facilitate BU by:
        i. Evaluating each dredging project for its potential to support the implementation of beneficial use by direct placement.
    b) **CDF owners** may facilitate BU by:
        i. Managing placement operations so as to keep high-value dredged material segregated from other materials, and prevent dissimilar materials from being mixed together.
        ii. Collecting and maintaining information about sediment characteristics (e.g. grain size, contaminant concentrations) for material in the CDFs. Identifying areas where usable material exists, and providing this information to prospective users of material.
        iii. Consider ways to allow access to usable material currently in the CDFs.
        iv. Develop a marketing plan to increase awareness of the availability of usable materials.

c) **States** may facilitate BU by:
   i. Implementing regulatory incentives.
   ii. Clarifying regulatory requirements for beneficial use, to reduce uncertainty for project sponsors.
   iii. Coordinating between states to simplify project planning by project sponsors.
   iv. Being open to early engagement by sponsors of beneficial use projects.
   v. Considering the use of dredged material at state-sponsored restoration or remediation projects.

d) **Developers, construction contractors**, and other project sponsors may facilitate BU by:
   i. Considering dredged material as an alternative to other sources of aggregate for all kinds of construction, restoration, and remediation projects.
   ii. Understanding the special issues that come with using dredged material and being willing to work with the dredger or CDF owner to address implementation challenges.

e) **All stakeholders** should assist in public outreach activities to address the negative perception that many in the public have about dredged material being used for various beneficial uses in their communities.

6. <u>Beneficial Use of dredged material for ecological restoration [also see Project Framework above.]</u>

a) **All stakeholders** may facilitate beneficial use for ecological restoration by:
   i. Supporting regional restoration planning and related research.
   ii. Collaborating on the development of reasonable, region-specific technical criteria for the use of dredged material in habitat restoration.

b) **USACE** may facilitate beneficial use for ecological restoration by:
   i. Actively developing multiple-purpose projects that involve an ecosystem restoration component.
   ii. Engaging the USACE Regulatory branch to facilitate the permitting of beneficial use applications that require federal permits.

c) **States** may facilitate beneficial use for ecological restoration by:
   i. Being open to the use of dredged material for habitat restoration in projects that require state permits.
   ii. Developing projects on state-owned lands.

d) **Other resource agencies** may facilitate beneficial use for ecological restoration by:
   i. Developing projects on agency-owned lands.

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Restoration and Beneficial Use White Paper Committee

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Delaware Estuary
Regional Sediment Management Plan
White Paper

Appendix C:

DREDGING AND DREDGED MATERIAL MANAGEMENT

May 2010

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Table of Contents

Appendices

List of Tables

List of Figures

Acronyms and Abbreviations

BMPS	Best Management Practices
C&D Canal	Chesapeake and Delaware Canal
CDF	Confined Disposal Facility
Co-op	Delaware River Basin Fish and Wildlife Management Cooperative
CY	cubic yards
DMMP	Dredge Material Management Plans
DOTS	Dredging Operations Technical Support Program
Estuary/Basin	Delaware River Estuary/Basin
NEPA	National Environmental Policy Act
NJDEP	New Jersey Department of Environmental Protection
O&M	Operations and Maintenance
ODST	Office of Dredging and Sediment Technology (New Jersey)
RDT	Regional Dredging Team
RSM	Regional Sediment Management
RSMP	Regional Sediment Management Plan
RSMW	Regional Sediment Management Workgroup
USACE/Corps	U.S. Army Corps of Engineers

Introduction

Summary

This white paper on Dredging and Dredged Material Management in the Delaware Estuary was completed in support of the Delaware Estuary Regional Sediment Management Plan (RSMP). It is one of several white papers prepared in support of the RSMP.

The white paper is based on data collected from a variety of sources, primarily the U.S. Army Corps of Engineers (USACE/Corps), state agencies, and member groups from the Regional Sediment Management Workgroup (RSMW) and Regional Dredging Team (RDT) for the Delaware Estuary. Much of the data were provided by RDT, who is charged with tracking statistics on dredging in the Delaware River Estuary/Basin (Estuary/Basin).

The information contained in this document is meant to aid the RSMW in developing the RSMP, which will provide recommendations for sediment-related management in the Estuary/Basin. It is anticipated that the RDT will continue to update dredging-related data for use in evaluating trends, future needs and successes of recommendations implemented as a result of the RSMP. The RDT will also be integral to the team implementing dredged material management options related to beneficial use and restoration projects that result from the RSMP.

The white paper focuses on the following topics regarding dredging and dredged material management for all dredging projects in the Delaware River Basin/Estuary (federal/private, maintenance/new improvements):

> Dredging Methods/Procedures

> Dredge Material Management/Disposal (Placement) Alternatives/Options

Peer Review

This white paper was reviewed by the RSMW committee members as well as other representatives from the USACE Philadelphia District not serving on the RSMW. The white paper was also reviewed by members of the Delaware Estuary RDT.

Purpose

The purpose of this white paper is to provide support information and recommendations to the RSMW regarding dredging operations (methods) and dredged material management (disposal, beneficial use) for maintaining navigation channels and berths (federal and non-federal) within the Delaware Estuary/River and its tributaries (Schuylkill, Christina, Salem, Maurice Rivers, and others) for use in preparing a RSMP. It will address all dredging interests in the Delaware Estuary: federal and private (non-federal).

Goals/Objectives

The RSMW has developed goals and objectives for each of the four white paper topic. For dredging and dredged material management, the goals and objectives include:

> *Evaluate and continually improve dredging and dredged material management activities such that navigational (commerce) and recreational needs are met while meeting environmental protection/restoration/enhancement goals.*

At the root of these goals is that maintenance of navigation channels and berthing areas/facilities is a priority, and that dredging and dredged material management methods meet environmental standards. Both sediment and dredged material should be promoted as a resource for ecosystem needs.

Data Sources

Data sources are primarily the RDT and USACE Philadelphia District. The RDT has been charged with inventorying and reporting on data collected from the federal activities in the basin as well as private activities, which include those undertaken by state, municipal, and private operations/entities. Included in Appendix A and B are tables summarizing data collected and inventoried by the USACE on behalf of the RDT. Additional historical data is included as Appendix D and Appendix E (information from the Environmental Assessment for the Delaware River Main Channel Deepening project).

For several decades, the Philadelphia District has compiled data on volumes and quality of material dredged from the Delaware River/Estuary navigation channels and berthing areas. The USACE has also inventoried the volumes of dredged material used from federal projects/facilities for various types of beneficial use within the basin. Material has also been used beneficially by private dredging operations, but the volumes have not been quantified for this paper. The historical information shows trends that are useful in projecting future sediment management needs in the basin.

The Delaware Estuary/Delaware River Basin – Boundaries

The Delaware Estuary extends from Trenton, New Jersey to the Delaware Bay entrance (transect line between Cape May, New Jersey and Cape Henlopen, Delaware), covers an area of approximately 800 square miles, and encompasses land in the states of New Jersey, Delaware and the Commonwealth of Pennsylvania (Figure 1). The watershed of the Delaware River Basin encompasses a much larger area, and originates in headwaters in the state of New York. The Delaware River is situated in one of the most densely populated areas in the country while simultaneously hosting some of the country's most unique ecosystems and natural resources.

Federal Dredging Interests

Background

The Delaware River provides a commercial navigation route from Trenton, New Jersey, to the Atlantic Ocean. There are major ports at Philadelphia, Pennsylvania; Camden, New Jersey; and Wilmington, Delaware. There are also smaller commercial navigation facilities along the river as far south as Delaware City, DE and Salem, NJ. The navigation channel extends 133 miles from the mouth of the Delaware Bay to the marine terminal at Trenton, New Jersey (Figure 1). The Port of Philadelphia and associated regional ports and industries on the Delaware River (such as the Port of Wilmington in Delaware, and the Beckett and Broadway Terminals in New Jersey) support one of the busiest navigation corridors in the U.S.

Dredging activities along the Delaware River are dominated by the USACE, which needs to maintain federal navigation channels and berths. Federal channels for the Delaware Estuary are shown in Table 1. Navigation improvements to the river were first authorized by Congress in 1836. Deep- draft navigation projects in the estuary include: (1) Delaware River, Philadelphia, Pennsylvania, to Trenton, New Jersey; (2) Delaware River, Philadelphia to the Sea; (3) Delaware River at Camden, New Jersey; (4) Schuylkill River, Philadelphia; and (5) Wilmington Harbor, Christina River, Delaware. Figure 1 shows the Authorized Channel Alignment.

21 April 2011

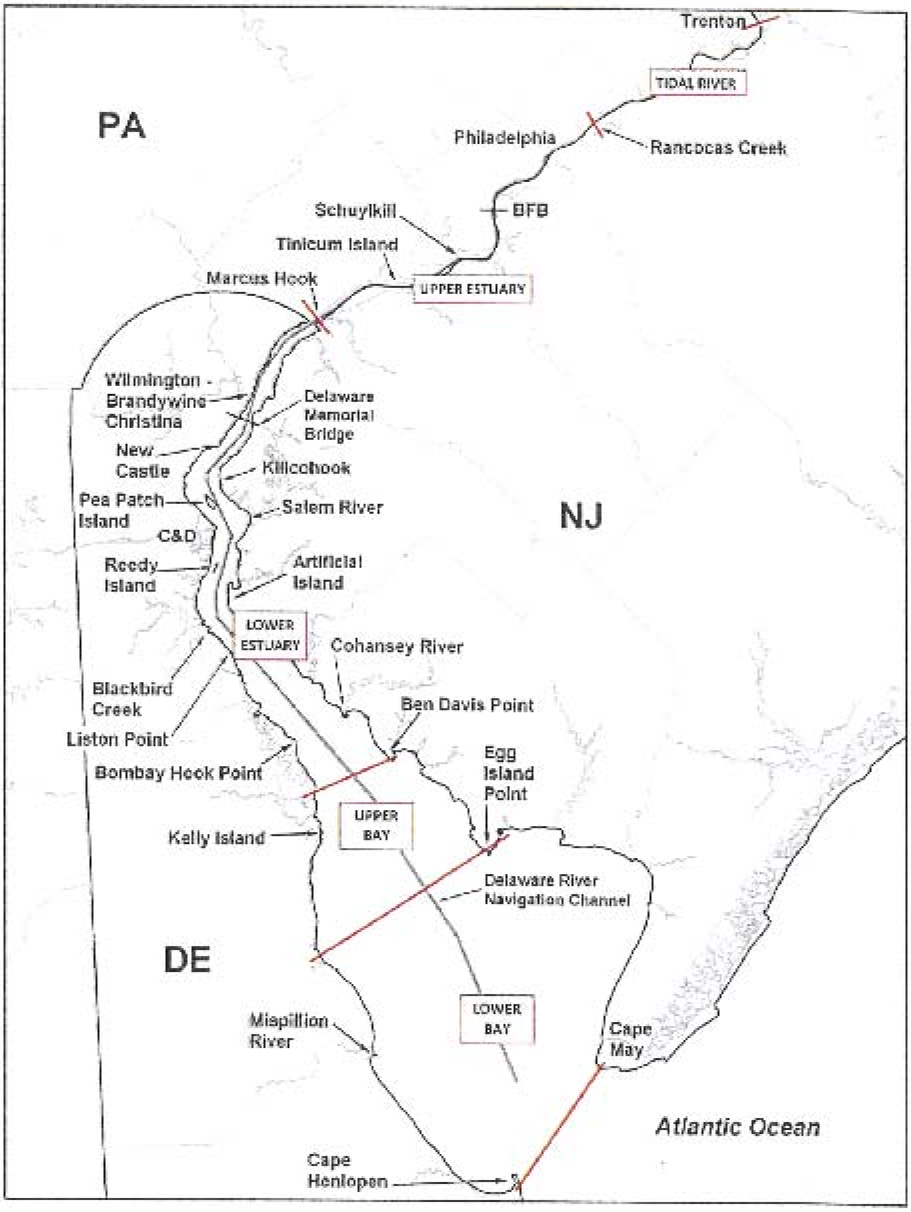


Figure 1 - Location Map

22

Figure 1: Federal Project/Ranges Locations Map

Table 1: Authorized Federal Channels for the Delaware Estuary

Project Description	Distance in Miles	Depth in Feet	Width in Feet
Delaware River	24	40	400
Philadelphia to Trenton	5	35	300
	1	varies	200
		(20-8)	
Delaware River	55	40	1000
Philadelphia to the Sea	43	40	800
	9	40	800 to 400
Delaware River	4	varies	800
At Camden		40 to 18	
Schuylkill River	3.5	33	300 to 400
	1	26	200
	2.5	22	200
Christiana River	1	38	340
Wilmington Harbor	0.5	35	400
	4	21	250 to 200
	4	10 to 7	200 to 100

There are also 17 anchorage areas between Delaware Bay and Philadelphia. Six of the anchorages are authorized under the Philadelphia to the Sea project; the remaining eleven are natural deep water areas. The authorized anchorages are located at Port Richmond, Gloucester, Mantua Creek, Marcus Hook, Reedy Point, and Deepwater Point.

Dredging in the Delaware Estuary has primarily been dominated by maintenance dredging over the last several decades (since the deepening of the main navigation channel to 40 feet). There are several proposals for new dredging activities in the Delaware River Basin/Estuary that include deepening of the Philadelphia to the Sea main channel to 45 feet, deepening of existing berths in this portion of the Delaware River, and several new berths (Southport Marine Terminal and the Port of Paulsboro) for commercial operations. Each is in a different stage in the process of approval/implementation or regulatory review.

Due to the physical dynamics of the Delaware River (described in detail in the *Sediment Quantity and Dynamics White Paper*), there are locations where sediment accumulates rapidly and must be frequently removed by dredging. These sediment “depo-centers” include the Marcus Hook, Deepwater, and New Castle Ranges of the Philadelphia to the Sea project, and the Wilmington Harbor project on the Christina River.

The USACE is responsible for maintaining federal navigation channels and anchorages. Maintenance dredging removes sediment that has accumulated in navigation channels and port berthing areas, reducing available depth and hindering navigation. Most of the present dredging in the Delaware Estuary is performed to maintain existing navigation channels, although some new dredging has been performed in the past two years as part of the plan to deepen the Philadelphia to the Sea project to 45 feet.

Because the Delaware River continuously transports sediment from upland areas in its watershed to the estuary, maintenance dredging is a near continuous process. Maintenance dredging of federal navigation projects within the estuary has averaged about 4 million cubic yards (CY) per year over the last decade, at a cost of approximately $8 million annually (averaging $2.00 – $5.00/CY). Material from maintenance dredging is almost exclusively placed onshore in diked areas called upland Confined Disposal Facilities (CDFs).

While approximately 95% of the maintenance dredged material within the Delaware Estuary comes from federal activities, dredging of private berth and access channels is also required periodically to maintain access between the main navigation channel and shore-based commercial/industrial and small craft harbor facilities (Section I-G). An average of about 350,000 cubic yards per year (5% of the total annual dredged material volume) is dredged from private facilities.

The principal types of dredges used on the Delaware River and its tributaries include (1) hydraulic cutter-head, (2) hopper, and (3) bucket. Appendix C is a summary of the types of dredging equipment traditionally used by the USACE Philadelphia District in the Delaware Estuary.

The majority of the maintenance dredging is performed by private contractors under USACE that use hydraulic cutter-head dredges. The hydraulic cutter-head rotates against the bottom sediment and a mixture of sediment solids and water is drawn in by suction. The dredged material slurry is then pumped through a pipeline and discharged into an upland CDF. The swing speed of the dredge is monitored and controlled to minimize turbidity at the cutterhead. Some of the Delaware River dredging is done by the Hopper Dredge *McFarland*, which is managed by the Philadelphia District, USACE.

In the Philadelphia to Trenton project, most dredging is performed with contractor-operated hydraulic pipeline dredges, although the *McFarland* has been employed on several occasions over the past decade. The hydraulic pipeline dredges are of the cutter-head type.

The USACE hopper dredge *McFarland* is a seagoing vessel equipped with centrifugal pumps that draw in a mixture of water and excavated material through vacuum suction. The material is discharged into hoppers contained in the hull of the vessel, without overflow. During loading, economics dictate close controls of the suction depths and the speed of the vessel, which results in minimal turbidity at the suction head. When full, the *McFarland* proceeds to a mooring barge and discharges its loaded hoppers through a pipeline to an upland CDF. Prior to about 1955, dredged material was typically bottom dumped into subaqueous basins from which it was later pumped ashore by a pipeline dredge. At present, essentially all dredged material is discharged directly into CDFs.

Dredging of private berth and access channels is also periodically required to maintain access between the main channel and shore-based commercial/industrial facilities. An average of about 350,000 cubic yards per year is dredged from private facilities. Although not a federal maintenance activity, private birth and access channel dredging is controlled and regulated by both federal and state permits and includes both industrial/commercial maintenance and small craft harbor maintenance. The permit process requires compliance with current environmental statutes including the National Environmental Policy Act (NEPA).

The USACE initiated a program several decades ago to develop a cost-effective and sustainable long range dredged material disposal plan that resulted in the development of a series of federally-owned upland CDFs for the Philadelphia to the Sea project. Historically, these facilities have been able to handle the maintenance needs for the federal activities at a reasonable cost. However, despite these planning efforts, the capacity of some of the currently active upland CDFs within the estuary is potentially limited. To date, the USACE has regenerated capacity in some upland CDFs by raising the berm heights and through limited beneficial use practices. The beneficial use of dredged material excavated from these upland CDFs creates renewable capacity. Projections (detailed in the *Sediment Quantity and Dynamics White Paper*) indicate CDFs have the capacity to manage expected needs for federal dredging for maintenance and potential new projects provided capacity continues to be regenerated in some of the priority use CDFs. Information on the projections for capacity is included as Appendix A.

In selecting dredged material disposal sites, the USACE coordinates with the various agencies charged with protecting the environment. Potential new disposal locations that are key fish and wildlife areas have been removed from consideration. Factors taken into consideration for disposal area selection focus on the effect of the disposal area on the local environment. These factors include the potential impact of the disposal area on fish and wildlife, water pollution, estuary ecology, recreation, economics, and planning requirements/needs of the local community. The selection of a proposed disposal area is coordinated with local and regional planning commissions, the Delaware River Basin Commission, and federal and state environmental protection/resource agencies. The USACE has not constructed any disposal areas in wetlands for the Philadelphia to the Sea project in the last 65 years; likewise, no disposal areas have been constructed in wetlands along the Philadelphia to Trenton channel in the last 50 years. Similar disposal area selection criteria and considerations have been evaluated historically for private sector solutions to the disposal of dredged material.

These practices have directed disposal activities that would have negative impacts on habitat away from wetlands and other vital habitats in the estuary. However, the site selection process has also directed dredging managers away from disposal projects that could potentially improve wetlands or other habitats through beneficial use.

The USACE has tracked dredge material volumes/statistics from the navigation channels and berth areas for years. Trend data are included in Appendix A and details described in the *Sediment Quantity and Dynamics White Paper*. Appendix F is a table from the April 2009 Environmental Assessment for the Delaware River Channel Deepening Project that provides additional data on dredged material volumes.

Projections for the Main Stem Channel Maintenance include approximately 3 million cubic yards of material to be dredged each year over the 5- to 10-year planning period. Theoretically, future maintenance dredged material volumes are anticipated to remain the same. During the 5 to 10 year planning window as in the last few years, maintenance dredged material volumes are projected to increase once the Main Channel Deepening project is completed. In the absence of other dredging projects, almost all existing upland CDFs have the capacity to manage the projected need for the Philadelphia to Sea reach (exceptions include Wilmington South); especially if materials contained in the upland CDFs can be beneficially used in an appropriate time period. From a planning perspective, any beneficial use projects that upland CDF managers are able to implement will only add to the available capacity for future activities.

Philadelphia to the Sea

The Philadelphia to the Sea project is currently maintained at a depth of 40 feet, with proposed deepening to 45 feet. There is over 100 million tons of waterborne freight travel on this important route annually. The regional economy is highly dependent on maintenance of the Philadelphia to the Sea navigation channel to depths sufficient to support deep draft vessels.

The Philadelphia to the Sea project requires the largest portion of maintenance dredging in the estuary, typically between 2 and 3 million cubic yards annually. The cost of dredging using current approaches/operations depends on the distance between the dredging operation and the disposal site. Disposal areas nearest to a dredging site are used most frequently. The repetitive and frequent use of these facilities requires more frequent management of the material at the site. In recent years, beneficial re-use of dredged material dewatered in upland CDFs has helped keep operation and maintenance costs down.

Dredged material from federal activities in the Philadelphia to the Sea project is disposed of in a series of federally-owned upland CDFs (Figure 2). The active federal government-owned disposal sites for maintenance dredging in the estuary, listed in down-river order from Philadelphia, are: Fort Mifflin, National Park, Pedricktown, Penns Grove, Penns Neck, Killcohook, and Artificial Island. Artificial Island is presently used only when dredging is performed in the Reedy Island Range area. Figure 2 shows that the largest federally-owned CDFs, representing most of the available dredged material disposal capacity in the estuary, are located in close proximity to the Delaware River main navigation channel reaches where most of the dredging is conducted.

One open-water disposal area, located near Buoy 10 west of Cape May, NJ, is maintained in the lower Delaware Bay to permit disposal of a small amount of material resulting from shoaling near that location. The amount of shoaling in this range varies so dredging does not occur on a regular basis. Approximately 500,000 cubic yards are dredged every 5 years in the lower Delaware Bay, all of which goes to Buoy 10.

The USACE dredged material managers indicate that under current procedures/economics/policies/ infrastructure, the most critical problem for dredged material management is to locate disposal sites close to the areas of greatest shoaling. Four high shoaling-rate locations within the navigation channel (sediment “depo-centers”), all of which lie in a 30 km reach from the Chesapeake and Delaware Canal (C&D Canal) upstream to Marcus Hook, require about 80% of the maintenance dredging within the entire estuary.

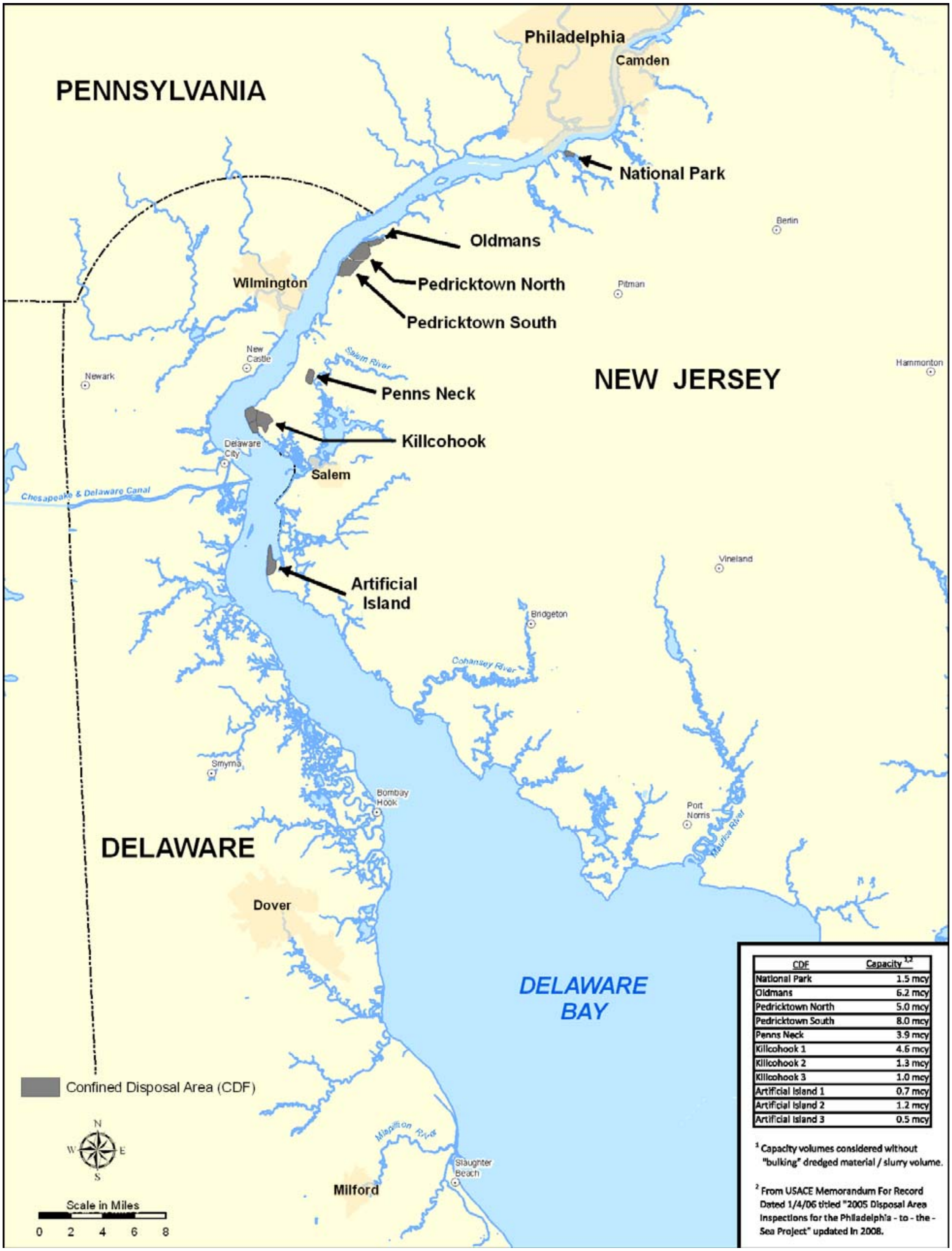
Philadelphia to Trenton

The Philadelphia District is required to maintain the Delaware River federal navigation channel from Allegheny Avenue in Philadelphia to Trenton, New Jersey. The table in 1F shows required depths of the reaches. The majority of the reach is maintained to 40 feet. The Philadelphia to Trenton section of the Delaware River was last dredged in 1993, which equates to approximately 900,000 CY of material each dredging cycle. However, emergency dredging of critical shoals was performed in 2007.

Pennsylvania and New Jersey are required to provide the disposal sites for their respective portions of the river (Figure 2). New Jersey, under Chapter 18, Laws of 1956, agreed to furnish, free of cost, all lands, easements, rights of way, and dredged material disposal areas within the state. The portion of the Delaware River in which New Jersey has provided upland CDFs extends from Allegheny Avenue, Philadelphia, PA to the New Jersey Turnpike Bridge over the Delaware River in Florence, New Jersey. Pennsylvania provides suitable disposal capacity to support USACE maintenance dredging operations along both the upper reach of the 40-foot channel and in the 25-foot project channel, which is intended solely for use by New Jersey port facilities. In addition, a partnership between Pennsylvania, Waste Management Inc., and the USACE aimed at the beneficial use of dredged material removed from the upper reach of the 40-foot channel continues to be managed successfully, resulting in the annual placement (beneficial use) of approximately 500,000 CY on nearby landfills for use as daily cover.

There are nine dredged material upland CDFs located on the Delaware River between Philadelphia and Trenton. These facilities are not federally owned, but are provided by lease from the Commonwealth of Pennsylvania and the state of New Jersey. All (100%) of the dredged material placed at the Money Island site is beneficially used for daily cover at a nearby landfill managed by Waste Management, Inc. Seven existing locations that were previously used for dredged material disposal have not been maintained by the New Jersey Department of Environmental Protection (NJDEP). In 2008, NJDEP agreed to implement a dredged material management plan for the New Jersey section of the Delaware River to facilitate the re-establishment of the upland CDFs.

Figure 2: Federally Owned CDF Locations and Capacity



CDF	Capacity[1,2]
National Park	1.5 mcy
Oldmans	6.2 mcy
Pedricktown North	5.0 mcy
Pedricktown South	8.0 mcy
Penns Neck	3.9 mcy
Killcohook 1	4.6 mcy
Killcohook 2	1.3 mcy
Killcohook 3	1.0 mcy
Artificial Island 1	0.7 mcy
Artificial Island 2	1.2 mcy
Artificial Island 3	0.5 mcy

[1] Capacity volumes considered without "bulking" dredged material / slurry volume.

[2] From USACE Memorandum For Record Dated 1/4/06 titled "2005 Disposal Area Inspections for the Philadelphia - to - the - Sea Project" updated in 2008.

Recently, the NJDEP Office of Dredging and Sediment Technology (ODST) initiated an evaluation of the seven existing upland CDFs, as well as other potential dredged material disposal sites proximate to the Delaware River. The ODST coordinated with various natural resource agencies, and determined that the following four upland CDFs appear to be most promising for use as disposal sites for the Philadelphia to Trenton project, while also meeting the USACE dredging equipment specifications (Figure 2):

- Delanco/Beverly CDF (#3)
- Cinnaminson CDF (#5)
- Burlington Island CDF (#2)
- Palymra Cove CDF (#6)

The ODST performed a title search of each of the above referenced disposal sites, and it appears that portions of a particular site(s) may not be entirely owned by the state of New Jersey. Specifically, certain portions may be owned by a municipality or deeded to other persons and still show unresolved tideland conveyances present on the property.

Wilmington Harbor

Approximately 750,000 cubic yards of dredged material are removed yearly from the Wilmington Harbor federal channel and associated private berth area. In recent years, the removal of one million cubic yards of dredged material has been a challenge due to funding issues.

Wilmington Harbor is dredged by contractor-operated hydraulic cutter-head dredges, using Corps-furnished dredged material disposal areas. These disposal sites include the Wilmington Harbor North and Wilmington Harbor South disposal areas at the mouth of the Christina River. These upland CDFs may not have capacity for projected maintenance needs, and alternatives are being evaluated.

Schuylkill River

Maintenance dredging of the Schuylkill River, by the USACE, is limited to the navigation channel from the Delaware River to University Avenue, Philadelphia. Before the 1970s, a coal culm removal project continued to remove deposits resulting from upstream coal mining activity. The Schuylkill River project is maintained by contractor-operated hydraulic cutter-head dredges. The typical maintenance cycle is about two years, with a dredged material quantity of 200,000 to 300,000 cubic yards. The dredge material is placed in the Fort Mifflin CDF. In recent years, dredging has not occurred every two years due to lack of funding.

Salem and Maurice Rivers

Although the Salem River and Maurice River are authorized federal navigation channels, the USACE has not conducted maintenance dredging of these two projects for some time. In the past, when the Salem River was dredged, material was sent to the USACE Killcohook Upland CDF for disposal.

Private/Non-federal Interests

In addition to the federal navigation channels and anchorages in the Delaware River, there are a number of private/non-federal interests that are an important component of the economy along the river and require routine maintenance dredging. These entities include private industrial berths for off-loading oil/gas products, marinas for recreational boating or commercial fishing, and municipal and state-owned marinas and berths.

Maintenance dredging for these activities totals approximately 350,000 cubic yards of dredged material a year, a small fraction of the total dredged from the estuary. The maintenance of these private areas has a significant impact on the economy along the river. Private/non-federal interests have been responsible for providing their own dredged material disposal sites, or have collaborated in certain reaches of the river to use a centralized disposal area. Due to the relatively small volumes of dredged material, the private/non-federal entities often rely on cooperation and coordinating dredging activities to reduce the cost of dredged material management.

Many of the private/non-federal interests have contracted dredges that historically disposed of dredged material at a private disposal facility called White's Basin. This facility has not been available for a few years as the property owner, America Atlantic, addresses local and county issues and explores potential sale of the property. Recently, the site was made temporarily available for private users.

Multiple viable alternatives for private sector dredged material disposal and/or beneficial use are needed. The USACE is working with private/non-federal interests to develop a short term plan that will allow them to use the federal disposal facilities contingent on the removal of existing dredged material from the upland CDFs prior to the disposal of dredged material from the private berths.

The USACE has tracked dredge material volumes/statistics from the private berths for years and analyzed for trends (Appendix A). Details are described in the *Sediment Quantity and Dynamics White Paper*.

Projections are for approximately 350,000 cubic yards of dredged material a year over the 5- to 10-year planning period. The private berths need a plan for disposal. Maintenance dredging has not been completed for several years (except at sites that have a private disposal facility) due to the temporary closure of White's Basin. Efforts are under way on several fronts to find options for these private entities. Some of the efforts include:

- Temporary use of federal facilities based on a commitment to remove an equal quantity of material for beneficial use prior to disposal.
- NJDOT is conducting a study to inventory previously approved disposal facilities for potential use by the state or other entities. The re-establishment of these disposal facilities has presented challenges due to the state permitting criteria and opposition by local municipalities.
- Searches for beneficial use projects.
- Searches for multiple disposal facilities and/or beneficial use sites in addition to White's Basin.

There is an effort underway by NJDOT to evaluate the potential use of abandoned/formerly used upland CDF sites. These sites were developed by various entities over the years prior to the USACE upland CDF site development program and the use of White's Basin. The NJDOT is evaluating former CDFs owned/maintained by the state of New Jersey or private entities that have been abandoned for retrofit potential. The potential for retrofits is being assessed specifically for maintenance dredging activities for private/non-federal berths. The assessment is also inventorying available dredged material for the beneficial use market. New Jersey has indicated that retrofitting presents several challenges, the primary one regulatory. The current approach to wetlands delineation on these managed sites, and in some instances the use of these managed sites by protected species, presents challenges. Other challenges include retrofit construction costs and testing of the dredged material.

Private/non-federal interests are required to obtain permits from the USACE and appropriate state agencies for their dredging and dredged material management activities. The permitting process ensures the projects comply with current environmental statutes and NEPA. The permits include conditions on the activities, dredging methods specifications, disposal area(s), dredging windows (seasonal restrictions), and other management requirements to address environmental protection concerns.

Sediment as a Resource

The RSMW considers sediment/dredged material to be a resource, which is integral to planning dredging and dredged material management activities. This view of sediments as a resource raises interesting considerations concerning the current assessment, regulations, potential markets for, and uses of dredged material. As described in the *Sediment Quantity and Dynamics White Paper*, sediment dynamics are an important process for maintaining the health of the Delaware River/Estuary ecosystem. A formal integrated sediment management program would facilitate the selection of location and determination of volume and frequency required to dredge and maintain navigation channels and berths. A sediment transport model has not been developed. If completed, it could present a great step forward in understanding these processes and refining recommendations made by the RSMW.

While it is recommended that sediment be considered a resource, historical activities have long affected sediment distribution or quality/composition through upland disposal/sequestration or due to contamination. Each of these activities affects potential use of some sediment as a viable resource. The *Sediment Quality White Paper* has conducted a planning-level evaluation of the suitability of sediments for aquatic habitat and potential upland beneficial uses of dredged material. Specific potential beneficial uses of sediment resulting from dredging operations are considered in the *Restoration and Beneficial Use White Paper*.

Currently, various federal regulatory and resource agencies, and their equivalents in each of the three states bordering the Delaware River/Estuary (DE/NJ/PA), have independent regulatory programs to manage dredged material that differ from one another in some significant ways. These differences can present challenges for the USACE and other organizations that perform dredging making it difficult to develop a single consistent program for the comprehensive management of sediment and dredged material in the Delaware Estuary/River Basin. In particular, some regulatory agencies consider sediments to be pollutants or solid waste, and manage them accordingly. Overcoming these challenges, and developing a common vision of sediment and dredged material as a valuable resource, will facilitate many opportunities for dredged material management.

Advocacy

The RSMW is encouraging continued support of the economic vitality of the region through maintenance of navigation channels and berthing areas, and promoting the use of dredged material as a resource to be employed for environmental restoration and beneficial use projects. The RSMW also supports the use of dredging and dredged material management activities that consider the effects of sediment dynamics on the Delaware River/Estuary ecosystem.

In order to realize increased dredged material beneficial uses and sediment reduction strategies in the Delaware Estuary/Basin, and to positively impact dredging operations in the Estuary/Basin, an advocate like the RSMW or Partnership for the Delaware Estuary will be needed to facilitate such policy and programmatic changes.

RSMP Workgroup/Regional Dredging Team

Dredging and dredged material management are being evaluated in the Delaware Estuary by the RSMW and the RDT. The USACE has established these groups as part of a strategic plan to address not only regional sediment management, but also the beneficial use of dredged material within the Delaware Basin/Estuary. The RSMW is looking at long term planning for dredging operations and management of the resultant sediments, as well as sediment sources in general in the estuary/basin. The RDT is primarily focusing on day-to-day operations and activities, tracking dredging projects and disposal facilities, and monitoring permit actions to ensure navigation needs are met.

The RDT has, and will continue to provide, data to the RSMW regarding dredging activities/statistics in the Delaware Basin/Estuary. Throughout their projected life span, the two groups will continue to meeting to discuss dredging activities in the basin.

Upon completion of the RSMP, RSMW anticipates conducting an implementation workshop to identify the strategies, programmatic approaches, funding framework, and preliminary types of projects to consider during the initial planning phases of RSMP implementation. The RSMP implementation workshop is intended to provide opportunities for collaboration and inclusion of various entities throughout the Basin/Estuary. The RDT will serve a significant role in promoting and tracking dredging and dredged material management components of the RSMP implementation.

Background – Estuary/River Basin Sediments

Sources of Sediment in the Delaware

Sources of sediment and sediment processes/dynamics within the Delaware River Estuary/Basin are discussed in the *Sediment Quantity and Dynamics White Paper*. To understand the dredging regime in the Delaware River, the source and quality of the sediments in the channel needs to be understood. The following summary provides context to the sources of sediments which affect the dredged material management approaches discussed in this paper.

Sediment sources in the Delaware River affecting navigation channels/berths include:

- Upland sources from exposed soils in the upper watershed
  - Non-point sources such as agriculture or construction sites
  - Point sources such as combined sewer outfalls
- Erosion of stream banks from contributing waters
- Erosion from the banks of the Delaware River, including fringing marshes
- Scouring of the river bottom.

Sediments entering the basin originate from sites of varying land cover/uses such as: agriculture, residential/commercial development, silviculture, urban centers, industrial sites, and others.

Information developed by the USACE indicates the sources of new sediment in the basin primarily originate from the Delaware River above Trenton (59%), with 14% from the Schuylkill River, and 4% from the Christina River.

General Sediment Characteristics

Characteristics of the sediment in the Delaware River Basin/Estuary are described in the *Sediment Quantity and Dynamics White Paper* and the *Sediment Quality White Paper*. In general, the Delaware Estuary is a muddy (fine particulate) system in its upper reaches. Sediment entering the aquatic ecosystem comes from a variety of soil associations. The mechanics of transport within the basin tend to affect the distribution and types of sediments found in any given location in the navigation channels and berth areas. The character and composition of the sediments varies depending on the location in the basin. There are some pollutants of concern at elevated levels at specific locales that may require targeted management approaches. Material dredged from the navigation channels is generally of suitable character for various uses including: construction; beach nourishment; fill for development; ecological restoration; and others.

The quality of the sediments in the estuary is generally suitable for a variety of beneficial uses. The *Sediment Quality White Paper* contains a planning-level discussion of the characteristics/quality of the sediment within the estuary. The data evaluated in the *Sediment Quality White Paper* indicates that almost all of the sediments may be suitable for some type of upland use, while a significant portion of the sediment appears to be suitable for aquatic habitat uses. There are significant opportunities for alternative beneficial use/restoration projects within the basin, which could affect future dredged material management strategies. Potential upland and aquatic uses for sediment are discussed in the *Restoration and Beneficial Use White Paper*. Large volumes of dredged material from the navigation channels are potentially suitable for various uses, including construction; beach nourishment; fill for development; ecological restoration; and others.

Matching Material and Use

There is currently a significant inventory of sediments available for use in the federally-owned and operated upland CDFs. There is an inventory of abandoned and currently serviceable state and private disposal facilities along the Delaware River Estuary with a significant volume of sediments available for use. Additionally, maintenance dredging for both federal and private sector needs will generate significant volumes of material for disposal/use in the near term, and likely in the long term. Under current practices, dredged material is disposed in upland CDFs. If beneficial use is contemplated, for the most part it will result in of removal of dredged material from the CDFs after dewatering. The disposal facilities were sited initially so as to optimize dredging operations – they are the most efficient locations for known maintenance or improvement activities - and are not necessarily optimized in locations for ease of the beneficial use of dredged material. Although the original siting of the upland CDFs was not based on beneficial use considerations, many of these facilities, such as Fort Mifflin and Money Island, have provided dredged material for beneficial use projects.

As described in the *Restoration and Beneficial Use White Paper*, there are a variety of opportunities for the beneficial use of dredged materials to restore ecosystems, to be used as construction materials, and other potential uses. Matching the materials dredged to appropriate uses (both from a physical character and chemical quality perspective) is not always easy, especially considering the locations of disposal facilities and dredging operations compared to the areas of potential need for sediment (dredged material). *The Sediment Quality White Paper* discusses the results of a planning-level approach evaluating the suitability of sediments for potential types of beneficial uses. The *Restoration and Beneficial Use White Paper* discusses potential restoration opportunities and beneficial use strategies for various locations within the Delaware River Basin/Estuary.

The Dredged Material Management System (DMMS), under development by the NJDOT, is intended to offer a marketplace for matching potential beneficial use projects with available and suitable dredged material. The state of New Jersey is currently undertaking an extensive effort to characterize and quantify the dredged material in upland CDFs and to evaluate their potential for beneficial use.

Planning

Policy/Program Considerations

For USACE directed operations, the USACE is required to meet federal standards for identifying *the most* environmentally acceptable least cost option (33 CFR Part 335). Private entities are required to obtain dredging permits from the USACE Regulatory Branch (Section 404/401 and 10 authorizations), as well as applicable state regulatory programs. Private/non-federal entities are required to evaluate potential alternatives and identify least environmental impact solutions. The states in the Delaware Estuary/Basin (Pennsylvania, Delaware and New Jersey) each have programs regulating activities, including dredging, in their waterways and programs for the disposal of sediments generated from these dredging activities. Each state evaluates sediment differently and each has different standards for defining sediment quality for potential use.

Dredged Material Management Plans (DMMP)

Dredged Material Management Plans a federal term based in legislation are typically required if a federal navigation project does not have the projected/planned capacity to meet 20 years of dredging activities pursuant to navigation mandates for federal channels/berths. The Delaware River/Estuary is unique in that existing upland CDFs are projected to be able to manage the 20 year projection for the Philadelphia to the Sea projects/reach. The USACE Philadelphia District has developed a long range disposal plan through construction of upland CDFs of sufficient size and location to meet needs. This has created challenges for beneficial use options within the Delaware Basin/Estuary.

The USACE has disposal site capacity issues for the Christina River. A DMMP is being prepared by the USACE for this navigation project and should be finalized in the future.

Although a DMMP is not required for the Delaware Estuary, agencies involved in the RSM Plan preparation and RDT have identified the need for a DMMP for the upper basin (Philadelphia to Trenton). Section IF-3 has a detailed discussion of the factors contributing to the need for a DMMP in this location.

Scheduling/Coordination – Logistics

A challenge facing dredge material management program managers is scheduling projects to optimize dredging “windows” (time periods without environmental restrictions on dredging), equipment mobilization/demobilization, and beneficial use projects. In addition to direct cost savings benefits from piggy backing private projects onto federal projects for operational efficiency, there are benefits in the minimization of disruptions to the environment and in the optimization of potential beneficial use.

Another potential benefit of “piggy backing” may be the indirect ability to justify what have generally been described as additional costs associated with conducting beneficial use/restoration projects. These costs are typically not considered feasible when completed solely by the USACE due to the federal standard for determining/using least cost options.

A long range plan connecting dredging with beneficial needs will facilitate some of the logistical challenges identified.

Potential Dredging Projects

The stakeholders recognize that there may be the need for new dredging (beyond current/historical maintenance activities) within the Delaware Estuary. While the RSMW can neither identify all of these projects nor attempt to inventory them, there is a recognition that the RSMP needs to take into account approaches for managing future dredging needs. It is important to consider facility capacity and alternatives for disposal in the Delaware River/Estuary.

Some potential major projects have been identified and are discussed below (for this paper, no position has been taken on these projects – rather recognition of the types of projects and the magnitude of sediments that could potentially require management are considered).

Main Channel Deepening

One potential federal project that could have significant impact on the dredge material management within the Delaware Estuary is the proposed deepening of the Delaware River Main Channel from the current 40 foot depth to 45 feet. Based on current data, this project could generate an additional 16 million cubic yards of material for the initial deepening and 3.6 million cubic yards for maintenance annually (total projected future maintenance volumes). Appendix D contains additional details.

Dredge material managers from the USACE indicate that there is sufficient capacity at the existing facilities to dispose of new material. Alternative options such as beneficial use and direct disposal options/alternatives for beneficial uses should be explored.

New/Expanded/Retrofit Berths

Several private projects that may affect dredged material management in the near term have been identified based on inquiries to the USACE Regulatory Branch and the Operations Division. Some of the larger projects include:

- Philadelphia Airport, which runway expansion may require partial removal of an existing CDF. The eliminated capacity will be replaced with equal or more capacity for maintenance material. The final location has not been secured.
- Hess LNG facility (former BP site) that may generate approximately 800K to 1M CY of material for disposal/beneficial use.
- Existing refinery/port berth deepening may be required to accommodate larger vessels.
- New dredging for port terminal development (Southport and Port of Paulsboro).
- Other undefined needs.

The total amount required by these projects is undetermined, but will be tracked by the RDT. The RSMW, in conjunction with the RDT, will provide strategies for dealing with increased dredge volumes beyond those required for maintenance of the federal navigation channels.

Operations

Historical/Current Operations

Figures 1 and 2 depict the major maintenance dredging projects and navigation ranges for the federal navigation program, and the locations of private/non-federal berths within the Delaware Estuary. Historic operational dredging methods and dredged material disposal procedures are described below.

Dredging Methods

Current federal methods for dredging are summarized in Appendix C.

Private sector methods vary and are based on sediment quantity, disposal location, ability to piggy back with other private projects, etc. state and federal permit requirements usually stipulate the type of dredging methods acceptable for private actions.

Best Management Practices (BMPs)

For current federal actions, BMPs such as turtle excluders, on board water handling, transport storage practices, etc., which have been developed in conjunction with the federal and state resource agencies, are used for dredging. BMPs are typically specific to the individual dredging method/equipment being employed and type of disposal facility.

Private/non-federal entities are required to incorporate BMPs into their dredging plan through the regulatory approvals from the federal and state agencies with jurisdiction over dredging.

The USACE is evaluating alternative BMPs for dredging operations. These same technologies are also being evaluated by the USACE Philadelphia District for inclusion into their dredging operational plans. The USACE has an agreement with the Dredging Operations Technical Support Program (DOTS) to evaluate current operations and provide recommendations on alternative BMPs. The DOTS effort may be supplemented with additional evaluations, pending results from the DOTS study (anticipated end of 2012 fiscal year). Results of the DOTS study will be shared with the RDT and RSMW for inclusion/consideration in the development of recommendations for the RSMP.

Equipment

Appendix C describes in detail the type of equipment that is needed to conduct federal navigation channel dredging. This is often the same equipment that is used for private/non-federal actions. Alternatives for private dredging on a smaller scale include bucket, clamshell buckets, and environmental closed clamshell buckets.

The USACE owns and operates the Federal Hopper Dredge *McFarland* which is used for various maintenance activities in all coastal environments within the U.S. *McFarland* is mandated for use on the Delaware River for 70 days per year for training purposes. Training activities are funded annually on the Delaware River/Estuary from Philadelphia to the Sea if sufficient funds are appropriated to the Delaware River – Philadelphia to Sea project.

Disposal Options

Disposal options have historically varied and been different in the basin for federal and private dredging operations. As described earlier, federal maintenance of navigation channels has traditionally used federally owned CDFs for disposal with limited beneficial uses opportunities. These facilities have a significant capacity, especially when the existing sediment inventory can be used beneficially. Private sector operations, except for limited small scale operations that dispose of material on site in uplands, have used White’s Basin for disposal. Multiple disposal and beneficial use alternatives are needed for the private sector.

Best Management Practices – Water Quality

By regulation, operations at federal upland CDFs implement best management practices for water quality. Some innovative BMPs have been used in other locations for small scale upland CDFs that can provide additional water quality benefits. BMPs for water quality will be evaluated by DOTS. The DOTS study will help USACE determine technologies that may be appropriate for use at the existing upland CDFs in the Delaware Estuary.

Private disposal permittees operate under permits from the USACE and the states. Water quality BMPs are conditional in these permits. Inspection and enforcement requirements are included in the permits. Pennsylvania’s Standard Operating Procedure 2005, for use of disposal areas, captures details on water quality requirements, effluent limits, and BMP practices.

Material Segregation

For most upland CDFs, dredged material is blended during disposal operations. Pilot projects have begun to intentionally segregate materials generated from different sources so as to deliberately separate material based on sediment chemical quality, physical characteristics, and composition to facilitate beneficial reuse.

Regulatory Considerations

Federal dredging operations are statutorily required to satisfy the federal acts and orders pertaining to dredging and dredged material disposal, management, and beneficial use. The federal agencies have to demonstrate compliance with NEPA, the Clean Waters Act, the Rivers and Harbors Act, and the Coastal Zone Management Act. Private/non-federal operations must also comply with Section 404 and 401 of the Clean Waters Act, and Section 10 of the Rivers and Harbors Act. They must also comply with state laws and regulations for the state in which the material is being dredged and disposed of, or beneficially used.

The regulatory programs set standards for dredging methods, seasonal restrictions, location of disposal, and the BMPs for operating the disposal sites. Generally, the private entities use existing upland CDF sites or upland disposal sites, which limit their permitting requirements. The development of any new upland CDFs requires permits from the federal and state regulatory agencies, in particular for water quality certification.

Potential Alternatives/Opportunities

This section discusses potential innovative alternatives/opportunities for dredging methods and dredged material management in the Delaware Estuary. Sediment quality, particularly in reference to the dredged materials' chemical composition (i.e., contamination), can affect the dredging methods and ultimately, the dredged material management options.   Methods to limit the re-suspension of sediments and any associated contaminants into the water column after disposal vary and are dependent on the type and concentration of the contaminants. Testing of dredged material following standard protocols is required to determine contaminant concentrations, and will ultimately determine management options.

Dredging Methods

Equipment

Dredging equipment is limited and only certain dredging technologies are currently practical for use in the estuary. The transport distance to upland CDFs from dredging locations influences the types of equipment that can be used. As a practical matter, there is also a market constraining factor: at this time, commercial dredging operators only have certain types of equipment, which is usually in high demand.

The USACE owns the Hopper Dredge *McFarland,* which could perform up to 70 days of navigation maintenance dredging in the Delaware River. Those 70 days of dredging have been legislated to maintain *McFarland*'s Ready Reserve Status in the event of a national emergency (for example, berm construction associated with the B.P. Gulf of Mexico Oil Spill). Maintaining *McFarland*'s Ready Reserve Status allows this piece of equipment to conduct various types of dredging and disposal operations in the estuary.

There are alternative methods of dredging that have not been tried in the Delaware River/Estuary. Water injection dredging is appropriate for streams with distinct hydraulic dynamics, morphology, and sediment characteristics. Dredging managers from the USACE indicate water injection dredging would likely only be appropriate within the Delaware Estuary for the Christina River (based on initial assessments and understanding of the various locations typically requiring routine dredging). Further evaluation of the potential use of this method in the Delaware Estuary/Basin is recommended.

Another non-traditional alternative is to reduce dredging volumes by limiting the amount of sediment reaching areas traditionally in need of maintenance dredging. Alternatives include bypassing sediments from the water column to locations downstream of areas where large volumes of sediments typically deposit over short time periods (i.e. sediment depo-centers). This alternative requires further evaluation, but a demonstration project using *McFarland* could potentially be implemented. Sediment bypassing presents some challenges, including a requirement for continuous year round application, permitting for appropriate discharge locations, and cost relative to other methods.

Another alternative is to pump sediments directly from the zone of maximum turbidity in the Delaware River to downstream marshes through thin layer application. This beneficial use/restoration alternative is being evaluated by the RSMW and member organizations for applicability/feasibility in the Delaware

Estuary/Basin. Challenges include reducing the energy needed to pump long distances appropriate for thin layer placement of dredged material, and not eroding the marshes (USACE, 2011). This alternative is being evaluated by the RSMW for a demonstration project.

Each of these alternatives assumes larger benefits for all navigation channels/berths. There are a variety of methods currently being used by the private/non-federal sector. There appears to be an opportunity to realize these broader benefits for private actions as well. Efforts to connect private dredging operations with federal activities could broaden the benefits to be realized by federal alternatives. Alternatives for the private dredging operations would need to be evaluated on a case by case basis absent this coordination.

Dredged Material Management Options

Disposal alternatives/opportunities primarily consist of beneficial use/restoration or methods described above.

Innovative Technologies

Innovative technologies include the pumping of sediments directly to restoration/beneficial uses, thus eliminating the need for upland CDFs or other intermediate dredged material management strategies (USACOE, 2011). Another innovative approach is to reduce the amount of sediment entering the system to reduce the need for dredging. For example, stabilizing upstream banks on the Delaware River and its tributaries, channel geometry changes, and upper watershed controls. Although it is recognized that these sources are only part of the sediment contribution to the estuary system, as dredge material managers recognize that the Delaware River bottom provides a significant amount of the sediment that is suspended in the water column (albeit sediments that originated from upstream sources), a combination of innovative technologies for reducing sediment loads in the upper watershed and redirecting sediments to starving locations may provide significant benefits.

Other innovative technologies include either directly pumping sediments out of the system (such as thin layer applications on agricultural fields or wetlands) or through habitat creation, flood control, island development, etc. Thin layer dredged material placement applications have been implemented in tidal marsh ecosystems in several coastal U.S. states which demonstrates the efficacy of the method as an appropriate alternative for serious consideration in the region. Further evaluation of this technology and its merit for application within the Delaware Estuary is recommended.

Best Management Practices

BMPs at dredged material disposal sites vary depending on the type of disposal site. For traditional upland CDFs, there are innovative technologies to improve water quality from disposal site discharge outfalls, such as flocculants and the use of created treatment wetlands. BMPs used at these facilities could also be adapted to fit with other dredged material management alternatives, such as segregated cells at the upland CDF. Some of these practices may be appropriate for smaller CDFs, but may not be effective for some of the larger federally owned CDFs.

BMP alternatives for beneficial use projects will be required to be tailored to the activity. It is also recommended that potential alternative BMPs be vetted with the various federal and state regulatory programs to determine their potential feasibility and permitability. Such a process would also facilitate inter-agency consistency in the review of such alternative BMPs in the Delaware Estuary/Basin.

Other Considerations

Multi-state Locations – Criteria

Opportunities for improving dredging methods and materials management require multi-state coordination. Dredging projects often occur in waters of more than one state, disposal facilities are located in several states, and executing beneficial use alternatives for a single project may involve several states, including states outside the basin.

Criteria for testing sediments, methods of dredging, and disposal vary within the multiple jurisdictions. Managers have difficulty navigating these various criteria especially to a beneficial end for sediments. The development of multi-state criteria is needed.

Seasonal Restrictions

Seasonal restrictions within the entire Delaware River Basin have been evaluated on a project-by-project basis since 1992. In that year, the Delaware River Basin Fish and Wildlife Management Cooperative (Co-op) began addressing both site- and project-specific impacts to watershed resources in relation to proposed operational activities. A re-evaluation of seasonal restrictions is presently underway. Co-op members will review each activity with its corresponding restriction. Inter-state consistency regarding duration of seasonal dredging windows is needed.

Seasonal time-of-year-restrictions (i.e., dredging windows) are typically recommended by both federal and state resource agencies so as to prevent direct, indirect, and cumulative impacts on both critical (i.e., forage, spawning, nursery) terrestrial or aquatic habitat and key resident or migratory species. In many instances, the preferred timing sequence (as dictated by prescribed project schedules) of both the dredging and/or disposal phases of an individual project coincides with seasonal restrictions. Regular planning through project pre-coordination/pre-consultation with the respective resource agency (-ies) is recommended.

Seasonal restrictions can affect dredging operations. There are also seasonal restrictions for potential activities proposed in disposal areas, and often these seasonal restrictions are in conflict with proposed dredging/disposal activities. An evaluation is needed to determine if the predicted benefits of the seasonal restrictions typically applied to certain activities are commensurate with the ultimate/realized environmental gains for the activities. Consistency across the federal and state programs that determine the need for these restrictions is also needed.

Retrofitting “Old” CDF Sites

There is an effort underway to evaluate the potential use of abandoned/formerly used (“old”) CDF sites that had been developed by various entities over the years prior to the USACE CDF program and use of White’s Basin. The NJDOT is evaluating former CDFs owned/maintained by the state of New Jersey or private entities that have been abandoned for their retrofit potential. New Jersey has indicated that retrofitting these sites presents several challenges; the primary one is regulatory. Current approaches to wetlands delineations on these managed sites, and in some instances the use of these managed sites by protected species, presents challenges. Other challenges include retrofit construction costs and testing of the materials in these facilities.

Factors Affecting Dredge Material Management/ Dredging Methods/Opportunities

Several factors affect the range of potential opportunities for improving dredging methods and dredged material management in the Delaware Estuary/Basin.

Sediment – Quantity/Characteristics

The type of sediment (sand, silt, gravel), and the volume to be removed/dredged, affects dredging methods. Appendix C contains a description of the dredging methods typically used for the Delaware Estuary/Basin.

The methods used in the basin for the federal projects tend to be consistent across projects due to the large quantities of sediment that need to be dredged. Methods for private berths vary due to several factors including the sediment characteristics and varied volumes.

Sediment quantities and characteristics as they affect dredging operations are discussed in detail in the *Sediment Quantity and Dynamics White Paper*.

Sediment Quality

Sediment quality, particularly in reference to the materials' chemical composition (i.e., contamination), can affect dredging methods and disposal options. Methods to limit re-suspension of sediments and associated contaminants into the water column after disposal vary and are dependent on the type and concentration of the contaminants. Testing of the dredged material following standard protocols is required and intended to determine contaminant concentrations and management options. Quality characteristics that could affect dredged material management approaches are discussed in detail in the *Sediment Quality White Paper*.

Regulatory Approvals

Regulatory approval affects dredging methods permitted in certain locations. In the Delaware Estuary, federal permits as well as state approval is required for private/non-federal dredging operations. Each state has a different application approval process as well as a specific set of permit conditions and management approaches desired for each dredge material type and dredge material management method.

Finances

The federal navigation program in the Delaware Estuary has historically received annual funding, but not always for the needs identified by program managers; funding for private entities, including municipalities/authorities, is limited. Sources to generate a funding stream are also limited. Alternative funding mechanisms should be evaluated. The RSMP will include an appendix identifying various potential funding sources for RSM and dredging related actions.

Beneficial Use/Restoration

A primary RSMW and USACE goal of dredged material management is to promote/expand dredged material beneficial use practices, including ecosystem restoration. The beneficial use of dredged material for construction applications/purposes within the USACE Philadelphia District Operations Division is a commonly accepted practice; for ecosystem restoration there is no steady/predictable funding source to accomplish these types of restoration/beneficial use projects. In a separate white paper *on Restoration and Beneficial Use*, the premises and types of opportunities for beneficial use/restoration using dredged material are discussed in detail.

Beneficial use include using dredged material for upland related projects such as building materials, elevating properties, etc. and for restoration projects such as beaches/dunes, wetlands, mud flats, bi-valve habitat, landfill capping, etc.

Proposed dredging projects should include an evaluation of opportunities for beneficial use/restoration of the dredged material. A coordinated effort between resource managers on potential beneficial uses, project location, permit processing, and dredged material characteristics is essential as well as a full accounting of all of the broader benefits and cost reductions - these efforts will likely fail (in particular for private/non-federal sector projects). There are many considerations, including project timing, dredged material volumes, dredging methods, and funding that need to be addressed under a long range regional dredged material beneficial use plan. The benefits attributed and therefore, cost savings with these approaches, and/or a predictable and steady source of funding outside of the USACE Operations and Maintenance (O&M) business line needs to be realized. Through the Planning Division of Philadelphia District or outside the USACE, general permits/authorizations with appropriate conditions to support these types of projects should be developed.

Financial Challenges/Opportunities – Economics of Dredging

The economics of dredging is typically fairly straight forward. Within the Delaware Estuary, the Philadelphia District has some unique challenges concerning economic evaluations due to historical investments/programming made to plan for dredged material disposal in large upland CDFs.

The federal navigation dredging program in the Delaware Estuary has historically received annual funding, but not always for the needs identified by district program managers. Funding for private entities, including municipalities/authorities, is usually limited. Additional sources are also limited. Alternative funding mechanisms should be evaluated. The RSMP will include an appendix identifying the various potential funding sources identified by the RSMW for funding RSM and dredging related actions.

Costs

Several decades ago, the Philadelphia District created an extremely cost effective approach to disposing of sediments from maintenance dredging activities from navigation channels and berthing areas. Due to the availability and capacity of the upland CDFs, the comparative costs associated with implementation of other alternatives (on a direct cubic yards-dredged vs. cubic yards-disposed basis), presents challenges for the implementation of beneficial use and ecosystem restoration actions that would normally incur additional costs. Opportunities for developing strategic funding partners or alternative cost: benefit evaluation methods should be explored. Evaluating costs and benefits for alternative dredged material management alternatives, including beneficial use, should be “re-engineered” to reflect broader federal interests for federal projects and the indirect overall savings associated with beneficial reuse.

For private/non-federal projects, costs tend to be more variable and higher due to the small scale of some operations, the location of the disposal facilities relative to the operation, and limited options for disposal as well as other factors.

Benefits

For federal projects, the models/programs used for evaluating benefits and the cost savings associated with them are very draconian and limited. There are many benefits to be derived from alternative dredged material management options such as beneficial use or restoration. The USACE Institute for Water Resources (IWR) has started to inventory/organize those benefits for various types of projects. Applying these benefits and methods of determining their value for dredging projects will be integral to the success of the plan to use alternative approaches for managing sediment on a systems basis.

“Creative” Partnerships

Until long term funding is secured, creative partnerships may be the appropriate mechanism for completing innovative dredging and dredged material management beneficial use projects.

Federal

There may be opportunities to leverage funds through a cost-sharing agreement with other federal agencies responsible for resource management, such as the U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration, U.S. Geological Survey, and the Natural Resources Conservation Service. These entities may be able to partner to provide the added financial backing or in-kind services cost share above the least cost federal standard to permit restoration or beneficial use if the proposed activities fit within their plans/programs.

State/Local

State and local agencies provide another source for sharing the cost of dredged material beneficial use projects. These entities may be able to provide matching funds proportionate to the difference between the traditional approach and the preferred approach. Land, as an in-kind service, is a viable option as well. Examples where cost share opportunities with state/local entities may be feasible (as for these types of projects other sources of funding may be available and beneficial use could provide cost savings) could include use of dredged material for elevating a park or school ball field or constructing levees to protect facilities or natural systems from flooding in their jurisdiction.

Commerce

Another potential partner could be commerce agencies: federal, regional, and state. There may be funds available from these entities to supplement federal navigation dollars so as to ensure that existing or proposed navigation related commerce facilities will remain sustainable.

Private

Private berth areas, in particular those where maintenance and improvement dredging needs exist, have in the past, and will continue to be in the future, a source of partnerships. Often the magnitude of dredging required at these smaller facilities versus the costs associated with alternative dredged material management practices is not equivalent. Private contributions to broader programs, or collecting funds from several private entities that will ultimately benefit from a coordinated dredged material management project, may be a practical option in some locations.

Examples

Examples of partnerships that have been successful in this region and others include:

- Mining companies – using dredged material from the Delaware River and NY-NJ Harbor to fill subsurface mines, or as caps on surface mines, in Central Pennsylvania.
- Island/shoreline stabilization/creation, such as projects completed by the Baltimore and New York Districts of the USACE.
- Use of dredged material as landscaping material/soil completed in several regions.

Recommendations

Recommendations according to policy, programmatic, operational, research/study, and fiscal considerations related to dredging and dredged material management within the Delaware Estuary/River Basin are evaluated as follow:

Policy

The RSMW and RDT have recognized that long term success of implementing alternative approaches to dredging operations and dredged material management are outside (cost share) funding sources (non-federal or other federal business lines – such as Ecosystem Restoration and Flood Risk Management in addition to the traditional Navigation Business Line of the USACE) to offset the low cost of disposing maintenance material in the federally owned upland CDFs using Navigation Funds. Unlike the NY/NJ Harbor area, which does not have federally owned upland CDFs adjacent to federal channels, the current cost of disposal is considered economical on the order of $2-$5 per cubic yard (Philadelphia District), not $50-$100 per cubic yard (NY District). It is critical for the managers in the Delaware Estuary to find creative dredged material management solutions through strategic partnerships, and to evaluate alternative policies regarding reasonable cost: benefit assessments. Presently, local companies who need materials suitable for construction purposes have taken advantage of this potential for partnerships.

Specific policy recommendations include:

> Recycle sediment through beneficial use to keep sediment in the watershed. This goal considers the beneficial use of 15% of all dredged material by 2015 and 5% more per year towards an ultimate goal of 50% by 2022 and increase the number and type of beneficial use projects.

> Modify existing sediment/dredged material management programs to facilitate implementation of the RSM paradigm.

> Promote consistency with state programs to new federal guidelines for benefit cost analyses (Principles and Standards) that provide for broader spectrum of benefits in analysis of cost justification.

Programmatic

Current federal and state regulatory programs within the Delaware Estuary/River Basin should be re-evaluated for consistency and modified to facilitate implementation of the recommendations in this White Paper. Effective dredged material management solutions require the ability to work across state lines by developing consistent regulatory standards to facilitate the management processes. It is also recommended that the USACE Regulatory Branch revisit with their federal partners regulatory processes and permit conditions to further facilitate implementation ideas generated as part of this study. Several regional studies are currently being conducted by others concurrent with this RSMP planning initiative that should be considered in RSMP development.

Specific programmatic recommendations include:

> Facilitate regional coordination of dredging and dredged material disposal/management, with the goal of reducing annual O&M dredging costs and the volume of sediment to be dredged over time.

> Identify potential alternative dredged material beneficial use and management/disposal options for private and federal navigation dredging projects.

> Strive for consistency in state standards for best management practices for dredging methodologies, particularly with respect to minimizing environmental effects. Develop one multi-state protocol for seasonal dredging restrictions (i.e. dredging windows).

- Solicit assistance from a broad spectrum of interests in changing the sediment paradigm/myths – sediment should be considered to be a resource, not a waste material.
- Continue to collaborate and develop/implement a long term dredged material disposal/management program for dredged material from private berth facilities.
- Identify and collaborate with potential partners to implement dredged material beneficial use projects. Such potential partners include federal resource agencies, the states, municipalities, non-profit organizations, and the private sector (ports/maritime industry).
- Conduct a cost-benefit analysis that compares the full range of effects/benefits (ecological, social, etc.) associated with disposal/management of dredged material for various alternatives, including beneficial use. The potential for green jobs creation should be included in the analysis.
- Continue with the Regional Dredging Team (RDT) meetings to monitor and facilitate dredging operations in the basin.
- Develop and implement a public education/outreach program to explain the options for dredging and the beneficial uses of the sediments in the basin.
- Support and collaborate with entities developing regional restoration plans and project registries to identify potential beneficial uses of dredged material for restoration projects.

Operational

Current operations in the basin can be categorized as either federally or privately/non-federally directed. Changes in the types of dredging equipment or their operations have limited opportunity. Further evaluating the potential to reduce sediment loads reaching the channels and berth areas (potentially through creative sediment dynamics-engineered alternatives or tributary contribution reductions) is of greatest interest. Opportunities to identify and implement upland CDF water quality management improvements are also recommended for further evaluation.

Although private/non-federal sector maintenance dredging contributions to dredge material volumes are small compared to the federal contributions, it is recommended that priority be given to developing a sustainable 5- to 10- year plan addressing effective disposal/management alternatives for these private sector activities.

Specific operational recommendations include:

- Conduct pilot projects for treatment of wetlands to provide water quality enhancements to the discharges from existing upland CDFs.
- Conduct pilot projects to evaluate the use of thin layer application of dredged materials on wetlands in strategic areas subject to subsidence and/or sea level rise.
- Conduct pilot projects to evaluate the use of living shoreline and other ecologically beneficial approaches (oyster reefs, etc.) to control shoreline erosion problems.
- Conduct pilot projects to reduce sediment loads from upstream tributaries, such as stream restoration/bank stabilization projects.
- Implement appropriate recommendations from DOTS study of existing upland CDF best management practices.
- Investigate application of nautical depth (active and passive) for Wilmington Harbor and possible other areas if significant amounts of fluid mud exists.

Research/Study

Significant research has been conducted to understand the sediment characteristics and dynamics in the Delaware Estuary/Basin. While these efforts have provided a baseline for preparing this document, further studies are recommended in order to understand the most appropriate alternatives for reducing the need to dredge the navigation channels and private berths, the most appropriate best management practices for ensuring water quality, and the most appropriate locations to beneficially use dredged material within the estuary.

Specific research/study recommendations include:

- Evaluate the need/options for modified/longer "windows" for dredging and dredged material management operations to take advantage of alternative dredged material management options.
- Evaluate alternative dredging methods (technical and management solutions) to reduce dredging needs (e.g. see Richard Price and Bob Blama's recommendations) and reduce sediment transfer to the disposal of dredged material in upland CDFs.
- Evaluate bedload collectors to reduce depo-centers.
- Evaluate programs to reduce the sediment being transported to depo-centers through technical/engineered and management solutions.
- Evaluate the potential for dredged material segregation at existing upland CDFs and conduct pilot projects to demonstrate this process.
- Evaluate feasibility of long distance pumping (http://el.erdc.usace.army.mil/elpubs/pdf/tr11-2.pdf and NAP Report, U.S. Army Engineer District, Philadelphia. 1969. Long range spoil disposal study, Part V, Substudy 4, pumping through long lines. 19 June. Philadelphia, PA.)

Fiscal

The RDT and RSMW have recognized that critical to the long term success of implementing alternative and creative approaches to dredged material management, in particular beneficial uses and ecosystem restoration, are outside funding sources (non-federal or other federal business lines) to offset the low cost of disposing maintenance material in the federally owned upland CDFs using Navigation Funds. Further evaluation of potential federal, state, local, commerce, and private partner joint-funding strategies is also recommended.

Specific fiscal recommendations include:

- Identify, evaluate and pursue/secure creative funding mechanisms to provide alternative dredged material management, upper watershed sediment loading reduction, and beneficial use options. Explore options alternative funding approaches.
- Recommend to Congress that USACE Federal Standard/least cost disposal option for dredging projects reflect a more accurate accounting of the full range of economic, environmental, and other relevant costs and benefits for options that reuse dredged material.
- Continue to work with commercial entities to find markets for dredged material currently contained in upland CDFs throughout the basin.

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Dredging and Dredged Materials Management White Paper Committee

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Appendix A

Historical Dredging Quantities

(Tables Completed through 2010)

2000			
Government, Contracted Dredging			
Del River, Phila to Sea	2,443,754	Pedricktown, Killcohook	
Murderkill	40,000		
Salem River	100,000	Killcohook	
Schuylkill River	241,483	Fort Mifflin	
Wilmington Harbor	550,000	Wilmington	
Wilmington Harbor Emergency	232,000	Wilmington	
Government, Dredge McFARLAND	624,542		
Private Dredging			
			4,231,779
2001			
Government, Contracted Dredging			
Del River, Phila to Sea	2,418,227	Pedricktown, Killcohook	
Wilmington Harbor	570,000	Wilmington	
Wilmington Harbor Emergency	570,000	Wilmington	
Government, Dredge McFARLAND	447,828		
Private Dredging			
			4,006,055
2002			
Government, Contracted Dredging			
Del River, Phila to Sea	2,546,508	Pedricktown, Killcohook	
Del River, Phila to Trenton	148,551		
Mispillion	22,500		
Murderkill	25,000		
Wilmington Harbor	465,600	Wilmington	
Government, Dredge McFARLAND	242,829		
Private Dredging			
			3,450,988
2003			
Government, Contracted Dredging			
Del River, Phila to Sea	1,221,113	Pedricktown, Killcohook	
Schuylkill	265,664	Fort Mifflin	
Wilmington Harbor	343,565	Wilmington	
Wilmington Harbor	550,000	Wilmington	
Government, Dredge McFARLAND	496,196		
			2,876,538
Private Dredging			
2004			
Government, Contracted Dredging			

Del River, Phila to Sea	1,256,118	Pedricktown, Killcohook	
Del River, Phila to Trenton	150,000		
Roosevelt Inlet, DE	180,000		
Schuylkill	265,000		
Wilmington Harbor	500,000	Wilmington	
Wilmington Harbor	300,000	Wilmington	
Government, Dredge McFARLAND	586,084		
Private Dredging			
PRPA-Pier 82S Emergency	10,000		
Conoco Phillips	60,127		
Sunoco-RW5	150		
Phila Marine Center	36,493		
			3,343,972
<u>2005</u>			
Government, Contracted Dredging			
Del River, Phila to Sea	2,116,409	Pedricktown, Killcohook	
Schuylkill	231,000		
Wilmington Harbor	325,000	Wilmington	
Wilmington Harbor	500,000	Wilmington	
Government, Dredge McFARLAND	423,933		
Private Dredging			
DRBA-Lewes Terminal	23,060		
DRPA-Phila Cruise Terminal	9,517		
Westway-Pier H	11,809		
PRPA-Pier 80S	29,071		
			3,669,799
<u>2006</u>			
Government, Contracted Dredging			
Del River, Phila to Sea	1,239,570	Pedricktown, Killcohook	
Del River, Phila to Trenton	695,887		
Salem River	139,008	Killcohook	
Phila. Naval Reserve Basin	789,162	Fort Mifflin	
Wilmington Harbor	467,240	Wilmington	
Government, Dredge McFARLAND	620,525		
Private Dredging			
Conoco Phillips	113,716		
National Gypsum	25,779		
SJPC-Broadway 1, 1A, Beckett 2-4	19,256		
Sunoco-Frankford	1,497		
Sunoco-Marcus Hook	82,619		
Sunoco-Ft. Mifflin	5,483		
PRPA-Packer	61,995		
			4,261,737

2007

Government, Contracted Dredging			
Del River, Phila to Sea	2,165,630	Pedricktown, Killcohook	
Wilmington Harbor	600,000	Wilmington	
Government, Dredge McFARLAND	603,174		
Private Dredging			
Sunoco - Marcus Hook	82,619		
Conectiv	45,986		
Conoco Phillips	93,298		
Exelon-Eddystone	12,856		
Citgo Asphalt	70,659		
PRPA-Pier 80S, 84S, Tioga	106,829		
PRPA- Kinder Morgan	13,959		
Crowley	13,769		
			3,808,779

2008

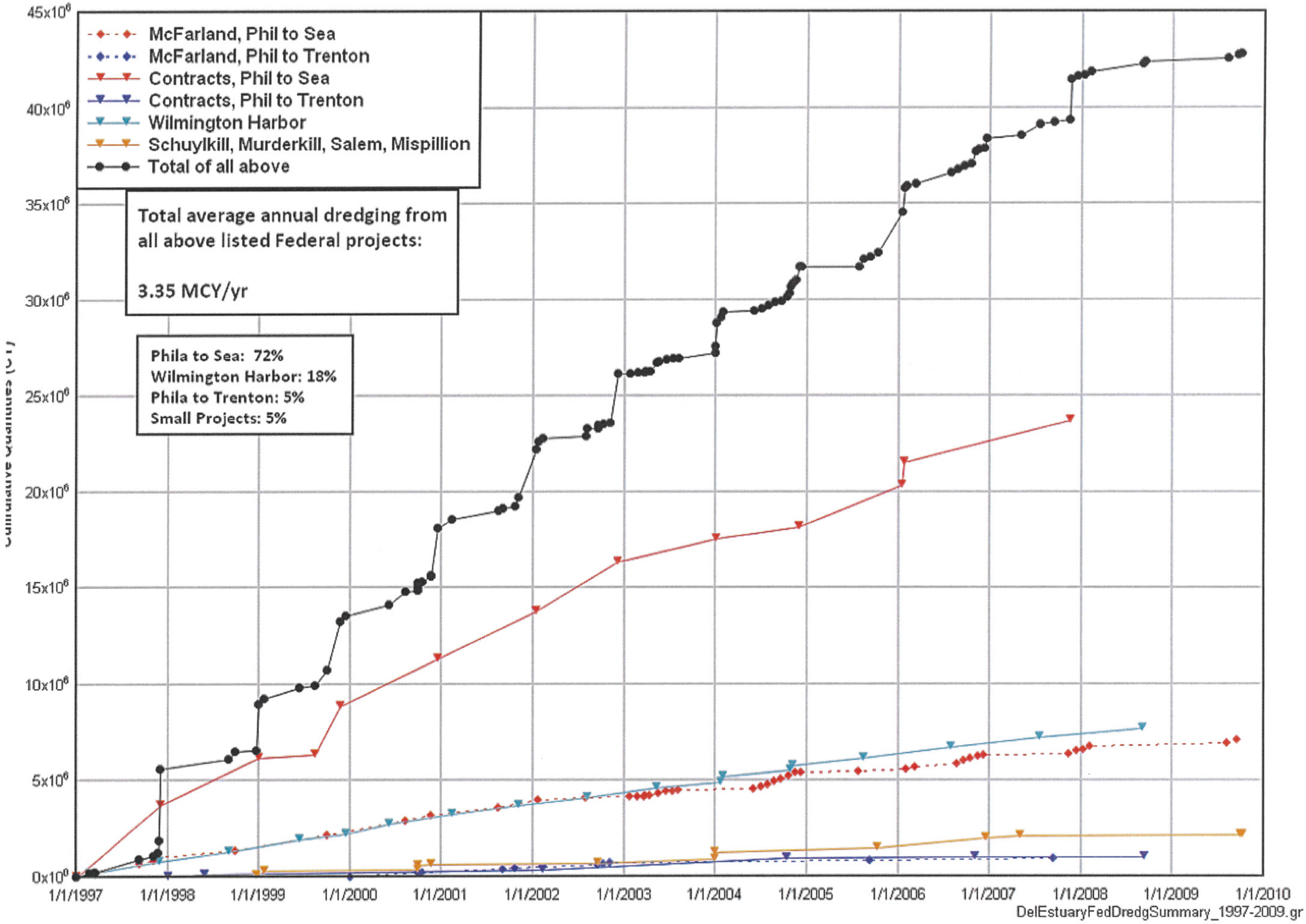
Government, Contracted Dredging			
Del River, Phila to Sea	2,222,211	Pedricktown, Killcohook	
Del River, Phila to Trenton	125,000		
Schuylkill	665,000		
Wilmington Harbor	650,000	Wilmington	
Government, Dredge McFARLAND	351,464		
Private Dredging			
Hess	8,276		
Oceanport	26,153		
PWD-Baxter	107,800		
			4,155,904

2009

Government, Contracted Dredging			
Del River, Phila to Sea	1,700,000	Pedricktown, Killcohook	
Del River, Phila to Trenton	863,060		
Indian River Inlet	360,000		
Mispillion	20,000		
Wilmington Harbor	450,000	Wilmington	
Phila Navy Yard Pier 4	100,000	Fort Mifflin	
Government, Dredge McFARLAND	351,979		
Private Dredging			
Conoco Phillips	140000		
			3,985,039

10 year total	37,790,590

Maintenance Dredging Summary, Delaware Estuary
1997 - 2009



Appendix B

Historical Beneficial Uses – by Quantity
(Tables Completed through 2010)

How to make this a sustainable list future

– create a demand

cy

Year	Disposal Area/Dredging Site	Quantity	Material	Use
1978	Penn's Grove	Sand	1,000,000	
1988	Wilmington North	Silt		Silt was blended with lime flyash for construction berm
1991	Cape May Canal	Sand	15,000	State of NJ excavated material for Cape May Meadows
1993	Grove Neck/Goose Point			Environmental Restoration
1992-1995	Reedy Point North	Sand	60,000	Created a berm at Wilmington South Disposal Area
1994	National Park	Sand	20,000	Construction of an off-ramp for Rt 295.
1995	Cape May	Sand		Material dredged from the Inlet was used to fill geotubes for loran tower anchors
1997	Fort Mifflin	Granular	1,900,000	Used for runway foundation at Phila Int Airport
1998	Mispillion River	Sand		Used to Protect the Seawall from flanking
1999	Barnegat Inlet	Sand		Used to fill geotubes and build foundation at Sedge Island
2000-	Phila to Trenton		150,000	150K cy annually used as landfill cover by Waste Management
2001	National Park		146,000	Used to cover contaminated area and create public golf course.
2002	National Park	Sand	30,000	Used for landscaping by Ash Materials
2003	Fort Mifflin	Granular	50,000	Donated to DRPA as a demonstration project for abandoned mine reclamation
2002-2003	Reedy Point North	Sand	1,000,000	Sold to Pierson construction
2002	Pea Patch Island		20,000	Material dredged from the adjacent federal channel
2004	Fort Mifflin			Dredged Material and Glass Blending donation
2005	Fort Mifflin			Sunoco using material for capping drainage pits
2004	Cape May			NJDEP removed material to cap a Magnesite Plant at Cape May Point.

Need to update last few years

Reedy Pt, Ft. Mifflin, Airport

Σ4M cy per year on average ~~removal~~ disposal

about 1M per year benefi use

Often material was used for construction projects

Material removed from basins – and used for the above

Appendix C

Philadelphia District Historical Dredging Equipment/Methods and Available Alternatives

Appendix C: Philadelphia District Historical Dredging Equipment/Methods and Available Alternatives

USACE Philadelphia District

Dredging Operations – Background Information

Dredging Methods – Equipment

The following summarizes dredging methods/equipment historically used in the Delaware River Basin/Estuary.

Overview

Dredging of the Delaware River/Estuary federal navigation channels conducted by the USACE is done by using both Government-owned equipment and through the work of contractors (primary method). Currently, methods/equipment available for dredging the Delaware Estuary/River are limited, in particular for the Main Channel maintenance dredging operations. There are a limited number of contractors with limited types of equipment that affect the available methods for dredging in the Delaware River/Estuary. The USACE owns equipment (the Hopper Dredge *McFarland*) and also contracts out to private dredging contractors. Private berths primarily use private contractors, while the state of Delaware also owns dredging equipment.

Dredging contractors employ several types of dredges in their operations. The type of dredging equipment used is generally dictated by the volumes of material to be dredged, the water depths, the size of the water body, and the distance to the disposal facilities. The actual dredging plant is a complex system comprised of numerous modules, each performing a particular operational function so as to excavate and remove sediments from a distinct area (i.e., navigation channel or berthing area) and ultimately transport and /or discharge the material in or at a prescribed disposal area/location. Dredging equipment generally consists of the dredge (equipment for removing the sediment from channel floor), transport mechanisms (equipment for transporting sediments to disposal area – barge, pipe or other), and discharge/dumping equipment at the disposal location.

Dredges designed primarily for open-ocean dredging or dredges intended for small channel/berth dredging vary and the Philadelphia District and private operators in the Delaware River Basin/Estuary have used various methods depending on location, scope and breadth of the project. However, Delaware River dredging conducted by the USACE has typically been accomplished by hydraulic means. Basically, for hydraulic dredging the contractor uses a hydraulic dredge, which will consist of a hopper, cutter head, or dustpan mechanisms. Historically, mechanical bucket dredges (dipper and clamshells) have not been used efficiently in the construction of beach projects; however, they are used on navigable waterway (channels/berths) projects on the Delaware River/Estuary and associated tributaries. Current methods often employ the use of dredging plants that pump dredged material through pipelines to disposal areas. Every type of dredge has specifications/parameters on how much material can be pumped per hour, the minimum pipe widths and maximum pipe lengths associated with various sediment characteristics.

The following discussion will focus on the methods used on the larger dredging projects in the Delaware River/Estuary and its tributaries: the hopper, cutter head, and dustpan type dredges. Their capabilities and differences will be briefly described to familiarize the reader with this specialized equipment. Private berths, which conduct smaller scale dredging operations use mechanical/bucket dredges. These methods are not described in detail in this section.

Hopper Dredges

Hopper Dredges, also known as Trailing Suction Hopper Dredges, are capable of placing on the order of 15-20K cubic yards of sand per day. Hopper dredges are used when the area to be dredged is 20 to 100 feet deep and the area to be dredged is 10+ miles away from a placement location.

The plant (dredge) moves to and from the borrow site under its own power and it has a self- contained crew (crew lives on board). Therefore, it requires no pipe set-up or booster pumps, and less attendant vessels during the operation, with no crew boat required for crew changes during 24 hour operations.

The illustration shows the dredge with drag arms down and the photograph shows the belly of the vessel being filled during the actual dredging operation (with the drag arms down). The intake is by drag arm, and the sand is then stored in the belly of the vessel. Once the dredge is filled, the operator will raise the drag arms and the captain will head to the discharge location. Depending on the project, there are various discharge methods. There is split hull bottom discharge (from the bow of the vessel). Should split hull bottom dump not be the choice of discharge, the sand must be re-liquefied in order to pump the sand out of the hull. In some cases booster pumps may be used, depending on the distance of the pipeline from the location of discharge to the beach/disposal facility.

On past projects within the Philadelphia District where a hopper dredge was utilized during the construction phase, several special conditions, coordinated with the District's Environmental Branch, were required that necessitated additional steps to be taken during the dredging operation. During the months of June through November in any given year, turtle excluder screens are mandatory and have been installed on the drag arm intakes. The dredging contractor is obligated to provide a formal written plan for review by the District. In addition , a National Marine Fisheries Service-certified inspector/observer is required to be on board at all times during dredging, and in some cases disposal operations so as to document evidence of the presence or absence of turtles and/or other aquatic (marine) life that may be caught in the drag arm intake. The inspector is expected to file/record through official documentation daily trip/incident reports.

Hydraulic Cutter Head Dredges

Hydraulic cutter head dredges are capable of placing on the order of 25-35K cubic yards of sand per day on average. These plants are flat bottom barges mounted with "giant" engine(s). The hull shape does not allow the dredge to tolerate high seas as well as the hopper dredge. As a result, the dredging contractor is responsible for monitoring weather patterns/conditions closely to ensure that ample time is allocated to bring the dredge into a sheltered harbor in the event that inclement weather events cause high seas. Generally, this is not an issue for dredging operations in the upper Delaware River but can be in the lower estuary.

Cutter head dredges use a spiral cutter head to dig into the water body floor. The cutter head is located at the end of what is known as the ladder. This ladder is lowered and raised via cable lines that are suspended from an "A" frame at the bow of the dredge. The cutter head spins and creates a sediment "cloud of" slurry, which is pumped through pipelines to the disposal area. This is the only form of discharge for the cutter head dredges. These cutter heads are capable of drilling rock and have been known to go right through ship wrecks (with the only evidence of the wreck being deposited at the disposal site). Therefore, all prohibited zones within the borrow site need be clearly marked.

The cutter head dredges are not mobile under their own power. Therefore, they require attendant vessels during the operation (such as tugs to reach the borrow site). Hence, a crew boat is needed for crew changes (the crew does not live on board).

Once the dredge is at the borrow site, the dredge is "spudded" down on spuds that are located at the stern of the dredge. The dredge can then swing in an arc like motion on the spud. Several anchors and associated cables enable the dredge to swing its arc and pull it forward within the borrow area when the spud is lifted.

Dustpan Dredges

Dustpan dredges are capable of placing up to 50K cubic yards of sand per day. Dredged material volumes rates of that magnitude were recorded when the "Beach Builder" was working the Ocean City New Jersey beach fill project. Similar in hull design to the cutter head dredge, the dustpan dredges are flat bottom barges mounted with "giant" engine(s). The Beach Builder is all engine. They are extremely powerful, which enables them to pump several miles without booster pumps.

The dustpan dredges are not mobile under their own power. Therefore, they require the aid of tugs to reach the borrow site. Hence, it requires attendant vessels during the operation, including a crew boat for crew changes (the crew does not live on board).

The dust pan dredge uses a spider configuration of six anchor cables to pull itself within the borrow site. The tugboats and other attendant vessels move the anchors into position. Once the dustpan dredge is into position, the "A" frame lowers the ladder and a wall of jet nozzles loosens the sediment. A suction pump then transfers the slurry to the desired location.

Similar to the cutter head dredge, the dustpan dredge cannot tolerate high seas. As a result, the dredging contractor is responsible for monitoring weather conditions closely to ensure that ample time is allocated to bring the dredge into a sheltered harbor in the event that inclement weather causes high seas.

Associated Equipment

Booster Pumps

Booster pumps in various configurations can be used in situations where the distance to the beach/disposal site is much greater than the capacity of the dredge's pumps. Booster pumps can be used on floating barges, jack-up barges, buoys, or simply land based.

Cranes and Derricks

Cranes and derricks also need to be inspected with the floating plant.

Boat Fleet and Barges

The boat fleet and barges are essential to an effective dredging operation. The typical boat fleet consists of tugboats, workboats, crew boats, and survey boats. For instance, the dredge Illinois has successfully worked the Ocean City Beach Fill Project several times. The photograph depicts a workboat, tugboat, work barge, and an anchor barge preparing for a beach fill. As you can see there are many mechanical devices associated with the floating plant. It is essential to inspect all forms of the plant at the beginning of the project. This includes the work barges and anchor barges, which sometimes get over-looked during the project.

Floating and Submerged Pipelines

Another key element to the floating plant is the pipeline. There are many types of pipelines that the contractor can use for any given project. The pipe is extremely dangerous to work with during mobilization and demobilization. The floating pipeline is typically located between the dredge and the riser pipe. Typically, the submerged pipe travels the majority of the distance to the beach/disposal site. The submerged pipeline comes in 500 to 1000 foot sections of seamless pipe. As per U.S. Coast Guard regulation, proper lighting needs to be in place, on riser pipes offshore and onshore and on all floating pipelines over the course of the entire project. Buoys are required along the submerged line so as to properly locate and identify it.

Appendix D

Table: Dredged Material Volumes April 2009 Environmental Assessment for Delaware River Channel Deepening

Major Dredging and Engineering Works History in the Delaware River Estuary: "Philadelphia to Sea"

Work Description	Project Adopted	Work Period	Quantity Dredged (c.y.)	Reference
Improvements in Phila. Harbor	unknown	1874-1885	3,467,000	USACE, 1973.
Removal of shoals at Mifflin Bar, Cherry Island Flats, Bulkhead Bar, and Dan Baker Shoal	unknown	1869-1885 (?)	(same as above reference?)	USACE, 1937.
Improvements to Marcus Hook Ice Harbor (12-24' deep)	unknown	1867-1889	unknown	USACE, 1973.
Fishers Point Dike (training/contraction dike)	unknown	1885-1886	NA	USACE, 1973.
Hog Island-Tinicum Island Dike (training/contraction dike)	unknown	1885-1888	NA	USACE, 1973.
26'and 30' Channel – Phila. to Sea	1885	1886-1909	51,470,000	USACE, 1973.
26' Channel (600' wide) – Phila to Sea.	1885	1885-1898	(combined in 26' and 30' reference above)	USACE, 1937.
Reedy Island Dike (Length= 6,300', Max Elev.= +5 MLW)	unknown	1887-1889	NA	USACE, 1973.
Bulkhead Bar Dikes	unknown	1891-1892	NA	USACE, 1973.
Reedy Island Dike (Length= 11,600', Max Elev.= +8 MLW)	unknown	1896	NA	USACE, 1973.
Removal of Smith Island and Windmill Island from the main channel between Phila., PA and Camden, NJ.	unknown	1898	unknown	USACE, 1937. USACE, 1973.
30' Channel (600' wide) – SE Phila. to Sea	1899 (River and Harbor Act of 1899)		(combined in 26' and 30' reference above)	USACE, 1937.
Artificial Island Disposal Area Dikes (Elev.= +10 MLW)	unknown	1900-1905	NA	USACE, 1973.
35' Channel (1000' wide Phila. Harbor, 1200' w at bulkhead Bar, 1000' w at other bends, 800' w in straight reaches) – Allegheny Ave. (Phila.) to deepwater in Delaware Bay ("Phila. to Sea")	1910 (River and Harbor Act of 1899 - modified)	1910-1930	49,424,000	USACE, 1937. USACE, 1973.
Chester Island Dike, Oldmans Point Dike, Stoney Point - Artificial Island Dike (contraction dikes)	unknown	1912-1915	NA	USACE, 1973.
Reedy Island Dike (Length= 16,900', Max Elev.= +8 MLW)	1910 (River and Harbor Act of 1899 - modified)	1912-1919	NA	USACE, 1973.
Hope Creek Dike (Length= 3,422', Max Elev.= +2 MLW)	1910 (River and Harbor Act of 1899 - modified)	1929 (repaired 1930, 31, 34, 36)	NA	USACE, 1973.
35' Anchorages at Port Richmond, PA, Mantua Creek, NJ. 30' Anchorage at Gloucester, NJ	1930 (River and Harbor Act of 1899 - modified)	1930-1934	8,645,000	USACE, 1937. USACE, 1973.

35’ Anchorage at Marcus Hook, PA	1935 (River and Harbor Act of 1899 - modified)	1935	2,878,000	USACE, 1937. USACE, 1973.
Pea Patch Island Dike (Length= ~20,000’, Max Elev.= +10 MLW)	1910 (River and Harbor Act of 1899 - modified)	1930-1932 (repaired 1953)	NA	USACE, 1937. USACE, 1973.
Camden Waterfront – 18’ harbor Cooper Point to Berkley St. Marine Terminal; 30’ harbor from Berkley St. to Newton Creek (All locations east from 35’ Allegheny Ave. to Sea channel)	1919, modified in 1930 and 1945	unknown	unknown	USACE, 1937. USACE, 1973.
37’ Channel – Benjamin Franklin Bridge to Navy Yard; 40’ Channel – Navy Yard to Sea (1000’ wide Phila. Harbor, 1200’ w at bulkhead Bar, 1000’ w at other bends, 800’ w in straight reaches to Ship John Light, 1000’ w to bay).	1938 (River and Harbor Act of 1938)	1940-1945	53,380,000	USACE, 1937. USACE, 1973.
Pennsville Dike (Length= 5,200’, Max Elev.= +3 MLW)	1910 (River and Harbor Act of 1899 - modified)	1942-1943 (repaired 1963)	NA	USACE, 1973.
37’ Channel –Allegheny Ave. (Phila.) to Benjamin Franklin Bridge and the Port Richmond anchorage	1945 (River and Harbor Act of 1938 - modified)	1959-1960	1,102,000	USACE, 1973.
37’ Anchorages at Mantua Creek and Marcus Hook	1945 (River and Harbor Act of 1938 - modified)	1947-1957	9,850,000	USACE, 1973.
40’ Channel – Allegheny Ave. (Phila.) to Navy Yard (400’ wide)	1954 (River and Harbor Act of 1938 - modified)	1962-1963	4,451,000	USACE, 1973.
40’ Anchorage at Marcus Hook	1958 (River and Harbor Act of 1938 - modified)	1964	16,686,000	USACE, 1973.

Major Dredging and Engineering Works History in the Delaware River Estuary: "Trenton to Philadelphia" and Other Major Tributaries

Work Description	Project Adopted	Work Period	Quantity Dredged (c.y.)	Reference
20' Channel (100' wide) – Schuylkill River mouth to Gibson Point	1870			USACE, 1973.
12' Channel (200' wide) Wilmington Harbor	1870	1873-1881	252,000	USACE, 1973.
7' Channel (200' wide) and other improvements to Philadelphia to Trenton Channel	unknown	1874-1910	497,000	USACE, 1973.
24' Channel (300' wide) – Schuylkill River mouth to Girard Point	1875	1870-1891	1,765,000	USACE, 1973.
15' Channel (200' wide) Wilmington Harbor	1881	1882-1884	1,000,000	USACE, 1973.
24' Channel (400' wide) – Schuylkill River mouth to Girard Point	1883	unknown		USACE, 1973.
20' Channel (250' wide) – Schuylkill River, Gird Point to Gibson Point	1892	1895-1917	3,066,000	USACE, 1973.
21' Channel (200' wide) Wilmington Harbor	1896 & 1899	1896-1901	2,463,000	USACE, 1973.
12' Channel (200' wide) – Phila. to Trenton	1910	1911-1922	2,774,000	USACE, 1973.
35' Channel (400' wide) Schuylkill River mouth to Girard Point 33' Channel (250' wide) – Schuylkill River, Girard Point to Gibson Point 22' Channel (200' wide) – Schuylkill River, Gibson Point to University Ave. Bridge	1917	1919-1923	4,054,000	USACE, 1973.
25' Channel (400' wide) Wilmington Harbor and Turning Basin	1922 & 1925	1924-1925	3,397,000	USACE, 1973.
20' Channel (200-300' wide) – Phila. to Trenton	1925	1930-1933	5,100,000	USACE, 1973.
28' Channel (300' wide) – Allegheny Ave. (Phila.) to Delair Bridge	1930	1931	218,000	USACE, 1973.
30' Channel (400' wide) Wilmington Harbor and Turning Basin	1930	1931	792,000	USACE, 1973.
25' Channel (300' wide) – Delair Bridge to Trenton	1933, 1935	1933-1937	9,263,000	USACE, 1973.
33' Channel (400' wide) Schuylkill River mouth to Girard Point 35' Channel (400' wide) – Schuylkill River, Girard Point to Passyunk Ave. Bridge 26' Channel (200' wide) – Schuylkill River, Passyunk Ave. Bridge to Gibson Point 22' Channel (200' wide) – Schuylkill River, Gibson Point to University Ave. Bridge	1946	1948-1966	3,463,000	USACE, 1973.
40' Channel (400' wide) – Allegheny Ave. (Phila.) to Newbold Island	1954	1957-1964	36,345,000	USACE, 1973.
35' Channel (400' wide) Wilmington Harbor and Turning Basin	1960	1962	1,736,000	USACE, 1973.

Maintenance Dredging Estimates in the Delaware River Estuary

Work Description	Work Period	Quantity (c.y.)	Annual Quantity (c.y.)	Reference
Philadelphia to the Sea	1885-1967	592,556,000	7,226,293*	USACE, 1973.
Philadelphia to Trenton	1914-1967	14,572,000	274,943*	USACE, 1973.
Schuylkill River	1870-1966	40,275,000	419,531*	USACE, 1973.
Wilmington Harbor	1870-1962	57,360,000	623,478*	USACE, 1973.
Philadelphia-Camden Sewage Deposits – Maintenance Dredge	1937-?		110,000	USACE, 1937.
Philadelphia to the Sea	1910-1937 (approx.)		10,000,000	USACE, 1937.
Philadelphia to the Sea	1976-1994		4,888,000	USACE, X. Comprehensive Economic Reanalysis Report, Appendix A
Philadelphia to the Sea	1995-2001		3,455,000	USACE, X. Comprehensive Economic Reanalysis Report, Appendix A

* calculated as the product of Quantity/Work Period

Appendix E

Philadelphia to Sea CDF Inventory Table

Table E.1: PROJECT: Maintenance Dredging, Delaware River, Philadelphia-to-the-Sea

9/22/2010

Summary Table - Disposal Area Features

Disposal Site	Sub Area	Latest Survey		Acres Diked (a)	Inspection Date	Last Date Inspected	Average Dike Elevation NAVD88 (FT)	Average Floor Elevation NAVD88 (FT)	Estimated Current Capacity (b) (MCY)	Estimated Current Cap. w/Bulking (c) (MCY)
		Aerial	Land							
1. National Park		5/2007		101		27 Jul 05	32	21	1.5	0.8
2. Oldmans #1		5/2007	6/2005	295		11 Aug 05	38	23	6.2	3.4
3. Pedricktown	N	11/1998	8/2009	517		11 Aug 05	42	34	5.0	2.8
	S	5/2007	8/2009	497		25-Feb-03	48	36	8.0	4.5
4. Penns Neck		5/2007		321		22 Sep 05	23	13	3.9	2.2
5. Killcohook	1	5/2007	7/2008	714		20 Jul 05	36	30	4.6	2.6
	2	5/2007	12/2003	276		20 Jul 05	52	47	1.3	0.7
	3	5/2007	6/2005	181		20 Jul 05	45	39	1.0	0.6
6. Artificial	1	5/2007		94		21 Jul 05	18	11	0.7	0.6
Island	2	5/2007	6/01	107		21 Jul 05	24	15	1.2	0.7
	3	5/2007	6/01	89		21 Jul 05	12	6	0.4	0.2
TOTALS:				**3,192**					**33.9**	**19.1**

Delaware Estuary
Regional Sediment Management Plan
White Paper

Appendix D:
SEDIMENT QUALITY

May 2010

Last Revised: November, 2011

Final Draft – September 2012

Table of Contents

List of Tables

List of Figures

Acronyms and Abbreviations

BaP	benzo(a)pyrene
COC	contaminants of concern
CWA	Clean Water Act
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
DRBC	Delaware River Basin Commission
ERL	Effects Range-Low
ERM	Effects Range-Median
HNRT	Highest Non-Residential Threshold
LRT	Lowest Residential Thresholds
NJDEP	New Jersey Department of Environmental Protection
NOAA	National Oceanic and Atmospheric Administration
PAH	polycyclic aromatic hydrocarbons
PBT	Persistent Bioaccumulative and Toxic chemicals
PCB	polychlorinated biphenyl
PEL	Probable Effects Level
REMAP	Regional Environmental Monitoring and Assessment Program
RSMP	Regional Sediment Management Plan
SQG	sediment quality guidelines
SQuiRT	Screening Quick Reference Tables
TCLP	Toxicity Characteristic Leaching Procedure
TEL	Threshold Effects Level
TEQ	Toxic Equivalency Quotient
TMDL	Total Maximum Daily Load
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

Introduction

Summary

Delaware Estuary Regional Sediment Management Plan (RSMP) Sediment Quality Objective: Manage and improve sediment quality in the Delaware Estuary/Basin system to ensure it is capable of supporting a healthy and productive ecosystem, meets water quality standards, and supports beneficial use of the sediment (including dredged material).

The purpose of the *Sediment Quality White Paper* is to evaluate the available sediment quality (i.e. chemistry) data from the Delaware Estuary and its watershed to aid in the development of the Delaware Estuary RSMP. The RSMP Workgroup views dredged material (i.e. sediment) as a resource and the Sediment Quality Committee has chosen to evaluate the quality of this resource in terms of its potential suitability for aquatic habitat restoration and upland beneficial uses.

A comprehensive evaluation of the suitability of sediment/dredged material for an aquatic habitat restoration or upland beneficial use project requires detailed project-specific analyses of the physical and chemical characteristics of the sediment/dredged material (as well as the beneficial use site). In addition, for most habitat restoration projects, potential contaminant bioavailability effects (toxicity and bioaccumulation) must also be evaluated (U.S. Army Corp of Engineers [USACE], 2003; U.S. Environmental Protection Agency [USEPA]/USACE, 1998; New Jersey Department of Environmental Protection [NJDEP], 1997). Given the planning-level objectives and geographic scope of the RSMP, and the limited time and resources available to conduct an assessment of sediment/dredged material quality, the Sediment Quality Committee determined that such project-specific and comprehensive analyses were not realistic. Therefore, a simplified sediment quality evaluation screening protocol was developed to provide the information needed to support the development of the RSMP.

Finally, a comprehensive watershed-level effort to identify and evaluate the factors that result in the observed sediment quality characteristics in the Delaware Estuary is beyond the scope of this project.

Methods

Contaminants of Concern

The Sediment Quality Committee has selected a set of “contaminants of concern” (COCs) whose presence in Delaware Estuary sediment have the potential to limit aquatic habitat restoration or upland beneficial uses of dredged material, and can be used to address the planning level objectives of the Delaware Estuary RSMP. Although not every contaminant that would be assessed as part of a project-specific regulatory review has been evaluated in this white paper, the selected COCs include those that have previously been shown to limit uses within the Delaware Estuary.

Under their Clean Water Act (CWA) Integrated Assessment programs, every even numbered year the states of Delaware and New Jersey, and the Commonwealth of Pennsylvania, compile and submit to the USEPA lists of water bodies not supporting designated uses. These state CWA Section 303(d) lists of water quality impairments also identify the causes of the impairments, including contaminants. A review of the listed segments along the Delaware River for the 2008 Integrated Assessment cycle (Table 1) shows all three states have listed polychlorinated biphenyl (PCBs) as a cause of impaired uses, with both New Jersey and Delaware also listing arsenic, mercury, and chlorinated pesticides.

Table 1. Chemicals Listed in the Delaware Estuary Reaches of the 2008 State Clean Water Act 303(d) Lists.

Delaware	New Jersey	Pennsylvania
PCBs	PCBs	PCBs (fish consumption)
Chlorinated pesticides	DDT/DDD/DDE	
	Dieldrin	
	Chlordane	
Arsenic	Arsenic	
Iron	Cadmium	
	Copper	
	Lead	
Mercury	Mercury	
Dioxin		

The USEPA had developed a list of priority Persistent Bioaccumulative and Toxic (PBT) chemicals (http://www.epa.gov/pbt/pubs/cheminfo.htm). This list also included PCBs, mercury, and chlorinated pesticides (chlordane and dichlorodiphenyltrichloroethane [DDT]/dichlorodiphenyldichloroethane [DDD]/ dichlorodiphenyldichloroethylene [DDE]), as well as dioxins/furans and benzo(a)pyrene.

Given the contaminants listed on the State CWA Section 303(d) and USEPA PBT lists, the planning-level objectives of the Delaware Estuary RSMP, and the limited resources and time available to complete this effort, the Sediment Quality Committee determined that the following COCs would be evaluated in the *Sediment Quality White Paper*:

- total PCBs
- total dioxins/furan Toxic Equivalency Quotient (TEQ)
- DDT and metabolites
- total chlordane
- dieldrin
- benzo(a)pyrene (BaP)
- mercury
- arsenic
- metals – cadmium, cobalt, copper, and lead.

It is important to emphasize that the Sediment Quality Committee’s use of these selected COCs is only appropriate to address the planning-level objectives of the Delaware Estuary RSMP. Future project-specific regulatory, management, or remedial decisions concerning sediment/dredged material will not be limited to these contaminants and will require more detailed project-specific evaluations of proposed aquatic habitat restoration and upland beneficial use projects.

Sediment Quality Thresholds

Given the complex nature of sediment, selecting criteria/guidelines to evaluate sediment quality can be difficult. Most ecotoxicologists agree that it is best to use a variety of metrics and a weight of evidence approach to address this problem. The Sediment Quality Committee has considered a variety of criteria and guidelines that are currently in use in the Delaware Estuary to evaluate sediment quality, including:

- state regulatory criteria used to evaluate the placement of fill (soil, dredged material, etc.) at upland sites;
- sediment quality guidelines (SQG) used for ecological effects screening purposes;
- state and Delaware River Basin Commission (DRBC) water quality criteria;
- state criteria used to develop fish advisories; and
- eco-effects data for toxicity, bioaccumulation, and community health indices.

To evaluate sediment quality at the planning level of the Delaware Estuary RSMP, the Sediment Quality Committee has developed a set of thresholds (i.e. critical contaminant concentrations) for each COC that indicates potential/probable limitations on the beneficial use of dredged material in aquatic habitat restoration or upland projects. The primary objective of the *Sediment Quality White Paper* is to use this threshold framework to evaluate the nature and geographical extent of sediment quality in the Delaware Estuary at the planning level, and to categorize sediment along a range in quality from “likely suitable for all beneficial uses” to “likely suitable for none.” Figure 1 shows the framework for this evaluation in which sediment is characterized as:

> (1) *probably suitable for all beneficial uses* – the concentrations of all COCs are lower than the Effects Range-Low (ERL)/Threshold Effects Level (TEL) for aquatic toxicity;
>
> (2) *probably not suitable for aquatic habitat restoration, but potentially suitable for at least some upland beneficial uses* - the concentration of at least one COC is greater than the Effects Range-Median(ERM)/Probable Effects Level (PEL) for aquatic toxicity and the concentrations of all COCs are less than the Highest Non-residential Threshold for upland beneficial use; or
>
> (3) *probably not suitable for either aquatic habitat restoration or any upland beneficial use* - the concentration of at least one COC is greater than the Highest Non-residential Threshold.

Selection of the sediment quality threshold concentrations used in the analyses is discussed in Appendix A, with the actual thresholds in Table A-1. These thresholds do not consider the physical suitability of dredged material for a specific beneficial use.

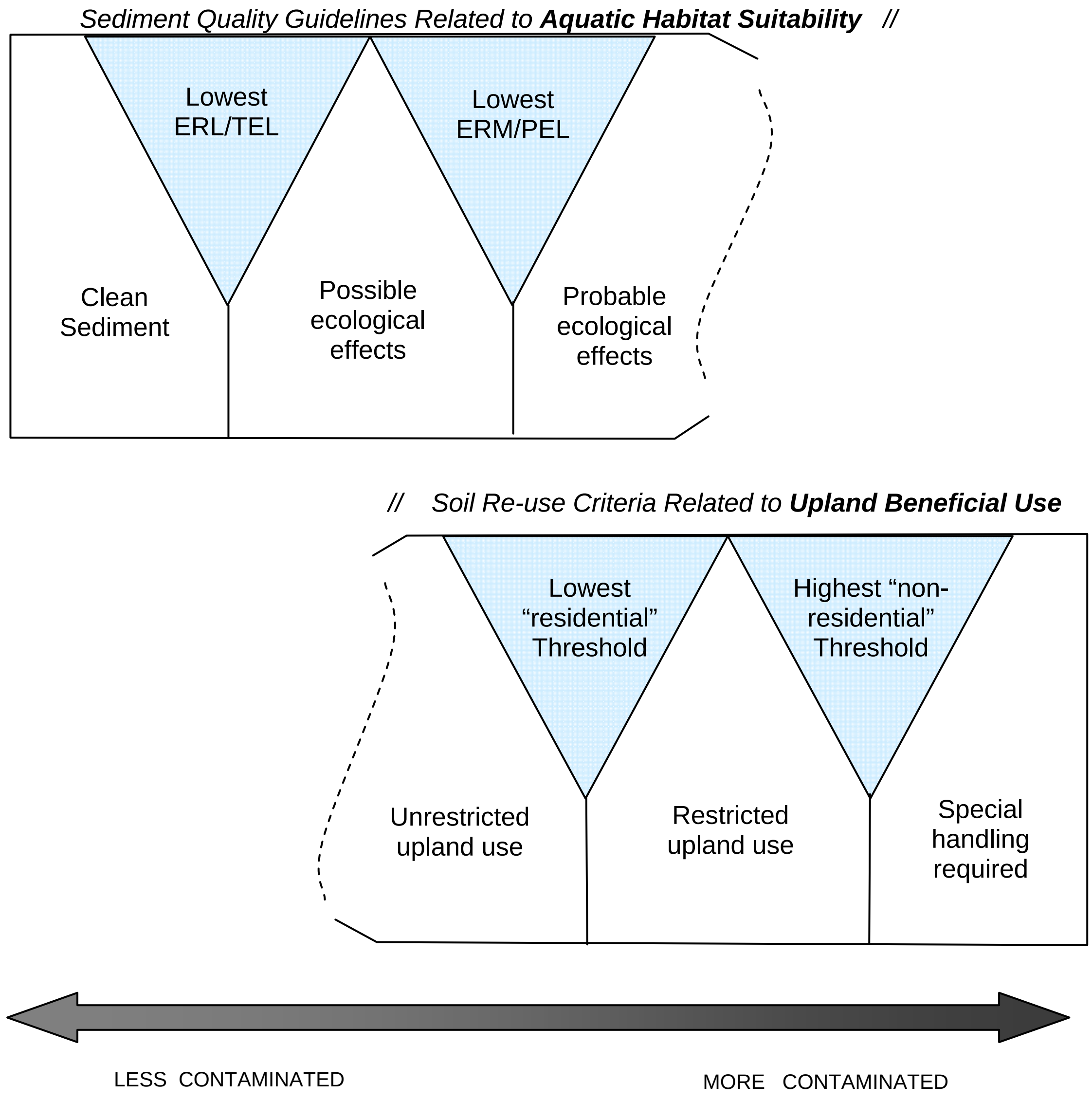
The Upland Beneficial Use threshold COC concentrations are derived from the regulatory criteria used by the three states to determine if soil (or other fill material) is acceptable for use in “residential” or “non-residential” areas. While each state has its own set of regulatory criteria, it is relatively simple to combine the individual state criteria into a composite set of thresholds. The use and interpretation of these composite Upland Beneficial Use thresholds are fairly straight-forward, as described below:

- If all of the COC concentrations in a sediment sample are less than the Lowest Residential Thresholds (LRT), the sediment is probably suitable for “unrestricted” upland beneficial use.
- If the concentration of at least one COC in a sediment sample is greater than the LRT, and the concentrations of all of the COCs are less than the Highest Non-Residential Threshold (HNRT), the sediment is probably suitable for “restricted/limited” upland beneficial uses.
- If the concentration of at least one COC in a sediment sample is greater than the HNRT, the sediment is probably unsuitable for upland beneficial use.

In contrast, the derivation, use, and interpretation of the aquatic habitat restoration suitability threshold COC concentrations are more complex and subjective in nature. Briefly, the SQG used in the threshold analysis - ERL/TEL and ERM/PEL – are derived from statistical analyses of large data sets relating the concentrations of the COCs in sediment and the resulting potential for the sediment to be toxic to benthic biota (Table A-1). The SQGs are not regulatory criteria, but “tools” that can be used (usually as part of a “weight of evidence approach”) to provide an indication of the potential likelihood that sediment with given

COC concentrations <u>may</u> be toxic. Although it is a simplification, one way to use and interpret the SQG thresholds is the following:

Figure 1. Categories of sediment quality and corresponding thresholds.



- If all of the COC concentrations in a sediment sample are less than the ERL/TELs, the sediment can be considered to be “clean” and probably suitable for aquatic habitat restoration.
- If the concentration of at least one COC in a sediment sample is greater than the ERL/TEL, and the concentrations of all of the COCs are less than the ERM/PELs, there is a small probability that the sediment may be toxic to aquatic biota.
- If the concentration of at least one COC in a sediment sample is greater than the ERM/PEL, there is a moderate probability that the sediment may be toxic to aquatic biota.

The more COCs in a sediment sample that have concentrations greater than the ERL/TEL and/or ERM/PEL, the greater the likelihood (i.e. “weight of evidence”) that the sediment may be toxic to aquatic biota. The higher the concentration of a COC relative to its SQG, the greater the likelihood that the sediment may be toxic to aquatic biota. However, the SQGs do not consider synergistic and antagonistic effects of the COCs on toxicity. The only way to determine if the sediment is actually toxic to biota is to conduct appropriate species- and site-specific sediment toxicity tests. Sediment may be toxic to some species (and to varying degrees), and not to others.

The SQGs used in the Aquatic Habitat Restoration Suitability Threshold Analysis do not consider the bioaccumulation of the COCs in estuarine food webs and the resulting possible effects on the aquatic ecosystem. Some COCs may be bioaccumulated to levels of concern even though the sediment COC concentrations are lower than the ERL/TELs. The use of SQGs that only reflect potential sediment toxicity may underestimate overall impacts to the aquatic ecosystem resulting from sediment contamination.

By its decisions to use the selected SQG/criteria concentrations, the committee is not judging the merits of other SQG/criteria. In addition, the committee emphasizes the inherent limitations on the use of SQGs to predict the suitability of sediment for an aquatic habitat restoration project, because SQGs only consider the potential toxic effects of contaminants.

Methods – Sediment Data Compilation and Analysis

The Sediment Quality Committee used historical data to describe and evaluate the quality of sediment in the Delaware River and Estuary from the head-of-tide at Trenton, New Jersey to the mouth of Delaware Bay. The committee compiled a database (the Delaware Estuary RSMP Sediment Quality Database; see Appendix B) of readily available sediment quality data in the Delaware Estuary. The sources of data included the URS/DuPont “Delaware Estuary Electronic Database”, USACE and non-federal dredging project reports, National Oceanographic and Atmospheric Administration (NOAA) Status and Trends reports, USEPA Regional Environmental Monitoring and Assessment Program (REMAP) and other reports, U.S. Geological Survey (USGS) and DRBC monitoring data, and university studies. Sediment data collected in association with smaller public and private dredging projects were not included in the database. The database included data from 109 sediment samples collected by NOAA National Coastal Assessment studies completed in 2003 through 2006; however, these data were not included in the analyses[1].

The Delaware Estuary RSMP Sediment Quality Database includes sediment samples collected in the Delaware Estuary from 1990 to 2009 (details included in Appendix C). Although some pre-1990 data are available, the Sediment Quality committee determined the use of older data problematic due to quality assurance concerns (elevated analytical detection limits relative to the selected sediment quality thresholds). Most of the PCB and pesticide data are from older samples (collected before 2001) analyzed using methods with detection limits greater than the aquatic habitat restoration suitability and upland beneficial use threshold criteria. This results in many of the sediment samples having non-detected

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[1] The Sediment Quality Committee was unaware of the data when the analyses were conducted.

concentrations for these COCs that are difficult to use and interpret. Elevated analytical detection limits for benzo(a)pyrene pose similar problems when using the sample data.

The rationale used to develop the sediment threshold concentrations is discussed in detail in Appendix A. The data for every sediment sample and COC were compared to the thresholds. Separate matrices have been prepared for each COC that identify the most stringent sediment evaluation criteria (aquatic habitat restoration suitability, upland beneficial use) met by each sediment sample for each COC. In addition, composite matrices have been developed that combine all of the data for the COCs and identify the most stringent sediment evaluation criteria met for each sample. The results of the sediment quality Aquatic Habitat Restoration Suitability and Upland Beneficial Use Threshold Analyses (i.e. the composite matrices) have been displayed on a series of GIS-based maps of the Delaware Estuary RSMP study area using a color-coded display system (Appendix E).

The GIS-based maps were used by the Sediment Quality Committee to evaluate the nature and extent of sediment quality in the Delaware Estuary. This evaluation focused on identifying (a) COCs present at concentrations that would potentially/probably limit the beneficial uses of dredged material, and (b) geographic areas where the concentrations of the COCs would potentially/probably limit the beneficial uses of dredged material. This geographic analysis was conducted at the level of the Delaware River "water quality zones" established by the DRBC (http://www.state.nj.us/drbc/).

Limitations on the Uses of the Results of this Sediment Quality Evaluation

The sediment quality analyses presented and discussed in this white paper are designed and intended solely to support the planning objectives and development of the Delaware Estuary RSMP. The main purpose of this white paper is to screen the available sediment quality data in the Delaware Estuary to evaluate its potential suitability for a variety of dredged material beneficial uses. While the Sediment Quality Committee believes that the evaluations conducted in this white paper are useful for planning purposes, more detailed project-specific sediment/dredged material sampling, testing, and evaluation will be needed to support the review of proposed aquatic habitat restoration or upland beneficial use projects by state and federal regulatory agencies. **The Delaware Estuary RSMP Sediment Quality Database, selected sediment quality thresholds, and results of the white paper cannot be used to make regulatory decisions concerning specific proposed projects.**

In order to accomplish its objectives, the Sediment Quality Committee established a set of sediment quality benchmarks to screen the available sample data for a selected set of COCs. The data evaluated primarily represent *in situ* bulk sediment chemistry concentrations of these COCs. While the presence of these COCs in the sediment may be indicative of potential problems with the beneficial use of dredged material, additional contaminants not evaluated in this white paper may also prove to be problematic; this limits the project-specific utility of the results.

The benchmarks selected for use by the Sediment Quality Committee were either used in existing regulatory programs (for example, New Jersey's Site Remediation Program) or widely accepted in the scientific literature (Sediment Quality Guidelines). However, the use of these benchmarks is itself subject to limitations and uncertainty as a result of the methods used to develop them, and their application to the Delaware Estuary must be qualified accordingly.

Finally, once dredged and otherwise managed (for example, placed in an upland confined disposal facility, a common practice in the Delaware Estuary), physical and chemical changes in the sediment/dredged material will occur, resulting in changes in the bulk chemistry contaminant concentrations (including the bioavailable fractions). Thus, *in situ* bulk sediment chemistry data provide limited information and can only be used as part of an initial (Tier I; USACE, 2003 and USEPA/USACE, 1998) evaluation of the suitability of dredged material for a proposed beneficial use. Additional Tier II and (potentially) Tier III analyses are needed to fully evaluate the suitability of dredged material for a proposed aquatic habitat restoration or upland beneficial use project. In particular, Tier III analyses – which involve direct assessment of the potential toxic and bioaccumulation impacts of dredged material – are almost always needed to evaluate the suitability of dredged material for a proposed aquatic habitat restoration project.

Results and Discussion

Types of Sediment Samples

Figure 2 shows the locations of the 932 sediment samples in the Delaware Estuary RSMP Sediment Quality Database and evaluated in this white paper. Each surface grab sample location shown in Figure 2 represents a single sample. In contrast, each core or composite sample location shown in Figure 2 can represent one or more sections of a core sample collected at that location. Overall, 77% of the sediment samples were grab samples, 21% core samples, and 2% composite samples.

The majority of the sediment samples were collected in DRBC Zone 5 (25%) of the Delaware River and in Zone 6-Delaware Bay (32%). About 11% of the samples were collected in each of DRBC Zone 3 and Zone 4, while only 4% of the samples were collected in DRBC Zone 2. Seventeen percent (17%) of the sediment samples were collected in estuary watershed tributaries, and almost all of these were grab samples.

The numbers of samples analyzed for each of the COCs are summarized in Table 2. Relatively large numbers of sediment samples were analyzed for metals (including mercury), PCBs, and chlorinated pesticides, with fewer samples analyzed for polycyclic aromatic hydrocarbons (PAHs). There are only limited data available for cobalt, and very few sediment samples were analyzed for dioxins/furans.

With the exception of cobalt and benzo(a)pyrene, most of the available data comes from surface grab samples, and almost all of the core and composite sediment samples were collected in navigation channels. There are also some large spatial gaps in sediment data from core samples, as well as areas with very few core samples (Figure 2). There are comparatively less data on buried sediment and by extension, historical sediment contamination in the Delaware Estuary, than on surface sediment.

The available sediment data for each of the COC also varies among the DRBC Zones (Table 3).

Figure 2: Locations of the surface grab, core, and composite sediment samples compiled into the Delaware Estuary RSMP Sediment Quality Database.

Placeholder for figure

Table 2: Number of sediment surface grab and core samples analyzed for each COC.

Contaminant of Concern	Number of Grab Samples	Number of Core Samples
Mercury Arsenic Cadmium Copper Lead	~ 600 Varies slightly with each COC	~195 Varies slightly with each COC
Cobalt	28	69
Total PCBs	441	151
Total Dioxin/Furan TEQ	24	0
4,4'-DDT	327	193
4,4'-DDD	312	193
4,4'-DDE	312	185
Chlordane	362	193
Dieldrin	311	193
Benzo(a)pyrene	135	193

Table 3: Approximate percentages of available sediment sample data for each COC by DRBC-designated Water Quality Zone.

Contaminant of Concern	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Watershed Tributaries
Mercury Arsenic Cadmium Copper Lead	3	11	12	24	33	17
Cobalt	0	39	12	11	0	37
Total PCBs	4	12	10	28	24	22
Total Dioxin/Furan TEQ	0	0	8	50	42	0
4,4'-DDT	5	17	14	24	20	21
4,4'-DDD	3	16	13	20	24	25
4,4'-DDE	3	15	13	20	24	25
Chlordane	5	16	13	23	22	22
Dieldrin	3	16	13	20	24	24
Benzo(a)pyrene	3	26	15	23	18	16

Sediment Contaminant Concentrations

Statistical summaries of the available bulk sediment chemistry data for each of the COCs are available in Appendix D.

Table 4 shows the observed trends in the magnitude of sediment COC concentrations by DRBC Zones and in tributaries to the estuary. Statistically significant differences in the concentrations of the COCs in the DRBC Zones are delineated in Table 4 (except as noted; pair-wise two-tailed t-tests, unequal variance, $p < 0.05$).

Table 4: Observed Trends in Mean Sediment Contaminant Concentrations by DRBC Zone[#].

Contaminant	DRBC Zones or Delaware River Tributaries			
Arsenic	Tributaries = Zone 5 >	Zone 2 = Zone 3 = Zone 4 >	Zone 6	
Cadmium	Zone 2 = Zone 3 >	Tributaries >	Zone 4 = Zone 5 >	Zone 6
Cobalt	Tributaries >	[a]Zone 3 = Zone 4 = Zone 5	No Data: Zone 2 & Zone 6	
Copper	Tributaries = Zone 2 >	[b]Zone 3 >	Zone 4 = Zone 5 >	Zone 6
Lead	Tributaries = Zone 2 = Zone 3 >	Zone 5 >	Zone 4 >	Zone 6
Mercury	Tributaries >	[c]Zone 2 = Zone 3 = Zone 5 >	Zone 4 >	Zone 6
Benzo(a)pyrene	Tributaries >	Zone 2 = [d]Zone 3 = Zone 4 = [d]Zone 5 = Zone 6		
4,4'-DDT	Zone 3 >	[e]Zone 2 = Zone 4 = Zone 5 = Tributaries >	Zone 6	
4,4'-DDD	Zone 2 = Zone 3 = Zone 4 = Zone 5 = Tributaries >	Zone 6		
4,4'-DDE	[f]Zone 2 ≥	[g]Zone 3 = Zone 4 = Zone 5 = Tributaries >	Zone 6	
Chlordane *	Zone 4 = Zone 5	Zone 3 >	Zone 6 = Tributaries >	Zone 2
Dieldrin	Tributaries = Zone 3 = Zone 4 = Zone 5 >	Zone 2 = Zone 6		
PCBs	Tributaries = Zone 3 = Zone 5 >	[h]Zone 4 = Zone 2 >	Zone 6	
PCDD/Fs**	Zone 5 >	Zone 4 = Zone 6	No Data: Zone 2, Zone 3, & Tributaries	

Statistical Exceptions:

a: cobalt – Zone 3 > Zone 4 $p = 0.0066$

b: copper - Tributaries > Zone 3 $p = 0.081$ NS

c: mercury – Tributaries > Zone 2 $p = 0.066$ NS

d: benzo(a)pyrene - Zone 3 & Zone 5 > Zone 6 $p << 0.001$

e: 4,4'-DDT - Zone 3 > Zone 2 $p = 0.166$ NS

f: 4,4'-DDE - Zone 2 > Zone 3 $p = 0.98$ NS; Zone 2 > Zone 4 $p = 0.725$ NS

g: 4,4'-DDE Zone 3 > Zone 5 $p = 0.040$

h: PCBs – Tributaries > Zone 4 $p = 0.064$ NS

** Due to the limited number of samples, statistical analyses were not performed on the PCDD/F data.

*Due to a large percentage of samples with non-detected Chlordane concentrations (55% of the available data), with variable detection limits, trends in the mean and median total Chlordane concentrations among the DRBC Zones differed. Trends in the mean total Chlordane concentrations are as shown in Table 4:

Zones 4 & 5 (~ 42 ug/kg) > Zone 3 (25 ug/kg) > Zone 6 (11 ug/kg) > Zone 2 & Tributaries (6 ug/kg).

Median total Chlordane concentrations were substantially lower, and with different trends:

Zones 2, 3 & 4 (~ 5 ug/kg) > Zone 5 (1.4 ug/kg) > Tributaries (0.8 ug/kg) > Zone 6 (0.2 ug/kg).

Despite the statistically significant differences shown in Table 4, the concentration of each COC in the available sample data varied considerably within each DRBC Zone. However, sediment COC concentrations were consistently lowest in DRBC Zone 6 (Delaware Bay).

For each of the COCs, contaminant concentrations were not detected in some of the sediment samples. To avoid the bias created by using a zero (0) value in place of a non-detect, one-half the detection limit was used for all non-detects. This is a common practice even though it may under or overestimate the actual COC concentrations.

Table 5 lists the percentages of the available data for each COC that were non-detect. For some COCs, the number of non-detects reported was a large percentage (pesticides and benzo(a)pyrene). For these COCs, the concentrations in the database may be more indicative of the elevated detection limits of the analytical methods than of actual sediment concentrations. Some of the non-detect samples were not used in the Aquatic Habitat Restoration Suitability and/or Upland Beneficial Use Threshold Analyses; for a more detailed discussion, see Appendix C.

Table 5: Percentage of non-detects

COCs	Percentage of Non-Detects
Mercury	20.2%
Arsenic	1.1%
Cadmium	8.8%
Cobalt	0%
Copper	1.8%
Lead	1.0%
Total PCBs	22.5%
Total Dioxin/Furan TEQ	4.2%
4,4'-DDT	64.5%
4,4'-DDD	42.5%
4,4'-DDE	34.3%
Chlordane	54.7%
Dieldrin	61.9%
Benzo(a)pyrene	41.6%

Aquatic Habitat Restoration Suitability Threshold Analysis Results

Figure 3 (and Appendix E) shows the results of the Aquatic Habitat Restoration Suitability Threshold Analysis. Overall, the samples were fairly evenly split among the three sediment quality categories:

- 35% of the samples did not have a COC concentration greater than the ERL/TEL (Category 0);
- 34% of the samples had at least one COC concentration greater than the ERL/TEL and no COC concentration greater than the ERM/PEL (Category 1);
- 31% of the samples had at least one COC concentration greater than the ERM/PEL (Category 2).

Based on concentrations of the selected COCs, approximately 35% of the sediment samples are probably clean enough to be beneficially used in aquatic habitat restoration projects (no COC > ERL/TEL), and an additional 34% of the samples are potentially clean enough for such beneficial uses (one or more COC > ERL/TEL, but none > ERM/PEL). About 31% of the samples are problematic for their suitability for beneficial use in aquatic habitat restoration projects (at least one COC > ERM/PEL). This threshold analysis did not consider the magnitude of the observed ERL/TEL and ERM/PEL COC exceedances.

In general, sediment quality relative to the three aquatic habitat restoration suitability threshold categories is heterogeneous throughout the Delaware River - “cleaner” sediment samples are usually interspersed among “more contaminated” samples (Figure 3). Despite this, a number of “geographic locations of interest” were identified where a large percentage of the sediment samples had at least one COC with a concentration greater than the ERM/PEL. Except in Delaware Bay (DRBC Zone 6), sediment samples with at least one COC concentration greater than the ERM/PEL can be frequently found throughout the Delaware River and its tributaries.

Figure 4 shows the fraction of samples in each DRBC Zone from the three aquatic habitat suitability restoration threshold categories; this analysis did not include a number of samples that were non-detect for pesticides and PCBs (Appendix C). DRBC Zone 6 had the largest percentage of samples with no COC concentration greater than the ERL/TEL (71.5%), and the smallest percentage of samples with a COC concentration greater than the ERM/PEL (1.3%; only 4 samples). Sediment samples with at least one COC concentration greater than the ERM/PEL were found most frequently in DRBC Zone 3 (70.5%), Zone 2 (58.3%), and in the tributary samples (50.6%). These three regions also had the lowest percentages of samples that did not have a COC concentration greater the ERL/TEL (10.5-16%).

Based on this analysis, from a contaminant standpoint, dredged material from DRBC Zone 6 would probably be suitable for aquatic habitat restoration beneficial use projects. In contrast, the beneficial use of dredged material from DRBC Zone 2, Zone 3, and the estuary tributaries would probably be problematic for such projects. Dredged material from DRBC Zone 4 and Zone 5 appear to have some potential to be beneficially used for aquatic habitat restoration projects. This uncertainty underscores the committee's belief that the **suitability of dredged material for a proposed aquatic habitat restoration beneficial use project must be thoroughly evaluated using project-specific data.**

Figure 3: Results of the aquatic habitat suitability threshold analysis.

Placeholder for figure

Figure 4: Aquatic Habitat Suitability Restoration Threshold Analysis - Fraction of the Sediment Samples in Each DRBC Zone

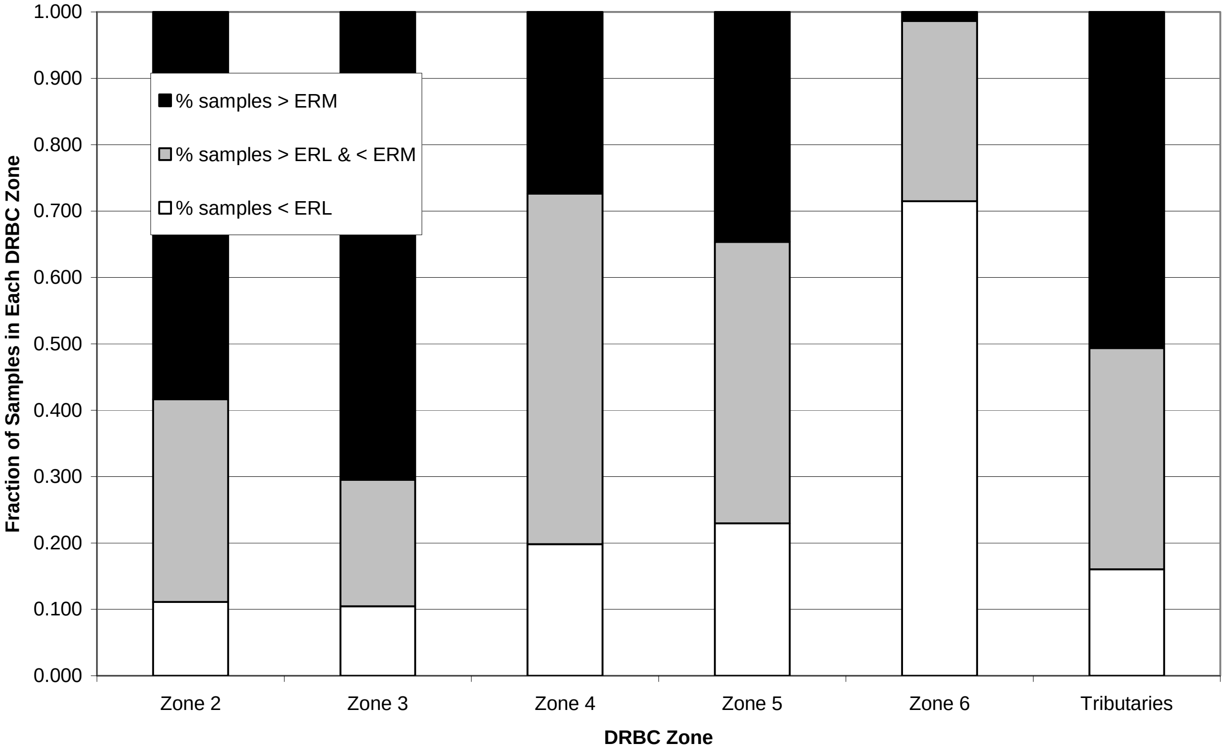


Table 6 shows the percentage of samples collected in each of the DRBC Zones that exceeded the ERM/PEL for each COC; this analysis did not include a number of samples that were non-detect for pesticides and PCBs (Appendix C). Only four of the samples from DRBC Zone 6 had a COC concentration greater than the ERM/PEL: arsenic (3 samples) and cadmium (1 sample). A wide variety of the COCs are present in the other areas of the estuary at concentrations that could potentially make dredged material unsuitable for aquatic habitat restoration beneficial use projects. In particular, the following COCs were found at concentrations greater than the ERM/PEL in about 10% or more of the samples collected in a DRBC Zone:

- DRBC Zone 2 – cadmium, 4,4’-DDT/DDD/DDE, and chlordane;
- DRBC Zone 3 – cadmium, total PCBs, and 4,4’-DDT/DDD/DDE;
- DRBC Zone 4 – total PCBs and 4,4’-DDD/DDE;
- DRBC Zone 5 – arsenic and total PCBs
- Tributaries – mercury, arsenic, copper, lead, benzo(a)pyrene, total PCBs, dieldrin, 4,4’-DDD/DDE, and chlordane.

Table 6: Percentage of samples in each DRBC Water Quality Zone that exceeded the ERM/PEL for each COC.

COC	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Chlordane	30.6	7.6	2.8	0.9	0.0
Cadmium	19.4	11.4	2.8	3.0	0.3
4,4'- DDT	33.3	22.9	4.7	3.0	0.0
4,4'- DDD	30.6	21.0	9.4	5.6	0.0
4,4'- DDE	36.1	38.1	14.2	5.6	0.0
Total PCBs	0.0	31.4	12.3	22.1	0.0
Arsenic	2.8	1.0	6.6	10.8	1.0
Mercury	2.8	0.0	3.8	7.8	0.0
Lead	8.3	8.6	3.8	8.2	0.0
Total # samples =	36	105	106	231	298

Note: < 3% of the samples were > ERM/PEL for copper, benzo(a)pyrene, dieldrin, and total PCDD/F TEQ in all zones – data not shown.

Sample Data - Tributaries: 50.6% of the samples collected in the tributaries had at least one COC with a concentration exceeding the ERM/PEL.

All 35 sediment samples collected in the Schuylkill River had at least one COC with a detected concentration greater than the ERM/PEL (Figure 3). Multiple COCs were found at elevated concentrations in 30 of the Schuylkill River samples, with 18 having 4 or more COC concentrations greater than the ERM/PEL. Total PCBs, benzo(a)pyrene, 4,4'-DDD, 4,4'-DDE, copper, lead, and mercury were found at concentrations greater than the ERM/PEL in 10 or more of the Schuylkill River samples; lead concentrations exceeded the ERM/PEL in 32 of the samples. In addition, non-detects with elevated detection limits affected the usability of 13 PCB samples, 22 4,4'-DDT samples, and 14 4,4'-DDD and 4,4'-DDE samples. Based on these data, it is unlikely that dredged material from the Schuylkill River will be suitable for aquatic habitat restoration beneficial use projects.

The remaining 44 tributary sediment samples with elevated COC concentrations were distributed throughout the estuary watershed. A variety of COCs had concentrations greater than the ERM/PEL, with arsenic and lead most frequently found at elevated concentrations. Thirty-four (34) of these 44 samples had only one or two COCs present at elevated concentrations. More detailed project-specific investigations and geospatial analyses are needed to further evaluate the potential suitability of dredged material from the individual tributaries for aquatic habitat restoration beneficial use projects.

Sample Data - Delaware River DRBC Zones 2 through 5: Considering only the samples collected in DRBC Zones 2-5, 204 samples (42.7%) collected along this length of the Delaware River had at least one COC concentration greater than the ERM/PEL. Only four of the COCs were found at elevated concentrations in more than 10% of the samples: total PCBs (20.3%), 4,4'-DDE (16.9%), 4,4'-DDD (11.7%), and 4,4'-DDT (10.0%).

There appear to be trends along the Delaware River DRBC Zones in those COCs that are more frequently found in sediment at concentrations greater than the ERM/PELs:

Zone 2	Zone 3	Zone 4	Zone 5
chlordane			
cadmium	cadmium		
4,4’-DDT/D/E	4,4’-DDT/D/E	4,4’-DDD/E	
	total PCBs	total PCBs	total PCBs
			arsenic

Based on all of the sample data, the mean chlordane concentration in DRBC Zone 2 is significantly lower than in DRBC Zones 3-5 (Table 4). However, while chlordane was detected in all of the Zone 2 samples, it was not detected in 63% of the DRBC Zone 3-5 samples. Eighty-three per cent (83%) these non-detects had one-half detection limits greater than the ERL/TEL, and thus were omitted from the Aquatic Habitat Restoration Suitability Threshold Analysis (Appendix C). In DRBC Zones 3-5, where chlordane was detected, its concentration was greater than the ERM/PEL in only 12% of the samples (compared to 30.6% of the DRBC Zone 2 samples). Thus, while it appears that chlordane may frequently limit aquatic habitat restoration beneficial uses of dredged material from DRBC Zone 2, the evaluation and interpretation of the chlordane data in DRBC Zones 3-5 are hampered by the large number of non-detects.

The mean cadmium concentrations in DRBC Zone 2 and Zone 3 were comparable, and statistically significantly greater than the mean concentrations for DRBC Zone 4 and Zone 5 (Table 4). The mean arsenic concentration in DRBC Zone 5 was significantly greater than in DRBC Zones 2-4 (Table 4). The Aquatic Habitat Restoration Suitability Threshold Analysis results and the sediment concentration data indicate that cadmium (in DRBC Zone 2 and Zone 3) and arsenic (in DRBC Zone 5) may frequently limit potential dredged material aquatic habitat restoration beneficial uses compared to other areas along the Delaware River.

Based on all of the sample data, the mean 4,4’-DDT, 4,4’-DDE, and 4,4’DDD concentrations were generally similar in DRBC Zones 2-5 (Table 4). Non-detects that had one-half detection limits greater than the ERL/TEL were omitted from the Aquatic Habitat Restoration Suitability Threshold Analysis (Appendix C). The sediment concentration data and results of the Aquatic Habitat Restoration Suitability Threshold Analysis indicate that 4,4’-DDT/DDD/DDE may frequently limit aquatic habitat restoration beneficial uses of dredged material from DRBC Zones 2-4 along the Delaware River.

Mean total PCB concentrations were significantly higher in DRBC Zone 3 and Zone 5 compared to DRBC Zone 2 and Zone 4 (Table 4). PCBs were detected in all of the DRBC Zone 2 samples, but 29-33% of the samples in each of DRBC Zones 3-5 were non-detects. Ninety-six samples from DRBC Zones 3-5 had a total PCB concentration greater than the ERM/PEL, but 66 of these samples (69%) were non-detects with one-half detection limits greater than the ERM/PEL. Use of the total PCB non-detects could potentially give false exceedances of the aquatic habitat restoration suitability threshold in a substantial percentage of the samples in DRBC Zones 3-5 (Appendix C).

Geographic Locations of Interest: In addition to the general trends in COC concentrations along the Delaware River that could potentially limit the suitability of dredged material for aquatic habitat restoration beneficial uses, a number of geographic locations were identified (e.g. the Schuylkill River) where 100% of the samples had at least one COC with a concentration greater than the ERM/PEL.

In DRBC Zone 3, downstream of the Walt Whitman Bridge, nine samples exceeded the ERM/PEL for at least one COC (Figure 3 and Figure 5). Three of these samples, collected in the Delaware River Main Navigation Channel, were non-detects for PCBs, 4,4’-DDD, 4,4’-DDE, and chlordane, with one-half detection limit values greater than the ERM/PEL. The remaining samples were collected closer to the western shoreline of the river and in pier areas, where samples exceeded the ERM/PEL for a variety of metals (copper, cadmium, lead), total PCBs, and/or pesticides (4,4’-DDT/DDD/DDE, chlordane).

Thirteen samples collected in the Philadelphia Naval Shipyard upstream of the mouth of the Schuylkill River (DRBC Zone 4) had a variety of COCs with detected concentrations greater than the ERM/PEL

(Figure 3 and Figure 6). The total PCB concentration was greater than the ERM/PEL in all of these samples, and the 4,4’-DDT, 4,4’-DDD, and/or 4,4’-DDE concentrations were greater than the ERM/PEL in at least five samples. Except for 4,4’-DDT, these COCs were also found at elevated concentrations in the Schuylkill River. These observations suggest localized contaminant sources (e.g. industrial or stormwater discharges) and/or sediment/contaminant transport processes (from the Schuylkill River) may affect COC concentrations in the sediment in this area of the Delaware River.

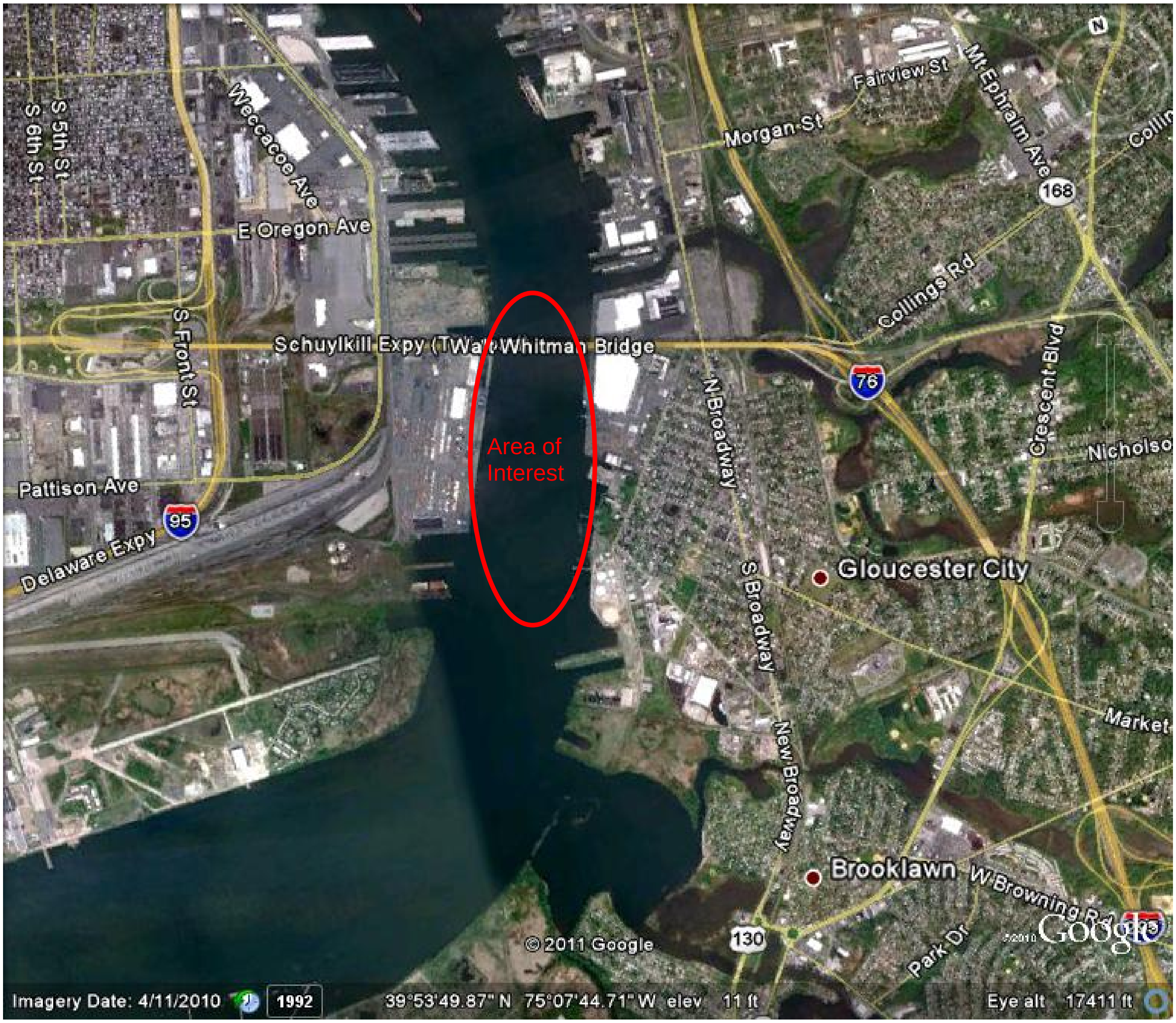


Figure 5: Area downstream of the Walt Whitman Bridge (DRBC Zone 3) with 100% sediment samples with COC concentrations greater than the ERM/PEL.

Figure 6: Area of the Philadelphia Naval Shipyard (DRBC Zone 4) with 100% sediment samples with COC concentrations greater than the ERM/PEL.

In DRBC Zone 5, upstream of Shellpot Creek, samples have a variety of COC concentrations greater than the ERM/PEL. Downstream from Shellpot Creek, samples collected off the mouth of the Christina River also have elevated COC concentrations (Figure 3 and Figure 7). Contaminants detected in the samples at concentrations greater than the ERM/PEL included arsenic, mercury, lead, and total PCBs. Three samples collected in the Christina River also had elevated mercury and/or lead concentrations, but arsenic and total PCB concentrations were less than the ERM/PEL.

Figure 7: Delaware River (DRBC Zone 5) offshore of Shellpot Creek (and upstream of the Christina River) with 100% sediment samples with COC concentrations greater than the ERM/PEL.

Also in DRBC Zone 5, offshore of the C & D Canal, a number of samples were found to have a variety of COC concentrations greater than the ERM/PEL (Figure 3 and Figure 8). Most of the samples from this area collected in the Main Channel of the Delaware River had detected concentrations of 4,4'-DDE greater than the ERM/PEL. Total PCBs were not detected in any of the navigation channel samples, with one-half detection limit values greater than the total PCB ERM/PEL (Appendix C). The samples located closer to the western shoreline of the Delaware River near Saint Georges Creek had detected concentrations of arsenic, mercury, and/or lead greater than the ERM/PEL.

Figure 8: Delaware River (DRBC Zone 5) offshore of the C & D Canal with 100% of sediment samples with COC concentrations greater than the ERM/PEL.

The data and results of the Aquatic Habitat Restoration Suitability Threshold Analysis for the DRBC Zone 5 samples are evaluated in further detail in Appendix C.

Only four sediment samples from DRBC Zone 6 had COC concentrations greater than the ERM/PEL. Most of the sediment samples from central locations in Delaware Bay had no COCs greater than the ERL/TEL (Figure 3). The concentrations of some COCs tended to be greater than the ERL/TEL along some shoreline areas of Delaware Bay and in some of its tributaries. Those areas that may need additional study include:

> Embayment near the mouths of Dennis Creek and East/West Creeks, NJ (arsenic, mercury, and cadmium);

> St. Jones River, DE (mercury, arsenic, copper, lead, total PCBs, and dieldrin);

> Maurice River, NJ and areas offshore of its mouth (mercury, arsenic, and lead).

Another indicator of the level of sediment contamination in each DRBC Zone is the number of COC ERMs/PELs exceeded by each sample (Table 7). Of the 287 sediment samples that exceeded at least one COC ERM/PEL, 134 samples (47%) exceeded only one ERM/PEL value.

Table 7: Number of Samples in Each DRBC Zone that Exceeded One or More COC ERM/PEL.

# COC ERM/PEL Exceeded	DRBC Zone 2	DRBC Zone 3	DRBC Zone 4	DRBC Zone 5	DRBC Zone 6	Tributaries	Total
1	7	34	12	49	4	28	**134**
2	3	14	7	10	0	12	**46**
3	2	14	5	7	0	10	**38**
4	6	9	3	8	0	7	**33**
5	1	3	0	1	0	7	**12**
6	2	0	2	3	0	4	**11**
7	0	0	0	2	0	6	**8**
8	0	0	0	0	0	1	**1**
9	0	0	0	0	0	3	**3**
10	0	0	0	0	0	1	**1**
Total # Samples	21	74	29	80	4	78	**287**

Five samples exceeded the ERM/PEL for eight or more of the COC, four of which were collected in the Schuylkill River; the fifth was collected from the Wissahickon Creek, a tributary of the Schuylkill River. In addition, 11 of the 17 tributary samples that exceeded the ERM/PEL for five to seven COCs were collected in the Schuylkill River. These samples were collected from 1997 to 2008, which suggests sediment in this tributary have been impacted by multiple contaminants over extended periods of time.

The remaining six tributary samples that exceeded the ERM/PEL for five to seven COCs were collected in the following tributaries: Shabakunk Creek (NJ; 7 COCs), South Branch Pennsauken Creek (NJ; 7 COCs), Cooper River (NJ; 7 COCs), Darby Creek (PA; 5 COCs), Maurice River (NJ; 5 COCs). In addition to the Darby Creek sample, four additional samples in the Delaware River (DRBC Zone 4) near the mouth of Darby Creek exceeded the ERM/PEL for two or four COCs, including mercury, arsenic, lead, total PCBs, 4,4’-DDD, 4,4’-DDE, and chlordane (Figure 9).

Six samples collected in DRBC Zone 5 exceeded the ERM/PEL for five to seven COCs (Figure 10).

Sample Data – Sample Type: Figure 11 shows that the type of sediment sample (composite, core, or grab) may be a factor affecting the aquatic habitat restoration suitability threshold. Only 18% of the composite samples exceeded the ERL/TEL or ERM/PEL, while 58% of the grab samples and 94% of the core samples exceeded the ERL/TEL or ERM/PEL. Possible explanations for these differences include:

> Thirty-nine percent (39%) of the grab samples were collected in DRBC Zone 6, compared to only 6% of the core samples; 81.5% of the core samples were collected in DRBC Zone 3, Zone 4, and Zone 5, compared to 38% of the grab samples.

> The core samples collected deeper sediment, which may have higher concentrations of the COCs (due to historical discharges) compared to the grab samples (which collect more recently deposited surface sediment).

> The core samples have been almost entirely collected by the USACE in support of federal navigation dredging projects. Analytical detection limits for many of the COC s (particularly PCBs and the other organic COCs) were elevated in many of the USACE studies, resulting in exceedances of the ERL/TEL and ERM/PEL when one-half the detection limit is used.

The potential effect of sample type on the Aquatic Habitat Restoration Suitability Threshold Analysis results is evaluated in greater detail in Appendix C. Except in DRBC Zone 5, sample type did not have a large effect on the Aquatic Habitat Restoration Suitability Threshold Analysis category.

Figure 9: Samples with multiple COCs with elevated concentrations in the Delaware River (DRBC Zone 4) offshore of Darby Creek.

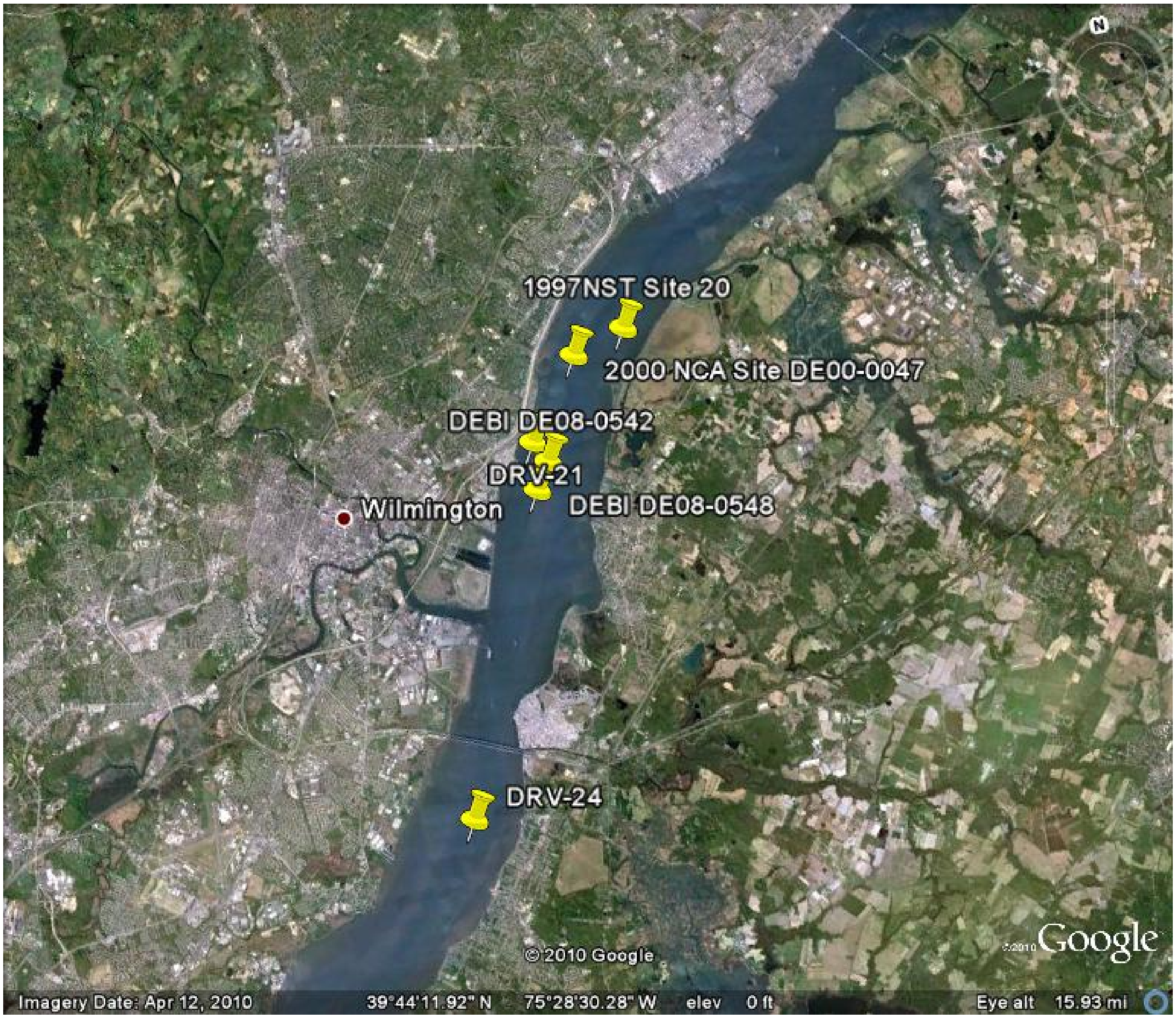
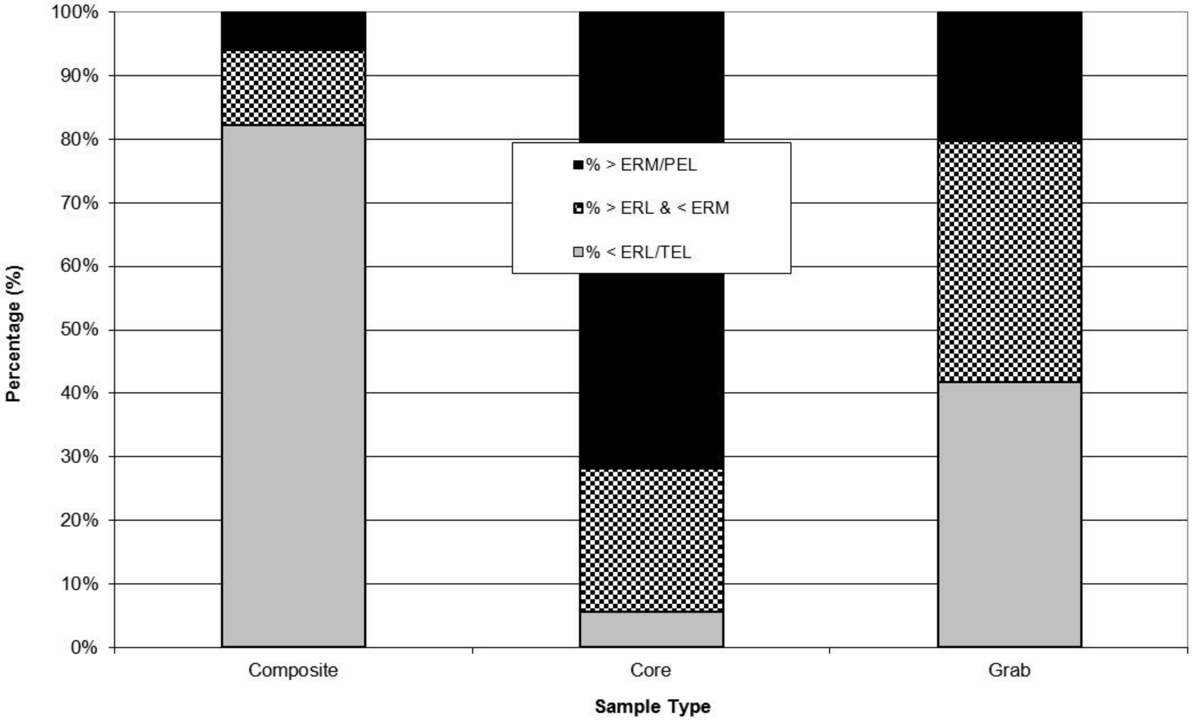


Figure 10: DRBC Zone 5 sediment samples that exceed the ERM/PEL for five to seven COCs.

Figure 11: Aquatic Habitat Restoration Suitability Threshold Analysis - Percentages of the Sediment Samples in each Threshold Category by Type of Sample



Upland Beneficial Use Threshold Analysis Results

Figure 12 (and Appendix E) shows the results of the Upland Beneficial Use Threshold Analysis for all sediment samples:

- 63% of the samples did not have a COC concentration greater than the Lowest Residential Threshold (LRT);
- 35% of the samples had at least one COC concentration greater than the LRT and no COC concentration greater than the HNRT;
- 2% of the samples had at least one COC concentration greater than the HNRT.

Based on concentrations of the selected COCs, approximately 63% of the samples are clean enough for “unrestricted” dredged material upland beneficial uses (no COCs > LRT), and an additional 35% of the samples are indicative of sediments that are potentially suitable for “limited/restricted” upland beneficial uses (at least one COC concentration > LRT and no COC > HNRT). Only 2% of the samples are indicative of sediments that are probably unsuitable for any dredged material upland beneficial uses (at least one COC concentration > HNRT). This analysis did not consider the magnitude of the observed exceedances of the LRT and HNRT.

Note: Subsequent to the completion of the threshold analysis, the sediment data for 4,4’-DDD, 4,4’-DDE, and total chlordane were added to the database and the analysis re-run. None of the samples exceeded the LRT for 4,4’-DDD and 4,4’-DDE. Four samples exceeded the LRT for chlordane, three of which were non-detects. Based on this, it was decided that revising the Upland Beneficial Use Threshold Analysis was not necessary.

In general, sediment samples suitable for “unrestricted” dredged material upland beneficial uses are interspersed among samples acceptable for “limited/restricted” upland beneficial uses. Very few locations have sediment contaminated at high levels that would make them unsuitable for any type of dredged material upland beneficial use.

Figure 13 shows the percentages of the samples in each DRBC Zone that were in each of the three upland beneficial use threshold categories. DRBC Zone 6 (Delaware Bay) had the largest percentage of samples with no COC concentration greater than the LRT (92%), and no sample from DRBC Zone 6 had a COC concentration greater than the HNRT. No samples in DRBC Zone 2 and Zone 4 had a COC concentration greater than the HNRT, and only 1-2% of the samples from DRBC Zone 3 and Zone 5 had such elevated COC concentrations. In contrast, 6.4% of the tributary samples had a COC concentration greater than the HNRT. This suggests that the tributaries are likely to be sources of contaminants to the Delaware River.

The data in Figure 13 suggest, from a contaminant standpoint, dredged material from DRBC Zone 6 (Delaware Bay) would probably be suitable for “unrestricted” upland beneficial use projects. Dredged material from DRBC Zones 2 through 5 and the tributaries would (except in a few instances) be suitable for either “unrestricted” or “limited/restricted” upland beneficial uses.

Figure 12: Results of the upland beneficial use threshold analysis.

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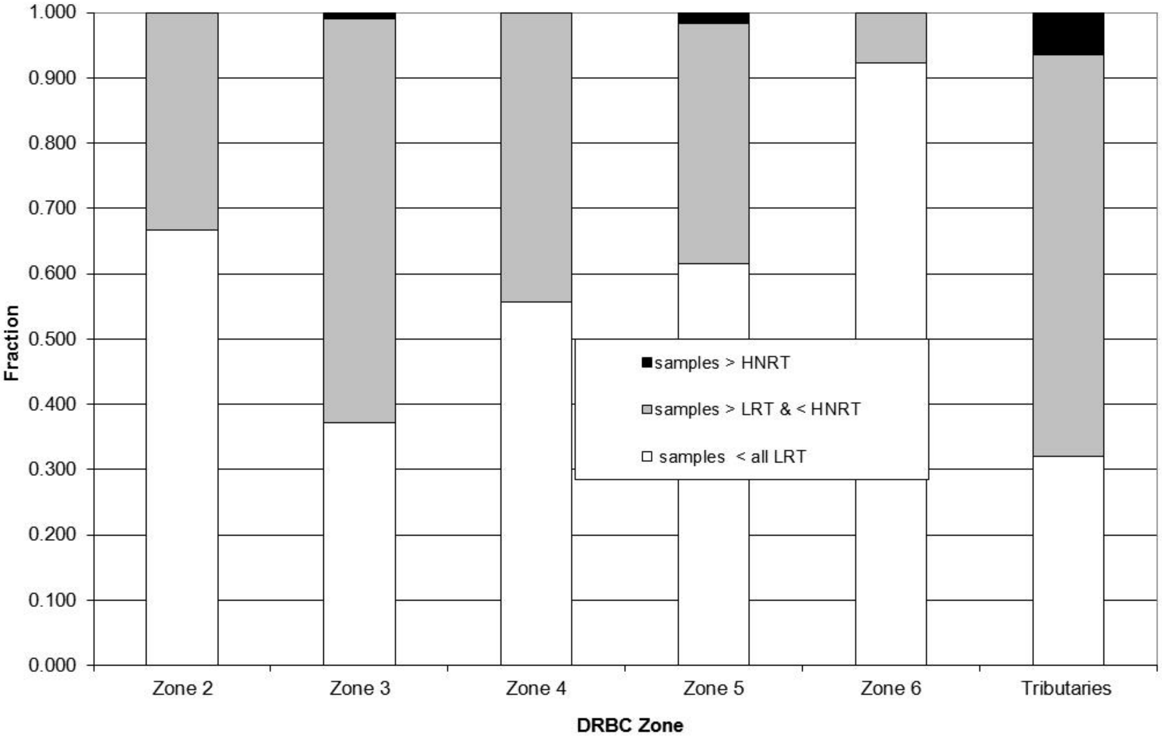
Figure 13: Upland Beneficial Use Threshold Analysis
Fraction of the Sediment Samples in Each DRBC Zone



The HNRT for arsenic, lead, and/or total PCBs were exceeded in 14 samples (Table 8).

Table 9 shows the percentage of sediment samples collected in each of the DRBC Zones that exceed the LRT for each COC. Very few of the sediment samples from DRBC Zone 6 (8%) are impacted by the COCs. Within DRBC Zones 2 through 5, potentially problematic COCs are limited to arsenic, cobalt, benzo(a)pyrene, and total PCBs. In addition to the COCs found at elevated concentrations in the Delaware River, small percentages of the tributary samples exceeded the LRT for lead (1.3%) and dieldrin (2.6%). As discussed in Appendix C, many of the samples with elevated benzo(a)pyrene, dieldrin, or total PCB concentrations may actually be non-detects, with one-half detection limits that result in false exceedances of the LRT.

Table 8: Observed Exceedances of the HNRT.

Sample ID	Arsenic	Lead	Total PCBs	Location/Date
1465950		X		1998 - N. Branch Rancocas Creek
USGS1467150	X			1999 – Cooper River
NJ01-0090-A	X			2001 – Maurice River
DE08-0542	X		X	2008 - DRBC Zone 5
DE08-0548	X			2008 - DRBC Zone 5
DRV-4			X	2005 – DRBC Zone 3
PQ-2 (surface)			X*	1992 - DRBC Zone 5
PQ-2 (depth)			X*	1992 - DRBC Zone 5
SR-771	X		X	2007 – Schuylkill River
SR-772	X		X	2007 – Schuylkill River
SR-773			X	2007 – Schuylkill River
SR-774	X		X	2007 – Schuylkill River
SR-775			X	2007 – Schuylkill River
SR-785	X			1997 – Schuylkill River
SR-787			X	1997 – Schuylkill River

X* = PCBs were not detected with detection limits 2-3 times the Highest “Non-Residential” Threshold.

Table 9: Percentage of samples in each DRBC Water Quality Zone that exceeded the LRT for each COC.

COC	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Cobalt	NSA	29.5	6.6	3.0	NSA
Total PCBs	0.0	31.4	10.4	21.6	0.0
Arsenic	22.2	12.4	10.4	21.2	3.4
Benzo(a)pyrene	13.9	37.1	29.2	15.6	4.7
Total # samples =	36	105	106	231	298

NSA = no samples analyzed for that COC

Only 97 samples were analyzed for cobalt, 80 of which exceeded the LRT. Cobalt exceedances were observed in DRBC Zone 3 (including the Fairless Turning Basin and the Philadelphia Naval Shipyard), Zone 4, Zone 5, the Schuylkill River, and a number of other smaller tributaries to the Delaware River.

The LRT for total PCBs was exceeded in 124 samples, and 10 samples exceeded the HNRT. PCBs were not detected in 77 of these samples due to elevated analytical detection limits (mean ± SD detection limit = 987 ± 372 ug/kg in these samples; LRT = 200 ug/kg); also see Appendix C.

The LRT for benzo(a)pyrene was exceeded in 161 samples. However, benzo(a)pyrene was not detected in 74 of these samples due to elevated analytical detection limits (mean ± SD detection limit = 0.562 ± 0.126 mg/kg in these samples; LRT = 0.2 mg/kg); also see Appendix C.

<u>Sample Data - Tributaries:</u> Ten of the 156 sediment samples (6.4%) collected in the tributaries had at least one COC with a concentration that exceeded the HNRT.

Seven of the samples were collected in the Schuylkill River, which has been identified as a potential contaminated sediment "hot spot" (also see ***Aquatic Habitat Restoration Suitability Threshold Analysis Results***). Arsenic and total PCBs were present at concentrations greater than the HNRT (Table 8). All but one of the other samples collected in the Schuylkill River exceeded the LRT for arsenic, total PCBs, cobalt and benzo(a)pyrene. Overall, 97% of the Schuylkill River samples had at least one COC concentration greater than the LRT.

The three remaining tributary samples with COC concentrations greater than the HNRT were collected in New Jersey waterbodies: North Branch Rancocas Creek (lead), Cooper River (arsenic), and Maurice River (arsenic). None of the other Rancocas Creek or Cooper River samples exceeded the LRT for lead or arsenic, suggesting that the very high concentrations may be isolated cases. Three of the six additional Maurice River samples had arsenic concentrations greater than the LRT, suggesting arsenic contamination may be more widespread in this tributary.

Sample Data – DRBC Zone 5: Four of the five Delaware River samples with COC concentrations greater than the HNRT were collected in DRBC Zone 5. Two of these samples had elevated concentrations of total PCBs and/or arsenic, and were collected near the mouth of Shellpot Creek (Table 8 and Figures 7 and 10). Additional samples collected in the vicinity of Shellpot Creek also exceeded the LRT for arsenic, cobalt, total PCBs, and/or benzo(a)pyrene. However, some (but not all) of the exceedances for total PCBs and benzo(a)pyrene occurred in samples with non-detects. The Shellpot Creek area has been identified a geographic location of interest (see ***Aquatic Habitat Restoration Suitability Threshold Analysis Results***).

The other two samples were collected in different strata of the same core sample, and were non-detect for PCBs.

Sample Data – DRBC Zone 3: One sample collected in DRBC Zone 3 had a detected total PCB concentration greater than the HNRT. This sample was collected just downstream of the Walt Whitman Bridge (Figure 5) in a previously identified geographic location of interest (see ***Aquatic Habitat Restoration Suitability Threshold Analysis Results***).

Another indicator of the level of sediment contamination in each DRBC Zone is the number of sediment samples that exceed the LRT for varying numbers of COCs (Table 10). Of the 344 sediment samples that exceeded at least one LRT, 217 samples (63%) exceeded the threshold for only one COC. This indicates that throughout the Delaware Estuary and its watershed the presence of multiple contaminants at elevated levels in sediment will probably not be of concern when evaluating the suitability of dredged material for potential upland beneficial uses.

Only seven sediment samples (2%) exceeded the LRT for four or more of the COCs. Four of these samples are located in the Schuylkill River and two were collected in DRBC Zone 5. The four Schuylkill River samples also exceeded the HNRT for at least one COC.

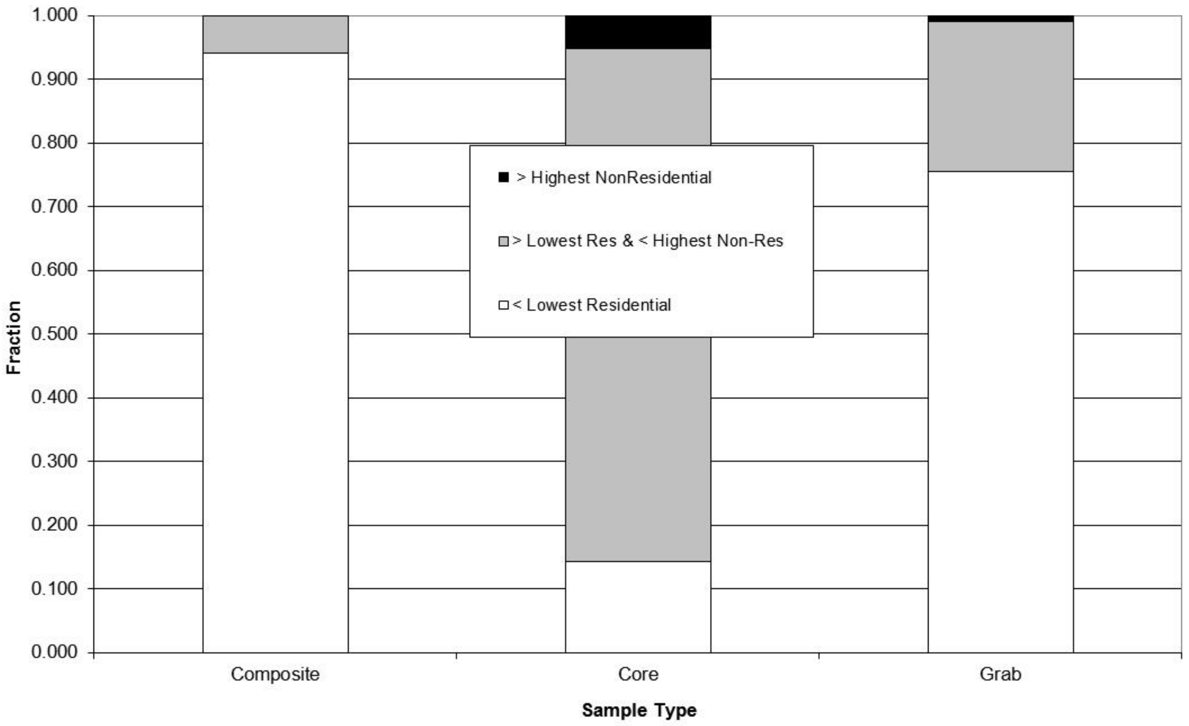
Most of the sediment samples from DRBC Zone 6 (Delaware Bay) appear to be suitable for "unrestricted" upland beneficial use; there is a very low probability of exceeding the LRT for any COC (Figure 13). However, as was the case for aquatic habitat restoration suitability, sediment of potential concern in DRBC Zone 6 appear to be limited to areas near the Delaware Bay shoreline and the mouths of certain tributaries (Maurice River, NJ; Dennis Creek, NJ; St. Jones River, DE). Arsenic and benzo(a)pyrene are potential concerns in these areas.

Table 10: Number of Samples in Each DRBC Zone that Exceeded One or More COC LRT.

# COC LRT Exceeded	DRBC Zone 2	DRBC Zone 3	DRBC Zone 4	DRBC Zone 5	DRBC Zone 6	Tributaries	Total
1	11	26	37	47	24	72	217
2	1	31	7	32	0	24	95
3	0	8	3	8	0	6	25
4	0	1	0	2	0	1	4
5	0	0	0	0	0	3	3

Figure 14 shows that the type of sediment sample (composite, core, or grab) may be a factor affecting the upland beneficial use threshold. Only 6% of the composite samples exceeded a LRT, while no composite sample exceeded a HNRT. Eighty-six per cent (86%) of the core samples exceeded a LRT, compared to 24% of the grab samples. Possible explanations for the differences observed in Figure 16 have been previously discussed in the ***Aquatic Habitat Restoration Suitability Threshold Analysis Results*** section of this report.

Figure 14: Upland Beneficial Use Threshold Analysis
Fraction of the Sediment Samples by Type of Sample



Quality Assurance Issue

When reviewing and comparing the metadata in the Delaware Estuary RSMP Sediment Quality Database with the sample locations shown on the GIS-based figures in this white paper, it was observed that some samples that were listed in the database as being located in one DRBC Zone were located within an adjacent DRBC Zone on the GIS-based maps. Such samples are usually located close to the border between DRBC Zones. These inconsistencies have not been evaluated in detail, but could result in limited errors in the various DRBC Zone-based analyses presented in this white paper.

Sediment Toxicity Data

In addition to analyzing sediment for contaminants, a number of studies conducted by NOAA and USEPA also evaluated the toxicity of the sediment to benthic biota. One method used to assess toxicity is to compare the survival of the amphipod *Ampelisca abdita* exposed to the collected sediment and a control/reference sediment in a bioassay under laboratory conditions. It should be noted that use of *A. abdita* to evaluate potential aquatic toxicity, while acceptable for marine waters, may be problematic in less saline waters of the Delaware Estuary. Additional toxicity testing of sediment from the Delaware Estuary is needed, preferably with an organism that is less sensitive to variation in salinity, such as *Leptocheirus plumulosus*.

Publicly available data (302 samples) from NOAA and USEPA bioassay studies were evaluated. Only 25 of these sediment samples (8%) had a mean survival of less than 80% in the acute toxicity tests, which is the value typically used to indicate that the sediment may be toxic to biota. Seventeen (17) of these samples exceeded one or more ERM/PEL, and three exceeded at least one ERL/TEL. Five of the samples did not exceed an ERL/TEL (Table 11).

Table 11: Number of toxic samples in various analyses for the 302 samples with *Ampelisca abdita* acute toxicity test data.

# Toxic samples	# samples > ERM/PEL	# samples > ERL/TEL
25	84	120
# Toxic samples:	17	3

Nine of the 25 toxic samples were collected in tributaries, seven in DRBC Zone 6, five in DRBC Zone 5, two in DRBC Zone 4, and one each in DRBC Zone 3 and DRBC Zone 2. This is a relatively large number of toxic samples from DRBC Zone 6 compared to the low percentage of samples in the larger database that exceed an ERL/TEL or ERM/PEL (Figure 4).

Sixty-seven (67) of the 302 samples that had a COC concentration greater than the ERM/PEL, and 117 of the samples that had a COC concentration greater than the ERL/TEL, were not toxic to *A. abdita* (Table 11). This suggests that the results of the Aquatic Habitat Restoration Suitability Threshold Analysis used in this white paper may, in general, be conservative in its predictions of the suitability of dredged material in relation to toxicity. However, five samples were toxic to *A. abdita* but did not have a COC concentration greater than the ERL/TEL.

The white paper sediment analyses did not consider potential effects of bioaccumulation and biomagnification of the COCs in aquatic food webs, populations, and communities. These effects typically occur at sediment contaminant concentrations lower than those that result in acute toxicity.

Summary and Conclusions

1. The *Sediment Quality White Paper* presents and discusses the results of a screening protocol that was developed to evaluate the potential suitability of sediment/dredged material for aquatic habitat restoration and upland beneficial uses. **Future regulatory, management, or remedial decisions concerning beneficial uses of dredged material will require more comprehensive project-specific evaluations. These would include, for most habitat restoration projects, an evaluation of potential contaminant bioavailability effects (toxicity and bioaccumulation).**

2. The Sediment Quality Committee has compiled a database of 932 *in situ* bulk chemistry sediment samples with data for the following COCs: arsenic, cadmium, cobalt, copper, lead, mercury, total chlordane, dieldrin, 4,4'-DDT/DDD/DDE, benzo(a)pyrene, total PCBs, and total dioxin/furan TEQ. Statistical analyses of the mean COC concentrations in each DRBC Water Quality Zone identified significant differences between DRBC Zones. In general, COC concentrations are consistently lowest in DRBC Zone 6 (Delaware Bay).

3. Most of the PCB and pesticide data are from older sediment samples, collected before 2001, and analyzed using methods with detection limits greater than the aquatic habitat restoration suitability and upland beneficial use threshold criteria. This results in many of the samples having non-detected concentrations for these COCs that are difficult to use and interpret. Likewise, elevated analytical detection limits for benzo(a)pyrene pose similar problems when using the data.

Aquatic Habitat Restoration Suitability Threshold Analysis

1. This analysis compared the bulk sediment chemistry data to threshold criteria based on established SQGs for toxicity to benthic organisms (ERL/TEL and ERM/PEL). Approximately 35% of the sediment samples are probably clean enough to be beneficially used in aquatic habitat restoration projects (no COC > ERL/TEL), and an additional 34% of the samples are potentially clean enough for such beneficial uses (one or more COCs > ERL/TEL, but none > ERM/PEL). About 31% of the samples appear to be problematic in regards to their suitability for beneficial use in aquatic habitat restoration projects (at least one COC > ERM/PEL).

2. Sediment quality is heterogeneous throughout Delaware River, with "cleaner" sediment samples interspersed among "more contaminated" samples. Except in Delaware Bay (DRBC Zone 6), sediment samples with at least one COC greater than the ERM/PEL can be frequently found throughout the Delaware River and its tributaries. The data suggest that dredged material from DRBC Zone 6 would probably be suitable for aquatic habitat restoration beneficial use projects, with that from DRBC Zone 4 and Zone 5 potentially suitable for such uses. In contrast, the beneficial use of dredged material from DRBC Zone 2, Zone 3, and the estuary tributaries would probably be problematic for such projects.

3. In DRBC Zones 2 through 5, some COCs are present at concentrations greater than the ERM/PEL in at least 10% of the samples collected in each zone. There appear to be trends along the Delaware River DRBC Zones in these COC:

Zone 2	Zone 3	Zone 4	Zone 5
chlordane			
cadmium	cadmium		
4,4'-DDT/D/E	4,4'-DDT/D/E	4,4'-DDD/E	
	total PCBs	total PCBs	total PCBs
			arsenic

Upland Beneficial Use Threshold Analysis

1. This analysis compared the bulk sediment chemistry data to threshold criteria for each COC based on state regulatory criteria for the placement of soil/fill at upland sites (LRT and HNRT). Approximately 63% of the samples are clean enough for “unrestricted” dredged material upland beneficial uses (no COC > LRT). An additional 35% of the samples are indicative of sediments that are potentially suitable for “limited/restricted” upland beneficial uses (at least one COC concentration > LRT, no COC > HNRT). Only 2% of the samples are indicative of sediments that are probably unsuitable for any dredged material upland beneficial uses (at least one COC concentration > HNRT). The only COCs found at concentrations greater than the HNRT were arsenic, lead, and total PCBs.

2. In general, sediment samples suitable for “unrestricted” upland beneficial uses are usually interspersed among samples acceptable for “limited/restricted” upland beneficial uses throughout the Delaware Estuary. The data suggest that dredged material from DRBC Zone 6 (Delaware Bay) would probably be suitable for “unrestricted” upland beneficial use projects. Dredged material from DRBC Zones 2 through 5 and the tributaries would (except in a few instances) appear to be suitable for either “unrestricted” or “limited/restricted” upland beneficial uses

3. The following geographic locations of interest have been identified where samples had at least one COC with a concentration greater than the HNRT, and/or a large percentage of the samples had at least one COC with a concentration greater than ERM/PEL:
    - Schuylkill River
    - DRBC Zone 3 – downstream of the Walt Whitman Bridge
    - DRBC Zone 4 – Philadelphia Naval Shipyard (near mouth of the Schuylkill River)
    - DRBC Zone 5 – near the mouths of Shellpot Creek, the Christina River, and the C & D Canal.
    - North Branch Rancocas Creek
    - Cooper River
    - Maurice River.

Recommended Actions

1. A number of data gaps have been identified that need additional study. Since sediment contamination in the Delaware Estuary appears to be present only rarely at concentrations that would preclude upland beneficial uses, these studies should focus on evaluating contaminant impacts on the suitability of the sediment for aquatic habitat restoration projects.
    a) Continued development, maintenance, and evaluation of the white paper database to include available sample data from small (i.e. non-USACE) dredging projects, as well as future larger dredging projects, research studies, etc.
    b) Collection and analysis of additional sediment core samples from areas outside of navigation channels and berthing areas to provide additional spatial and temporal data. This work should focus on areas where few core samples have been collected in the past and locations along the shoreline of the Delaware River and Bay.
    c) Analysis of additional samples using state of the art methods (with low detection limits) for cobalt, dioxins/furans, PCB congeners, pesticides, and PAHs.
2. Additional studies are needed to evaluate and confirm the presence of tentatively identified contaminated sediment “hot spots” in the Delaware River and its tributaries. This should be followed by trackdown studies to identify the source(s) of contamination. Remediation alternatives for the contaminated sediment should also be evaluated

3. Additional studies are needed to evaluate the bioavailability of the contaminants of concern, including risks to the aquatic ecosystem resulting from acute and chronic sediment toxicity, and the bioaccumulation of these contaminants.

References Cited

New Jersey Department of Environmental Protection (NJDEP) Dredging Task Force 1997. The Management and Regulation of Dredging Activities and Dredged Material in New Jersey's Tidal Waters. October 1997, 55 pp. + appendices.

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U.S. Environmental Protection Agency (USEPA) and Department of the Army - U.S. Army Corps of Engineers (USACE) 1998. Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. - Testing Manual (Inland Testing Manual). EPA 823-B-98-004, February 1998, 409 pp.

Sediment Quality White Paper Committee

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Appendix A

Sediment Quality Thresholds

Appendix A: Sediment Quality Thresholds

Sediment quality can be a complex ecosystem index to evaluate, due in part to the lack of a clear definition of “impaired sediment”. In addition sediment, unlike the water column, tends to be spatially and temporally heterogeneous in both physical and chemical characteristics. Since the Delaware Estuary Regional Sediment Management Plan (RSMP) is a planning exercise, it is less important to argue the scientific merits of methods to assess sediment quality than it is to define a way to partition Delaware Estuary sediment into categories of greater or lesser quality. A relatively simple procedure is needed to determine the nature and extent of sediment contamination, and the suitability of sediment for aquatic habitat restoration and upland beneficial uses.

The simplest threshold analysis would allow the Sediment Quality Committee to divide the sediment of the Delaware Estuary into two categories: “clean” and “contaminated”. For several hundred years the Delaware River and its watershed have been used for extensive industrial, commercial, and agricultural land uses. It is unlikely that any of the sediment can be considered truly clean. Therefore, more discerning thresholds are necessary, with the basic presumption that the cleanest sediment is suitable for a wide range of uses, while potential uses become more restricted as contamination increases.

Development of the sediment quality thresholds by the Sediment Quality Committee relied upon the use of (1) nationally-recognized Sediment Quality Guidelines (SQG), and (2) state soil, sediment, and dredged material regulatory criteria. Because the choice of criteria can be controversial, the committee chose not to determine the merits of any of the SQG/criteria when developing the thresholds. Rather, the Sediment Quality Committee chose to use as thresholds either the highest or lowest SQG/criteria concentrations available for each contaminant-application. This provides a conservative approach suitable for the Delaware Estuary RSMP planning exercise.

The Sediment Quality Committee recognizes the limits of the analyses and does not advocate the use of the selected sediment quality thresholds for regulatory purposes. By choosing to use one SQG/criteria over others, the committee is not judging the merits of the other SQG/criteria. One of the limitations of the use of SQGs to predict sediment suitability for aquatic habitat restoration is that it only considers potential toxic effects of contaminants. The committee did not consider potential effects of bioaccumulation on aquatic food webs and the aquatic ecosystem.

Sediment Quality Guidelines (SQG)

The National Oceanic and Atmospheric Agency (NOAA) has published tables of widely accepted SQGs to help predict the potential for a specific concentration of a sediment contaminant to result in a measurable biological effect in the aquatic environment (Screening Quick Reference Tables, SQuiRT; http://response.restoration.noaa.gov/book_shelf/122_NEW-SQuiRTs.pdf). Typically, SQGs provide both a lower (ERL/TEL; Effects Range Low/Threshold Effects Level) and an upper (ERM/PEL; Effects Range Median/Probable Effects Level) concentration threshold for each COC. The Sediment Quality Committee has decided to use a similar approach, dividing the sediment into categories of Clean, Possible Eco-Effects, and Probable Eco-Effects (Figure A-1). The criteria were primarily used to identify sediment contaminant levels that would limit uses of sediment for aquatic habitat restoration. The thresholds chosen varied with the COC, but were the lowest contaminant concentrations available of the two SQG (ERL or TEL, ERM or PEL) in the SQuiRT tables.

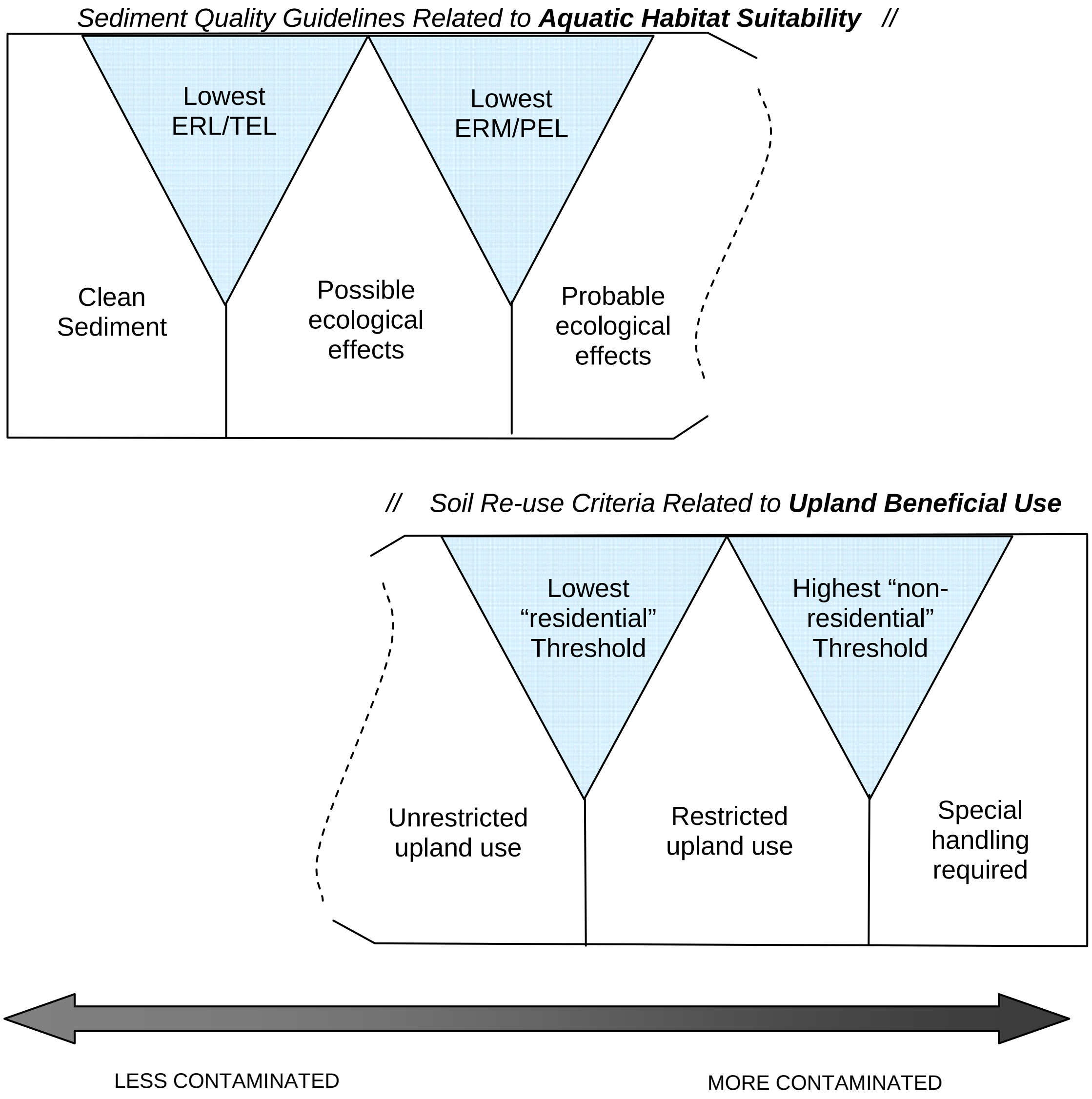
State Soil, Sediment, and Dredged Material Regulatory Criteria:

The states of Pennsylvania, New Jersey, and Delaware have incorporated contaminant specific sediment (dredged material) quality criteria into fill and use limits associated with the regulatory review of dredged material upland beneficial use projects.

In New Jersey, sediment/dredged material sampling and analyses are required on a project-specific basis, and typically would include bulk sediment chemistry analyses of a representative number of core/composite samples. Analytical results are compared to the New Jersey Residential and Non-residential Soil Remediation Standards (N.J.A.C. 7:26D; http://www.nj.gov/dep/srp/regs/rs/rs_appendix1.pdf) to determine suitable upland uses for the dredged material after it has been dewatered. Some dredged material may be processed (e.g. through the addition of lime or other additives) to allow for a variety of beneficial uses.

The upland criteria for the state of Delaware were published in the 1999 revision to the Uniform Risk-Based Remediation Standards (Remediation Standards Guidance Under the Delaware Hazardous Substance Cleanup Act, DNREC, 1999). The standards are for human health based cleanups. The lower standard is for unrestricted use in critical water resource areas and the upper standard for restricted use in non-critical water resource areas.

Figure A-1. Categories of sediment quality and corresponding thresholds.



In Pennsylvania, bulk sediment chemistry data are required to (1) develop Clean Water Act Section 401 Water Quality Certificate conditions, and (2) identify waste management options for the sediment/dredged material. Most dredged material falls into one of four categories[22]:

1. Hazardous Waste, which exceeds the criteria for the Toxicity Characteristic Leaching Procedure (TCLP);
2. Wastes which do not meet regulated fill limits (materials may be placed pursuant to a project-specific permit);
3. Regulated fill (meets all limits for regulated fill);
4. Clean fill (meets all values for clean fill).

The committee adopted the standards currently used to make decisions regarding the suitability of soils for beneficial use in Delaware, Pennsylvania, and New Jersey. These standards, while developed primarily to determine potential human health impacts, are also used by the states to evaluate the suitability of dredged material for upland beneficial use. Thus, they provide a convenient and accepted set of thresholds for the COCs, and are particularly relevant to the Delaware Estuary RSMP planning exercise. The states make a distinction between residential and commercial/industrial (i.e. non-residential) uses of soils, and have two thresholds for each COC. Since the states differ on their promulgated standards, for each COC the Sediment Quality Committee chose to use the Lowest “Residential” Threshold, and the Highest “Non-residential” Threshold (Figure A-1) from the different states’ values. The rationale for using the highest of the state’s “non-residential standards” is that sediment that exceeded the highest standard would not be suitable in any of the three states for upland placement without special handling.

Sediment Quality Thresholds

The Sediment Quality Committee integrated the various SQGs and state soil/sediment regulatory criteria to develop a set of sediment quality thresholds for each COC. The main objective of this effort was to identify sediment contamination levels (i.e. thresholds) that would distinguish clean sediment suitable for all potential uses from those that would potentially limit the suitability of sediment for aquatic habitat restoration or upland beneficial uses of dredged material. Figure A-1 shows the conceptual scheme developed to establish the sediment quality thresholds, and Table A-1 shows the thresholds developed for each COC.

In most cases, the white paper sediment quality thresholds progress from lower COC concentrations to higher COC concentrations in the order ERL/TEL < ERM/PEL < Lowest Residential < Highest Non-residential. However, exceptions were found for arsenic and benzo(a)pyrene, both of which are human health concerns. In these two cases, the Lowest Residential threshold concentration was less than the ERM/PEL threshold.

It is important to stress that the concentrations of the various COCs present in a single sediment sample are likely to meet different sediment quality thresholds. However, the COC present at a concentration that exceeds the least stringent (i.e. highest COC concentration) sediment quality threshold essentially establishes the overall sediment quality for that sample.

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[2] PA Department of Environmental Protection, Bureau of Land Recycling and Waste Management, Document No. 258-2182-773 – “Management of Fill”, April 24, 2004; PA Department of Environmental Protection, Bureau of Waste Management, General Permit for Processing/Beneficial Use of Residual Waste, Permit No. WMGR096SE003, April 23, 2009)

Table A-1: Sediment Quality Thresholds

	Clean Sediment Threshold *Lower of ERL/TEL (marine and freshwater)*	Probable Eco-Effects Threshold *Lower of ERM/PEL (marine and freshwater)*	Unrestricted Upland Use Threshold *Lower of DE, NJ, or PA Clean/Residential Fill*	Restricted Upland Use Threshold *Higher of DE, NJ, or PA WMGR/Non-Residential Fill*
Sum PCBs (ug/kg)	21.6[3]	189[4]	200[7]	1,000[8]
4,4'-DDT (ug/kg)	1[1]	4.77[4]	2,000[7]	230,000[10]
4,4'-DDE (ug/kg)	1.42[5]	6.75[6]	2,000[7]	170,000[10]
4,4'-DDD (ug/kg)	1.22[3]	7.81[4]	3,000[7]	30,000[10]
Dieldrin (ug/kg)	0.02[3]	4.3[4]	40[7]	440[10]
Benzo(a)pyrene (ug/kg)	31.9[5]	763[4]	90[12]	11,000[10]
Dioxin/furan TEQ (ug/kg)	0.00085[3]	0.0215[4]	0.120[9] 0.5[11]	1.0[11]
Chlordane (ug/kg)	0.5[1]	6[2]	200[7]	16,000[13]
Cobalt (mg/kg)	Not Available	Not Available	8[9]	12,000[13]
Arsenic (mg/kg)	5.9[5]	17[6]	12[9]	53[10]
Mercury (mg/kg)	0.13[3]	0.49[6]	10[9]	610[13]
Copper (mg/kg)	18.7[3]	108[4]	310[12]	45,000[8]
Lead (mg/kg)	30.24[3]	91.3[6]	400[7]	1,000[13]
Cadmium (mg/kg)	0.596[5]	3.53[6]	4[12]	100[13]

[1] Effects Range Low – Marine (Long and Morgan ERL)

[2] Effects Range Medium – Marine (Long and Morgan ERM)

[3] Threshold Effect Level – Marine (Persaud, TEL)

[4] Probable Effect Level – Marine (Persaud, PEL)

[5] Threshold Effect Level – Freshwater (Persaud, TEL)

[6] Probable Effect Level – Freshwater (Persaud, PEL)

[7] NJ Residential Cleanup Standard

[8] NJ Non Residential Cleanup Standard

[9] PA Clean Fill Standard

[10] PA Regulated Fill Standard

[11] NJ Upland Fill criterion

[12] DNREC URS Unrestricted Use

[13] DNREC URS Restricted Use

Appendix B

Data Compilation Methods

Appendix B: Data Compilation Methods

In order to develop the Delaware Estuary RSMP *Sediment Quality White Paper*, it was necessary to compile readily available sediment quality data into an appropriate electronic database (Delaware Estuary RSMP Sediment Quality Database). In this paper sediment quality refers to sediment concentrations (expressed on a mass per dry weight sediment basis) for the selected contaminants of concern (COCs). Other parameters that can be used to characterize the quality of sediment (e.g. grain size distribution and percentage organic carbon) were not evaluated.

The Delaware Estuary RSMP Sediment Quality Database (Final Version 1.1) and analysis matrices developed and used by the Sediment Quality Committee can be obtained by contacting Joel A. Pecchioli (NJDEP Office of Dredging and Sediment Technology, joel.pecchioli@dep.state.nj.us).

The Sediment Quality Committee did not conduct an independent Quality Assurance review of the sediment data compiled and used in its evaluations. The absence of such a review was deemed acceptable by the committee given the objectives of this effort, and the planning and management (i.e. non-regulatory) purposes of the Delaware Estuary RSMP.

When sediment data were reported as non-detect, a value of one-half the detection level was used in the database. If the detection limit was not reported in the original data source, a value of zero was used.

For replicate/split samples (i.e. two concentrations for a COC), to be conservative the higher COC concentration was used. In general, there was very little difference in these two COC concentrations, and the replicate/split samples would each have met the same threshold.

The database includes 109 sediment samples from NOAA National Coastal Assessment studies completed in 2003 through 2006; however, the existence of this data was not known until the white paper analyses had been completed.

Data Compilation – Geographic Scope

The geographic scope of the Delaware Estuary RSMP consists of the tidal Delaware River and Bay and its non-tidal contributing watershed. The Sediment Quality Committee attempted to obtain data from all readily available sources within this geographic area. However, given the limited resources and time available to complete this white paper, this effort was undoubtedly not 100% successful. In addition, at this point in time, the Delaware Estuary RSMP Sediment Quality Database does not include sediment data collected in association with smaller public and private dredging projects that are available only in hard copy form. The committee’s data compilation activities have been prioritized to focus on sediment quality data from the tidal Delaware River and Delaware Bay and their major tributaries.

Data Compilation – Electronic Sources of Sediment Data

A “Delaware Estuary Electronic Database” has been recently developed by URS and DuPont. This database includes a compilation of all existing sediment quality data that was available in electronic format at the time the database was developed (2010); it does not include sediment quality data that was only available from hard copy sources. In addition, URS did not conduct an independent review of data quality before incorporating the data into its database.

Table B-1 lists all of the data sets incorporated into the URS/DuPont database. This list was provided to the NJDEP by URS in April 2010 in a document titled “Table 2 – Working Draft of Physical, Chemical, and Biological Datasets – Delaware Estuary Database – Phase 2: Delaware River Study” (undated). Queries of the URS database have been run for sediment data for each of the general types of contaminants listed in Table B-1. The query results were edited to remove unneeded content and exported into the Delaware Estuary RSMP Sediment Quality Database. Any samples in the URS/DuPont database that were (a) not located in the Delaware Estuary or its watershed, and (b) collected prior to 1990, were not included in the Delaware Estuary RSMP Sediment Quality Database. Some sample data were reported in two of the data sets that were compiled into the URS/DuPont database; to avoid duplication, the samples from only one of these data sets were used in the Delaware Estuary RSMP Sediment Quality Database.

Table B-1: Electronic Sources of Sediment Quality Data Compiled into the "Delaware River Estuary RSMP Sediment Quality Database".

Study	Contaminants Measured	Year(s) Collected	Electronic Data Source
DEBI2009	PCBs – PCDD/Fs	2008	URS/Dupont Database & DRBC files
DRBC – Delaware Estuary Upload (1991)	Metals	1991	URS/Dupont Database
DRBC - PCB Sediment Data (2001)	PCBs - Pesticides	2001	URS/Dupont Database
NOAA - NS&T: Bioeffects (1997)	PCBs - Pesticides PAHs - Metals	1997	URS/Dupont Database
Rutgers – Hg (2002)	PCBs – DDE - Hg	2002	URS/Dupont Database
USACE High Resolution PCBs (1996)	PCBs	2000-2001	URS/Dupont Database
USEPA - National Coastal Assessment (1990-2001)	PCBs - Pesticides PAHs - Metals	EMAP: 1990, 1991, 1992, 1993, 1997, 2000, 2001	URS/Dupont Database
USEPA - STORET	PCBs - Pesticides PAHs - Metals	1998, 2000	URS/Dupont Database
USGS - NAWQA (1991-2007)	PCBs - Pesticides PAHs - Metals	1998, 1999, 2000	URS/Dupont Database
USEPA-National Coastal Assessment	PCBs - Pesticides PAHs - Metals	2002	http://www.epa.gov/emap/nca/html/data/index.html

Given the number of data sets compiled into the URS/DuPont database (54) and the number of potential analyte categories of interest (14), a total of 756 separate queries of the database would have to be run to completely verify that the list in Table B-1 provided by URS contains all of the sediment data in the database. Given the limited resources and time available to complete this white paper, this was not done, and the Sediment Quality Committee relied on the list of sediment data sets provided by URS in Table B-1.

In addition to those data sets compiled into the URS/DuPont database, a number of additional available electronic data sets were identified by the Sediment Quality Committee and incorporated into the Delaware Estuary RSMP Sediment Quality Database; these data sources are also identified in Table B-1.

Data Compilation – Hard Copy Sources of Sediment Data

Sediment quality data for the COCs available only from hard copy sources were obtained and incorporated into the Delaware Estuary RSMP Sediment Quality Database. Given the limited available time and resources, the hard copy sources used were largely limited to studies conducted by the USACE in support of navigation dredging projects. Table B-2 lists all such studies from which sediment quality data were obtained.

Table B-2: Hard Copy Sources of Sediment Quality Data Compiled into the "Delaware River Estuary RSMP Sediment Quality Database".

Study	Contaminants Measured	Year(s) Collected	Hard Copy Data Source
Philadelphia Naval Shipyard	PCBs - Pesticides PAHs - Metals	2009	Versar (2009). FY 2008, Pier 4 Chemical Analysis of Sediment Samples. Apr 2009. 38 pp + App
USACE Philadelphia to Trenton	PCBs - Pesticides PAHs - Metals	2009	Versar (2009). FY 2008 Philadelphia to Trenton Chemical Analysis of Sediment Samples. June 2009. 72 pp + App
Philadelphia Naval Shipyard	PCBs - Pesticides PAHs - Metals	2007	Versar (2007). FY 2007 Pier 4 Chemical Analysis of Sediment Samples. Nov 2007. 38 pp + App
USACE Schuylkill River	PCBs - Pesticides PAHs - Metals	2007	Versar (2007). Schuylkill River Chemical Analysis of Sediment Samples. July 2007. 23 pp + App
USACE Fairless Turning Basin	PCBs - Pesticides PAHs - Metals	2007	Versar (2008). FY 2007 Fairless Turning Basin Chemical Analysis of Sediment Samples. Jan 2007. 36 pp + App
USACE Maintenance Dredging	PCBs - Pesticides PAHs - Metals	2005	Versar (2005), Delaware River, Philadelphia, Pennsylvania to New Castle, Delaware – Chemical Analysis of Dredged River Sediments, Nov 2005, 319 pp.
NOAA Athos I Preassessment	PAHs	2004	NOAA (2006), Final Preassessment Data Report *M/T Athos I,* Oil Spill Delaware River, June 2006, 36 pp + App
USACE Maintenance Dredging	PCBs - Pesticides PAHs - Metals	2003	Versar (2003), Chemical Analysis of Maintenance Dredge Material from the Marcus Hook, Deepwater Point, and New Castle Navigational Ranges, Oct 2003, 50 pp.
USACE Philadelphia to Trenton	Pesticides PAHs - Metals	2003	Versar (2003), Chemical Analysis of Maintenance Dredge Material from the Marcus Hook, Deepwater Point, and New Castle Navigational Ranges, Oct 2003, 50 pp.
USACE Philadelphia to Trenton	Pesticides PAHs - Metals	2001	Versar (2003). Delaware River, Philadelphia, Pennsylvania to Trenton, New Jersey Chemical Analysis of Dredged River Sediments. Jul 2003. 34 pp + App
USACE Schuylkill River	PCBs - Pesticides PAHs - Metals	1997	Versar (2001). Delaware River, Philadelphia, Pennsylvania to Trenton, New Jersey Chemical Analysis of Dredged River Sediments. Jun 2001. 18 pp + App
USACE Main Channel Deepening	PCBs - Pesticides PAHs - Metals	1994	Greely-Polhemus Group (1995), Delaware River – Philadelphia to the Sea Chemical Analysis of Sediments, May 1995, 113 pp + App.
USACE Main Channel Deepening	PCBs - Pesticides PAHs - Metals	1992	Greely-Polhemus Group (1993), Delaware River Comprehensive Navigation Study Chemical Analysis of Sediments, Feb 1993, 19 pp + App

Appendix C

Selected Database Analyses

Appendix C: Selected Database Analyses

Effects of Using One-Half the Detection Limit for Non-detected Contaminant Concentrations

A value of one-half the detection limit was used in the Delaware Estuary RSMP Sediment Quality Database as the sample concentration for those contaminants of concern (COCs) that were non-detects. Table C-1 shows the percentage of non-detects for each COC, as well as how the one-half detection limit concentrations are related to the sediment quality thresholds established by the Sediment Quality Committee. Concentrations of all of the organic COCs, mercury, and cadmium, were frequently not detected in the sediment samples. Thus, the results of the white paper threshold analyses for these COCs could be affected to varying degrees by non-detected sample concentrations and the use of one-half the detection limit.

Table C-1: For selected COCs, percentages of all sample concentrations that were non-detect, and percentages of the non-detect samples relative to the White Paper sediment quality thresholds.

% of Non-Detect Sample Concentrations that are:	<ERL/TEL	> ERL/TEL	> ERM/PEL	> LRT	> HNRT	% of Sample COC Concentrations that are ND
Mercury	93%	7%	0.6%	-	-	20%
Cadmium	99%	1%	0%	-	-	9%
4,4’-DDT	48%	52%	31%	-	-	64.5%
4,4’-DDD	39%	61%	51%	-	-	42.5%
4,4’-DDE	39%	61%	57%	-	-	34.3%
Chlordane	36%	64%	43%	1%	-	54.7%
Dieldrin	16%	84%	38%	0%	-	62%
Benzo(a)pyrene	24%	76%	0%	73%	-	41%
Total PCBs	15%	85%	60%	58%	1.5%	23%
LRT = Lowest “Residential” Threshold, HNRT = Highest “Non-residential” Threshold						

Very few samples (0-1.8% of the total collected) were non-detect for arsenic, cobalt, copper, and lead, and only 4.2% of the samples were non-detect for PCDD/Fs (including 2,3,7,8-TCDD; data for these COCs are not shown in Table C-1). The results of the white paper threshold analyses for arsenic, cobalt, copper, lead, and PCDD/Fs will be affected very little by non-detected sample concentrations and the use one-half the detection limit.

Further analysis showed that conclusions regarding the sediment data will be little effected by using one-half the detection limit for non-detected mercury and cadmium sample concentrations. One-half the detection limit for almost all of the non-detect mercury and cadmium samples were less than the ERL/TEL, and none of these samples had non-detected concentrations that exceeded the Lowest “Residential” Threshold (Table C-1).

For the pesticides 4,4’-DDT, 4,4’-DDD, 4,4’-DDE, and dieldrin, one-half the detection limit concentrations were less than the Lowest “Residential” Threshold in all of the non-detect samples. Only 1% of the non-detect total chlordane samples had one-half detection limit concentrations greater than this threshold. The upland beneficial use component of the *Sediment Quality White Paper* threshold analysis would not be affected for these contaminants.

Approximately 31% to 57% of the non-detects for 4,4'-DDT, 4,4'-DDD, 4,4'-DDE, dieldrin, and total chlordane would have concentrations greater than the ERM/PEL using one-half the detection limit. In addition, 52-84% of the non-detects for these pesticides would exceed the ERL/TEL. This could result in a significant number of false exceedances of the aquatic habitat restoration suitability concentrations in the threshold analysis. In addition, the Sediment Quality Committee noted a number of analytical Quality Assurance concerns that typically occur with sediment pesticide data. Therefore, it was determined that those non-detect samples in which one-half the detection limits for 4,4'-DDT, 4,4'-DDD, 4,4'-DDE, dieldrin, or total Chlordane exceeded their respective ERL/TEL would be deleted from the database (for these parameters only) used in the Aquatic Habitat Restoration Suitability Threshold Analysis.

An analysis of the samples with non-detected concentrations of dieldrin, 4,4'-DDT, 4,4'-DDD, 4,4'-DDE, and total chlordane was conducted to determine the potential impact on the results of the Aquatic Habitat Restoration Suitability Threshold Analysis of omitting the sample data with one-half detection limit values greater than the ERL/TEL. Combined, a total of 23 additional samples may have exceeded an ERL/TEL value: three of these samples were in DRBC Zone 3, 13 in DRBC Zone 6, and 10 in various tributaries. An additional 50 samples with non-detected concentrations of these pesticides may have exceeded an ERM/PEL: one of these samples was in DRBC Zone 3, 34 were in DRBC Zone 4 and were collected in support of the Main Channel Deepening Project, one sample was from DRBC Zone 5, 12 were from DRBC Zone 6, and there were two tributary samples.

For benzo(a) pyrene, approximately 76% and 73%, respectively of the non-detect samples in the Aquatic Habitat Restoration Suitability Threshold Analysis and upland beneficial use analysis could be affected by the use of one-half the detection limit (Table C-2). Most of these samples were collected in 1992, 1994, or 1997. Benzo(a)pyrene non-detects would have no or small impacts on both of the threshold analyses in DRBC Zone 2 and Zone 3, and in the Delaware River watershed tributaries. However, potential false exceedances of both the aquatic habitat restoration suitability and upland beneficial use thresholds could occur in a substantial percentage of the samples in DRBC Zone 4, Zone 5, and Zone 6 (Table C-2).

Table C-2: Number of benzo(s)pyrene non-detect samples in each DRBC Zone greater than the ERL/TEL and Lowest "Residential" standard (LRT).

Total # Non-detects = 135	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Tributaries
> ERL/TEL	0	16	23	40	19	7
> LUS	0	15	23	40	19	3
Total # Samples	10	84	49	74	60	51

The Sediment Quality Committee also noted (a) that a number of recent dredging projects have had elevated sediment benzo(a)pyrene concentrations greater than the Lowest "Residential" Threshold, and (b) there was a significant oil spill in the Delaware River (M/V Athos I) in 2004. The committee decided to take a conservative approach and include all of the samples that were non-detect for benzo(a)pyrene in both the aquatic habitat restoration suitability and upland beneficial use components of the *Sediment Quality White Paper* threshold analysis.

Approximately 80% of the non-detect total PCB samples in the Aquatic Habitat Restoration Suitability Threshold Analysis, and approximately 58% of the non-detect samples in the upland beneficial use analysis, could be affected (Table C-3). About 65% of the non-detect PCB samples were collected in 2001 or earlier (mostly in 1992, 1994, or 1997), with the remaining 35% of the samples collected in 2002, 2003, and 2005. Samples that were non-detect for PCBs would have no or small impacts on both of the threshold analyses in DRBC Zone 2 and Zone 6. The non-detects may have impacted the aquatic habitat restoration suitability threshold results in DRBC Zone 3, Zone 4, and Zone 5, and in the Delaware River watershed tributaries. Potential false exceedances of the upland beneficial use threshold could occur in a substantial percentage of the samples in DRBC Zone 3 and Zone 5.

Table C-3: Total PCBs - Total number of non-detect samples and number of non-detect samples in each DRBC Zone compared to the various contamination thresholds used in the White Paper.

PCBs	# Samples	# Non-Detects	< ERL	>ERL	>ERM	> LUS	>HUS
Zone 2	25	0	-	-	-	-	-
Zone 3	73	22	1	21	16	16	0
Zone 4	57	16	1	15	7	5	0
Zone 5	165	48	1	47	44	43	2
Zone 6	143	11	11	0	0	0	0
Tributaries	128	36	6	30	13	13	0
Overall	592	133	20	113	80	77	2

An initial spatial analysis of the total PCB non-detect samples using a draft version of the Delaware Estuary RSMP Sediment Quality Database was conducted by DRBC Zone. Those non-detect samples in each DRBC Zone that had one-half the detection limit total PCB concentrations significantly different from those samples in which PCBs were detected were deleted from the final database (46 samples).

Given that DRBC has established a Total Maximum Daily Load (TMDL) for PCBs in the Delaware River, the committee decided to take a conservative approach and include all of the remaining samples that were non-detect for total PCBs in both the aquatic habitat restoration suitability and upland beneficial use components of the *Sediment Quality White Paper* threshold analysis.

Year of Sample Collection

The Delaware Estuary RSMP Sediment Quality Database includes sediment samples collected in the Delaware Estuary from 1990 to 2009. Table C-4 lists the percentage of the available sediment sample data for each COC that were collected in 1990-2001 and 2002-2009. Samples analyzed for metals (except cobalt) and benzo(a)pyrene (i.e. PAHs) were collected about evenly during these two time periods. Most of the samples analyzed for PCBs and pesticides were collected in 1990-2001, and thus most of the data are at least ten years old. All of the available dioxin/furan data are from samples collected in 2008.

Table C-4: Percentage of sediment samples in the Database for each COC collected from 1990-2001 and 2002-2009.

Contaminant of Concern (COC)	1990-2001	2002-2009
Mercury Arsenic Cadmium Copper Lead	~55% Varies slightly with each COC	~45% Varies slightly with each COC
Cobalt	29%	71%
Total PCBs	71%	29%
Total Dioxin/Furan TEQ	-	100%
4,4'-DDT	82%	18%
4,4'-DDD	75%	25%
4.4'-DDE	74%	26%
Chlordane	77%	23%
Dieldrin	75%	25%
Benzo(a)pyrene	52%	48%

DRBC Zone 5 Aquatic Habitat Restoration Suitability Threshold Analysis

A total of 231 sediment samples were collected in DRBC Zone 5 (180 grab samples, 48 core samples, and 3 composite samples). Twenty-three percent (23%) of the DRBC Zone 5 samples did not exceed an ERL/TEL for any COC, 42% of the samples exceeded at least one ERL/TEL, and 35% of the samples exceeded at least one ERM/PEL (Appendix E). While 94% of the core samples exceeded at least one ERM/PEL, only 18% of the grab samples did so.

Most of the samples in DRBC Zone 5 collected downstream of the Christina River that exceeded an ERM/PEL were core samples. As discussed below, many of these may be false exceedances due to using one-half the detection limit for non-detect total PCBs. A number of samples collected downstream of the Christina River, but closer to the shorelines and outside of the main navigation channel, were contaminated with mercury, arsenic, and/or lead at concentrations greater than the ERM/PEL.

In contrast, most of the samples in DRBC Zone 5 collected near the mouth of the Christina River, and upstream in the Delaware River, that exceeded an ERM/PEL value were grab samples with detected COC concentrations.

Core Samples

The 48 DRBC Zone 5 core samples were collected during three U.S. Army Corps of Engineers (USACE) studies in support of navigational dredging activities:

- Main Channel Maintenance (2005) – 11 samples (11 locations)
- Main Channel Deepening (1994) – 16 samples (8 locations, 2 sections each)
- Main Channel Deepening/Bends (1992) – 21 samples (10 locations/1 section each; 1 location/6 sections; 1 location/5 sections).

Thirty-seven (37) of the samples were collected over 15 years ago, with the most recent core samples over five years old.

Three of the core samples did not exceed any ERM/PEL. PCBs were not detected in any of the remaining 45 samples, so one-half the detection limits were used for the analysis. These values were greater than the total PCB ERM/PEL of 189 ug/kg, and may be false exceedances of the ERM/PEL.

Only nine of the core samples had a detected COC concentration greater than the ERM/PEL (Table C-5 and Figure C-1). None of the core samples exceeded the ERM/PEL for benzo(a)pyrene, dieldrin, chlordane, and copper; the samples were not analyzed for PCDD/Fs.

Table C-5: DRBC Zone 5 Core Samples – Detected Exceedances of Contaminants of Concern ERM/PELs.

Sample	Mercury	Arsenic	Cadmium	Lead	4,4'-DDT	4,4'-DDD 4,4'-DDE
DRV-21	X	X	X	X	X	
DRV-23						X
DRV-24	X	X		X	X	X
DRV-25						X
DRV-09-94 (deep section)		X	X			
DRV-10-94 (surface section)		X	X	X		
DRV-10-94 (deep section)			X			
DRV-15-94 (surface section)				X		X
DRV-15-94 (deep section)			X			

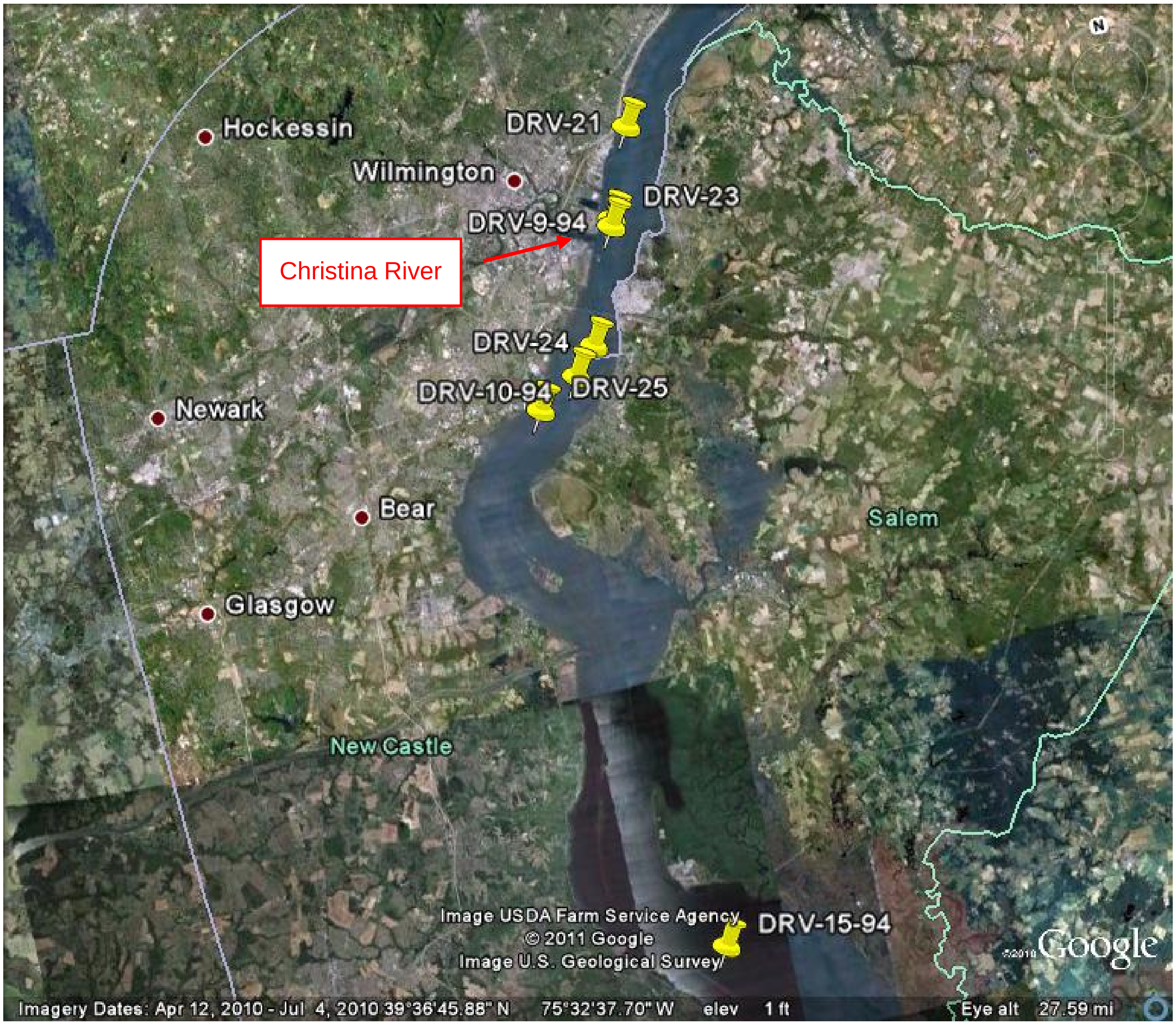


Figure C-1: DRBC Zone 5 Core Samples Location

Grab Samples

Thirty-three (33) of the 180 DRBC Zone 5 sediment grab samples exceeded the ERM/PEL for one or more detected COC, as follows:

- Mercury – 15 samples
- Arsenic – 21 samples
- Copper – 3 samples
- Cadmium – 2 samples
- Lead – 15 samples
- PCDD/Fs TEQ – 1 sample
- Total PCBs – 6 samples
- 4,4'-DDT – 5 samples
- 4,4'-DDD – 9 samples
- 4,4'-DDE – 9 samples

- > Chlordane – 2 samples

None of the grab samples exceeded the ERM/PEL for benzo(a)pyrene and dieldrin.

Ten (10) grab samples exceeded the ERM/PEL for at least four of the COCs (Table C-6 and Figure C-2).

Table C-6: DRBC Zone 5 Grab Samples with Detected Concentrations Greater than the ERM/PELs for Four or More COCs.

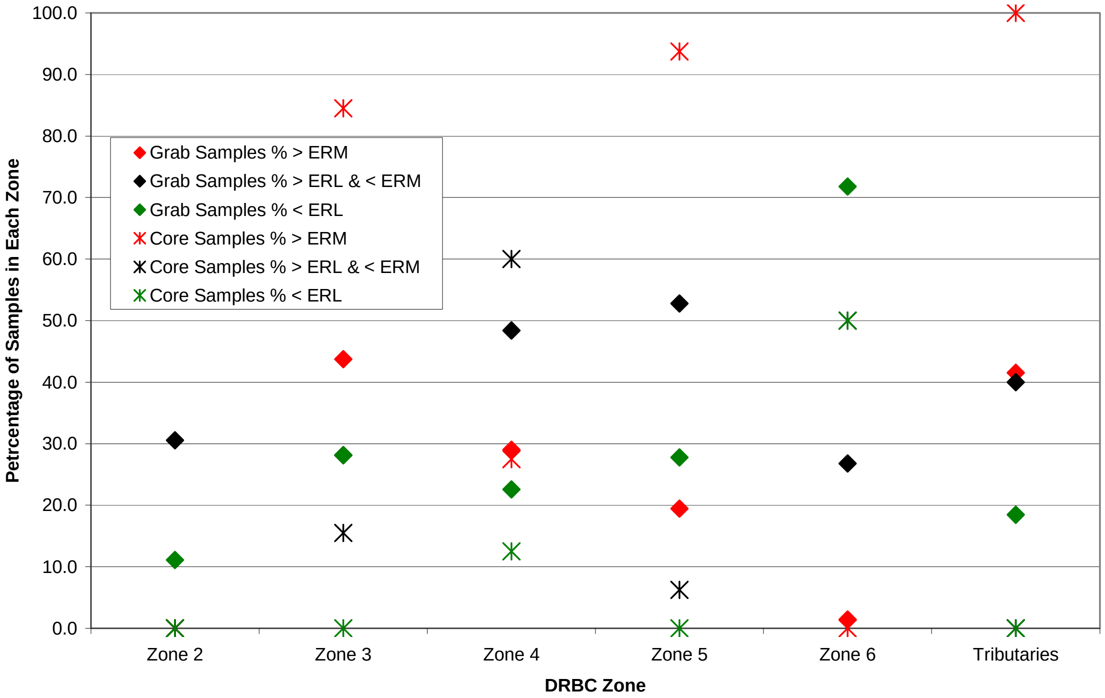
Sample:	NST 1997 DEB-19	NST 1997 DEB-20	NST 1997 DEB-21	DE-00-0047A	MA97-0422	MA97-0423	MA97-0424	DE08-0542	DE08-0548	DE08-0556
Mercury		X		X		X		X	X	X
Arsenic		X	X	X		X	X	X	X	X
Copper		X		X					X	
Cadmium								X	X	
Lead		X		X		X		X	X	X
PCDD/F TEQ								X		
Total PCBs		X				X		X	X	X
4,4'-DDT	X		X	X	X		X			
4,4'-DDD	X		X	X	X		X			
4,4'-DDE	X		X	X	X		X			
Chlordane	X				X					

Figure C-2: DRBC Zone 5 Grab Samples with Exceedances of Four or More COC ERM/PELs.

Aquatic Habitat Restoration Suitability Threshold Analysis – Effect of Sample Type

Figure C-3 shows the percentage of sediment samples (grab or core) in each DRBC Zone that fell into each of the three Aquatic Habitat Restoration Suitability Threshold Analysis categories. No core sample data are available from DRBC Zone 2.

Figure C-3: Aquatic Habitat Suitability Analysis Results Gab and Core Samples in Each DRBC Zone



In DRBC Zone 3, Zone 5, and the tributaries (all but two of the tributary core samples were collected in the Schuylkill River), the percentage of the core samples with a COC greater than the ERM/PEL (84.5% to 100%) was much greater than in the grab samples (19% to 28%). Most of these core samples were collected in association with USACE dredging projects, while most of the grab samples were collected in shallower waters closer to the shoreline, which suggests that sediment in the navigation channels (or berthing areas) in DRBC Zone 3, Zone 5, and the Schuylkill River may be more contaminated than sediment from other locations in these areas.

> DRBC Zone 3 – of the 60 core samples that had a COC concentration greater than the ERM/PEL, only eight (13%) were non-detects (total PCBs and pesticides). The COCs were detected in all 14 of the grab samples that had a COC concentration greater than the ERM/PEL. This suggests that in DRBC Zone 3, sample type had only a minimal effect on its Aquatic Habitat Restoration Suitability Threshold Analysis category.

> DRBC Zone 5 – 45 of the core samples had a COC concentration greater than the ERM/PEL. In all but one of these samples, these exceedances were due to the use of one-half the detection limit for non-detected PCBs and/or pesticides. Thirty-five (35) grab samples had a COC concentration greater than the ERM/PEL; these exceedances were largely due to detected concentrations of arsenic, lead, mercury, and/or pesticides. This suggests that in DRBC Zone 5, sample type had a significant effect on its Aquatic Habitat Restoration Suitability Threshold Analysis category.

> Tributaries - 24 core samples, all but two of which were collected in the Schuylkill River, had a detected COC concentration greater than the ERM/PEL. Similarly, 54 of the grab samples had a detected COC concentration greater than the ERM/PEL. This suggests that in the Schuylkill River,

sample type had only a minimal effect on its Aquatic Habitat Restoration Suitability Threshold Analysis category.

In DRBC Zone 4, the percentage of core samples that had a COC concentration greater than the ERM/PEL (27.5%) was similar to that for grab samples (29%). None of the DRBC Zone 6 core samples, and only 1.4% of the grab samples (for arsenic or cadmium), had a COC concentration greater than the ERM/PEL.

With the exception of DRBC Zone 5, the higher percentages of the core samples with a COC concentration greater than ERM/PEL (Figure C-3) are not an artifact of the types of sample collected.

Appendix D

Statistical Summaries of the Sediment Data Compiled in the Delaware Estuary RSMP Sediment Quality Database for Each Contaminant of Concern

Appendix D: Statistical Summaries of the Sediment Data Compiled in the Delaware Estuary RSMP Sediment Quality Database for Each Contaminant of Concern

Arsenic Database Summary Statistics

Total # Samples	# Grab Samples	# Core Samples	# Composite Samples	# Detected Concentrations	# Non-Detections
795	601	193	1	786	9
% of Total:	75.6%	24.3%	0.1%	98.9%	1.1%
	Mean (mg/kg)	**Standard Deviation**	**Median (mg/kg)**	**# Detected Concentrations**	**# Non-Detections**
1990	5.56	4.84	4.13	36	0
1991	6.51	7.43	4.09	36	0
1992	7.19	3.33	7.20	48	0
1993	10.58	8.55	8.01	11	0
1994	4.97	5.30	3.28	44	0
1997	10.96	10.69	9.40	165	0
1998	18.61	15.52	11.55	10	0
1999	14.59	14.63	8.80	13	0
2000	7.93	5.41	7.09	39	1
2001	10.31	10.06	8.00	37	1
2002	6.61	4.76	5.00	32	4
2003	11.90	3.90	12.75	22	0
2005	8.47	10.86	5.86	28	2
2007	23.47	31.36	9.95	18	0
2008	7.40	22.57	4.60	226	1
2009	6.62	3.11	5.80	21	0
Overall	8.81	15.00	6.00		
Total # Samples	**# Samples <= ERL**	**# Samples > ERL**	**# Samples > ERM**	**# Samples > LUS**	**# Samples > HUS**
795	395	400	64	143	8
% of Total	49.7%	50.3%	8.1%	18.0%	1.0%
Note: 46 (5.8%) of the samples > NJ Non-residential Soil Remediation Standard (19 mg/kg)					

The following samples/locations > HNRT:

1. USGS01467150 (Cooper River at Haddonfield, NJ - 1999)
2. NJ01-0090-A (Maurice River – 2001)
3. DE08-0542 (Delaware River Zone 5 – 2008)
4. DE08-0548 (Delaware River Zone 5 – 2008)
5. FY2007 SR4 (Schuylkill River – 2007)
6. FY2007 SR5 (Schuylkill River – 2007)
7. FY2007 SR7 (Schuylkill River – 2007)
8. 1997 SR5Lower (Schuylkill River – 1997)

	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Tributaries
# Samples	22	89	92	195	265	132
% of Total	2.8%	11.2%	11.6%	24.5%	33.3%	16.6%
% Detects	100%	100%	97.8%	100%	98.5%	97.7%
Mean (mg/kg)	9.54	7.40	7.11	11.93	4.70	14.47
Standard Dev (mg/kg)	4.92	4.92	6.18	24.81	3.27	17.30
Median (mg/kg)	10.40	6.50	5.72	7.81	3.84	9.25

Benzo(a)pyrene Database Summary Statistics

Total # Samples	# Grab Samples	# Core Samples	# Composite Samples	# Detected Concentrations	# Non-Detections
328	135	193	0	193	135
% of Total:	41.2%	58.8%	0%	58.8%	41.2%

	Mean (mg/kg)	Standard Deviation	Median (mg/kg)	# Detected Concentrations	# Non-Detections
1990	-	-	-	-	-
1991	-	-	-	-	-
1992*	0.2714	0.0518	0.2650	0	36
1993	-	-	-	-	-
1994*	0.2469	0.0818	0.2310	0	44
1997	0.3300	0.4996	0.1200	78	5
1998	-	-	-	-	-
1999	-	-	-	-	-
2000	-	-	-	-	-
2001*	0.1306	0.0923	0.1075	1	7
2002*	0.1000	0.1626	0.0100	15	21
2003	0.4729	1.1764	0.1900	19	3
2004	0.2411	0.2469	0.1890	27	0
2005*	0.1454	0.2611	0.0280	15	18
2007	0.6878	0.9117	0.2150	18	0
2008	-	-	-	-	-
2009	0.3312	0.2201	0.2500	20	1
Overall	0.2857	0.4817	0.2000		

*Greater than 50% of the sample data were non-detect – used ½ detection limits

Total # Samples	# Samples <= ERL	# Samples > ERL	# Samples > ERM	# Samples > LUS	# Samples > HUS
328	73	255	22	227	0
% of Total	22.3%	77.7%	6.7%	69.2%	0%
# Non-detects at ½ DL	33	102	0	98	0
% of samples	45.2%	40.0%	0%	43.2%	0%

	Zone 2	**Zone 3**	**Zone 4**	**Zone 5**	**Zone 6**	**Tributaries**
# Samples	10	84	49	74	60	51
% of Total	3.0%	25.6%	14.9%	22.6%	18.3%	15.5%
% Detects	100%	73.8%	34.7%	37.8%	53.3%	86.3%
Mean (mg/kg)	0.2801	0.2428	0.3167	0.1998	0.0929	0.6791
Standard Dev (mg/kg)	0.2694	0.2176	0.7954	0.1319	0.1142	0.7483
Median (mg/kg)	0.2029	0.1980	0.2300	0.2007	0.0249	0.4300

Cadmium Database Summary Statistics

Total # Samples	# Grab Samples	# Core Samples	# Composite Samples	# Detected Concentrations	# Non-Detections
793	599	193	1	723	70
% of Total	75.5%	24.3%	0.1%	91.2%	8.8%

	Mean (mg/kg)	Standard Deviation	Median (mg/kg)	# Detected Concentrations	# Non-Detections
1990	0.578	1.242	0.208	36	0
1991	1.610	2.405	0.566	34	2
1992	0.507	1.440	0.206	11	37
1993	1.935	2.686	0.592	10	1
1994	1.911	1.350	1.465	42	2
1997	0.766	0.918	0.426	162	3
1998	1.785	1.622	1.120	8	0
1999	1.353	0.768	1.100	13	0
2000	0.491	0.746	0.220	39	1
2001	1.376	1.939	0.370	36	2
2002	0.697	0.893	0.325	33	3
2003	1.552	1.149	1.080	22	0
2005	0.740	1.417	0.229	16	14
2007	2.853	1.831	2.200	18	0
2008	0.450	0.532	0.300	222	5
2009	1.933	0.640	2.200	21	0
Overall	0.901	1.298	0.400		

Total # Samples	# Samples <= ERL	# Samples > ERL	# Samples > ERM	# Samples > LUS	# Samples > HUS
793	503	290	39	30	0
% of Total	63.4%	36.6%	4.9%	3.8%	0%

	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Tributaries
# Samples	22	89	92	195	265	130
% of Total	2.8%	11.2%	11.6%	24.6%	33.4%	16.4%
% Detects	100%	96.6%	75.0%	86.2%	95.8%	95.4%
Mean (mg/kg)	3.027	2.042	0.766	0.735	0.307	1.311
Standard Dev (mg/kg)	2.547	1.644	1.001	0.973	0.383	1.547
Median (mg/kg)	2.072	1.900	0.359	0.400	0.200	0.701

Chlordane (total) Database Summary Statistics

Total # Samples	# Grab Samples	# Core Samples	# Composite Samples	# Detected Concentrations	# Non-Detections
540	361	179	0	244	296
% of Total	66.9%	33.1%	0	45.2%	54.8%

	Mean (ug/kg)	Standard Deviation	Median (ug/kg)	# Detected Concentrations	# Non-Detections
1990	-	-	-	-	-
1991*	0.71	0.87	0.26	4	10
1992*	103.64	69.42	120.00	4	44
1993	2.19	2.18	1.46	7	4
1994*	116.23	24.86	112.50	0	44
1997	2.07	5.90	0.26	120	31
1998	3.57	1.01	3.45	4	2
1999*	22.35	27.99	4.00	6	7
2000	3.21	8.49	0.31	25	14
2001	11.78	28.96	0.81	63	24
2002*	4.04	4.98	0.18	1	35
2003*	4.77	0.97	4.90	0	22
2004	-	-	-	-	-
2005*	5.87	4.04	4.80	0	30
2007	8.02	8.30	6.28	5	13
2008	-	-	-	-	-
2009	7.07	8.40	1.70	5	16
Overall	23.37	46.90	1.70		

*Greater than 50% of the sample data were non-detect – used ½ detection limits

Total # Samples	# Samples <= ERL	# Samples > ERL	# Samples > ERM	# Samples > LUS	# Samples > HUS
540	202	338	166	3	0
% of Total	37.4%	62.6%	30.7%	0.6%	0%
# Non-detects at ½ DL	106	190	126	3	-
% of samples	52.5%	56.2%	75.9%	100.0%	-

	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Tributaries
# Samples	24	88	73	126	120	109
% of Total	4.4%	16.3%	13.5%	23.3%	22.2%	20.2%
% Detects	100.0%	27.3%	38.3%	43.7%	42.5%	56.9%
Mean (ug/kg)	6.03	25.09	42.21	41.26	10.69	6.43
Standard Dev (ug/kg)	4.00	38.39	60.16	65.50	31.16	13.79
Median (ug/kg)	5.06	5.15	4.50	1.40	0.16	1.83

Cobalt Database Summary Statistics

Total # Samples	# Grab Samples	# Core Samples	# Composite Samples	# Detected Concentrations	# Non-Detections
97	28	69	0	97	0
% of Total	28.9%	71.1%	0%	100%	0%
Total # Samples	**# Samples <= ERL**	**# Samples > ERL**	**# Samples > ERM**	**# Samples > LUS**	**# Samples > HUS**
97	NA	NA	NA	80	0
% of Total	NA	NA	NA	82.5%	0%
Note: none of the samples > NJ Non-residential Soil Remediation Standard (590 mg/kg)					

	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Tributaries
# Samples	0	38	12	11	0	36
% of Total	-	39.2%	12.4%	11.3%	-	37.1%
% Detects	-	100%	100%	100%	-	100%
Mean (mg/kg)	-	12.9	8.2	9.9	-	28.8
Standard Dev (mg/kg)	-	4.8	4.7	5.1	-	32.4
Median (mg/kg)	-	13.1	9.0	11.2	-	20.0

Year	Mean (mg/kg)	Standard Deviation (mg/kg)	Median (mg/kg)
Over All Years	17.9	21.7	15.0

Copper Database Summary Statistics

Total # Samples	# Grab Samples	# Core Samples	# Composite Samples	# Detected Concentrations	# Non-Detections
794	599	193	2	780	14
% of Total	75.4%	24.3%	0.3%	98.2%	1.8%
	Mean (mg/kg)	**Standard Deviation**	**Median (mg/kg)**	**# Detected Concentrations**	**# Non-Detections**
1990	11.52	15.43	4.62	36	0
1991	41.46	47.68	25.70	36	0
1992	11.21	14.91	8.36	47	1
1993	45.18	61.90	15.30	10	1
1994	7.80	10.02	4.10	43	1
1997	32.28	36.14	18.28	165	0
1998	43.66	52.79	31.90	15	0
1999	65.77	26.11	60.00	13	0
2000	24.16	23.71	17.00	39	1
2001	25.31	25.23	17.50	38	0
2002	10.14	15.35	6.00	21	9
2003	38.94	14.50	36.40	22	0
2005	22.51	30.30	9.13	30	0
2007	116.17	104.15	66.75	18	0
2008	13.70	17.38	8.30	226	1
2009	40.94	18.96	38.30	21	0
Overall	25.12	35.85	11.70		
Total # Samples	**# Samples <= ERL**	**# Samples > ERL**	**# Samples > ERM**	**# Samples > LUS**	**# Samples > HUS**
794	498	296	21	3	0
% of Total	62.7%	37.3%	2.6%	0.4%	0%

	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Tributaries
# Samples	22	87	91	193	265	136
% of Total	2.8%	11.0%	11.5%	24.3%	33.4%	17.1%
% Detects	100%	100%	100%	99.0%	96.6%	97.8%
Mean (mg/kg)	54.34	42.80	18.71	22.16	6.36	54.15
Standard Dev (mg/kg)	18.53	36.84	20.79	23.25	5.87	59.89
Median (mg/kg)	53.87	38.30	9.97	13.10	4.10	36.84

4,4’-DDT Database Summary Statistics

Total # Samples	# Grab Samples	# Core Samples	# Composite Samples	# Detected Concentrations	# Non-Detections
520	327	193	0	185	335
% of Total	62.9%	37.1%	0	35.5%	64.5%

	Mean (ug/kg)	Standard Deviation	Median (ug/kg)	# Detected Concentrations	# Non-Detections
1990	-	-	-	-	-
1991*	2.98	8.83	0.13	6	8
1992*	10.64	6.66	12.00	2	46
1993*	1.74	3.27	0.13	2	9
1994*	11.67	2.52	11.25	0	44
1997*	6.58	16.75	0.03	68	97
1998*	2.32	3.23	1.00	1	5
1999	6.82	11.85	2.00	9	4
2000	8.65	38.81	0.43	23	16
2001	3.72	8.98	0.50	47	41
2002	1.9	-	1.9	1	0
2003*	14.15	39.97	3.45	4	18
2004	-	-	-	-	-
2005*	2.06	2.12	1.40	3	27
2007*	8.97	10.21	4.35	6	12
2008	-	-	-	-	-
2009	31.96	69.06	8.20	13	8
Overall	7.97	22.56	1.21		

*Greater than 50% of the sample data were non-detect – used ½ detection limits

Total # Samples	# Samples <= ERL	# Samples > ERL	# Samples > ERM	# Samples > LUS	# Samples > HUS
520	254	266	170	0	0
% of Total	48.8%	51.2%	32.7%	0%	0%
# Non-detects at ½ DL	171	164	109	-	-
% of samples	67.3%	61.7%	64.1%	-	-

	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Tributaries
# Samples	25	86	71	123	106	108
% of Total	4.8%	16.5%	13.7%	23.7%	20.4%	20.8%
% Detects	92.0%	38.4%	25.4%	36.6%	19.8%	41.7%
Mean (ug/kg)	11.06	18.79	6.09	7.78	1.26	6.77
Standard Dev (ug/kg)	14.85	43.38	7.53	22.97	3.27	11.39
Median (ug/kg)	3.85	6.90	2.00	0.81	0.05	1.10

4,4’-DDD Database Summary Statistics

Total # Samples	# Grab Samples	# Core Samples	# Composite Samples	# Detected Concentrations	# Non-Detections
504	311	193	0	290	214
% of Total	61.7%	38.3%	0	57.5%	42.5%

	Mean (ug/kg)	Standard Deviation	Median (ug/kg)	# Detected Concentrations	# Non-Detections
1990	-	-	-	-	-
1991	2.63	5.17	0.71	8	6
1992*	19.13	56.19	12.00	6	42
1993	5.03	3.79	5.66	8	2
1994*	11.76	3.66	11.25	1	43
1997	9.65	18.82	2.09	141	24
1998*	2.62	4.62	0.50	2	4
1999	8.17	12.81	2.40	12	1
2000	4.56	15.07	0.76	34	5
2001	4.09	5.06	1.50	24	13
2002*	1.07	2.81	0.11	7	29
2003*	16.18	17.16	6.25	8	14
2004	-	-	-	-	-
2005	3.58	4.86	1.40	7	23
2007	14.84	8.84	11.50	18	0
2008	-	-	-	-	-
2009	6.75	4.44	6.90	14	7
Overall	8.90	21.91	3.20		

*Greater than 50% of the sample data were non-detect – used ½ detection limits

Total # Samples	# Samples <= ERL	# Samples > ERL	# Samples > ERM	# Samples > LUS	# Samples > HUS
504	184	320	186	0	0
% of Total	36.5%	63.5%	36.9%	0%	0%
# Non-detects at ½ DL	72	142	109	-	-
% of samples	39.1%	44.4%	58.6%	-	-

	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Tributaries
# Samples	16	82	63	100	119	123
% of Total	3.2%	16.3%	12.5%	19.8%	23.6%	24.4%
% Detects	100.0%	46.3%	42.9%	52.0%	61.3%	68.3%
Mean (ug/kg)	27.9	10.4	10.5	12.7	1.4	8.7
Standard Dev (ug/kg)	42.3	10.6	10.9	40.5	3.1	12.7
Median (ug/kg)	9.0	9.5	9.5	6.3	0.1	2.2

4,4’-DDE Database Summary Statistics

Total # Samples	# Grab Samples	# Core Samples	# Composite Samples	# Detected Concentrations	# Non-Detections
496	311	185	0	326	170
% of Total	62.7%	37.3%	0	65.7%	34.3%

	Mean (ug/kg)	Standard Deviation	Median (ug/kg)	# Detected Concentrations	# Non-Detections
1990	-	-	-	-	-
1991	4.10	8.55	1.04	10	4
1992*	11.55	6.10	12.00	8	40
1993	6.00	8.76	1.25	6	5
1994*	12.39	5.65	11.25	1	43
1997	13.83	34.20	2.75	150	15
1998	4.88	5.39	4.00	4	2
1999	5.99	6.73	4.10	12	1
2000	5.23	19.20	0.99	38	1
2001	3.59	6.00	1.50	28	1
2002*	0.36	0.75	0.09	8	28
2003	21.29	18.24	17.00	19	3
2004	-	-	-	-	-
2005	25.96	89.98	1.60	11	19
2007	49.54	44.65	37.00	18	0
2008	-	-	-	-	-
2009	6.21	5.69	4.80	13	8
Overall	12.51	32.84	3.40		

*Greater than 50% of the sample data were non-detect – used ½ detection limits

Total # Samples	# Samples <= ERL	# Samples > ERL	# Samples > ERM	# Samples > LUS	# Samples > HUS
496	192	304	206	0	0
% of Total	38.7%	61.3%	41.5%	0%	0%
# Non-detects at ½ DL	65	105	97	-	-
% of samples	33.9%	34.5%	47.1%	-	-

	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Tributaries
# Samples	16	74	63	100	120	123
% of Total	3.2%	14.9%	12.7%	20.2%	24.2%	24.8%
% Detects	93.8%	68.9%	47.6%	51.0%	71.7%	68.3%
Mean (ug/kg)	23.4	23.2	20.9	8.8	1.6	13.9
Standard Dev (ug/kg)	15.4	58.0	48.3	13.5	3.1	27.2
Median (ug/kg)	23.0	11.1	11.3	6.2	0.2	3.3

Dieldrin Database Summary Statistics

Total # Samples	# Grab Samples	# Core Samples	# Composite Samples	# Detected Concentrations	# Non-Detections
504	311	193	0	192	312
% of Total	61.7%	38.3%	0	38.1%	61.9%

	Mean (ug/kg)	Standard Deviation	Median (ug/kg)	# Detected Concentrations	# Non-Detections
1990	-	-	-	-	-
1991*	0.222	0.236	0.130	2	12
1992*	10.432	6.841	12.00	5	43
1993*	0.423	0.397	0.250	5	6
1994*	11.614	2.495	11.250	0	44
1997	3.268	8.669	0.180	106	59
1998*	1.083	1.160	0.500	2	4
1999*	10.231	18.797	1.000	6	7
2000	1.207	2.874	0.240	29	10
2001	2.500	4.063	0.190	26	11
2002*	0.101	0.081	0.085	0	36
2003*	3.382	0.718	3.400	0	22
2004	-	-	-	-	-
2005*	2.754	4.678	1.400	0	30
2007	27.678	48.545	9.500	11	7
2008	-	-	-	-	-
2009*	3.533	4.304	0.900	0	21
Overall	5.101	12.375	0.709		

*Greater than 50% of the sample data were non-detect – used ½ detection limits

Total # Samples	# Samples <= ERL	# Samples > ERL	# Samples > ERM	# Samples > LUS	# Samples > HUS
504	61	443	134	4	0
% of Total	12.1%	87.9%	26.6%	0.8%	0%
# Non-detects at ½ DL	49	263	118	0	0
% of samples	80.3%	59.4%	88.1%	0%	0%

	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Tributaries
# Samples	16	82	63	100	120	123
% of Total	3.2%	16.3%	12.5%	19.8%	23.8%	24.4
% Detects	87.5%	14.6%	33.3%	40.0%	32.5%	53.7%
Mean (ug/kg)	1.128	5.184	5.462	5.596	1.113	8.866
Standard Dev (ug/kg)	1.197	4.706	5.889	6.732	3.091	22.814
Median (ug/kg)	0.711	3.400	1.750	1.646	0.052	0.500

Mercury Database Summary Statistics

Note: these summary statistics only consider the surface section of the sediment core samples collected in 2002 at Oldmans and Woodbury Creeks.

Total # Samples	# Grab Samples	# Core Samples	# Composite Samples	# Detected Concentrations	# Non-Detections
799	602	195	2	638	161
% of Total:	75.3%	24.4%	0.3%	79.8%	20.2%

	Mean (mg/kg)	Standard Deviation	Median (mg/kg)	# Detected Concentrations	# Non-Detections
1990	0.082	0.130	0.042	29	7
1991	0.135	0.135	0.100	20	16
1992	0.095	0.084	0.087	12	36
1993	0.184	0.177	0.118	10	1
1994	0.093	0.082	0.070	3	41
1997	0.187	0.262	0.115	155	10
1998	0.110	0.099	0.070	11	0
1999	0.226	0.148	0.150	13	0
2000	0.122	0.192	0.080	38	3
2001	0.137	0.177	0.085	35	3
2002	0.099	0.149	0.033	32	6
2003	0.173	0.062	0.178	22	0
2005	0.110	0.213	0.020	20	10
2007	0.526	0.558	0.315	18	0
2008	0.103	0.187	0.050	199	28
2009	0.170	0.095	0.150	21	0
Overall	0.130	0.212	0.075		

Total # Samples	# Samples <= ERL	# Samples > ERL	# Samples > ERM	# Samples > LUS	# Samples > HUS
799	559	238	40	0	0
% of Total	70.0%	29.8%	5.0%	0%	0%

	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Tributaries
# Samples	22	89	92	195	265	136
% of Total	2.8%	11.1%	11.5%	24.4%	33.2%	17.0%
% Detects	81.8%	84.3%	65.2%	76.9%	81.5%	87.5%
Mean (mg/kg)	0.184	0.155	0.105	0.183	0.052	0.250
Standard Dev (mg/kg)	0.114	0.098	0.122	0.291	0.048	0.301
Median (mg/kg)	0.166	0.148	0.077	0.091	0.040	0.180

Lead Database Summary Statistics

Total # Samples	# Grab Samples	# Core Samples	# Composite Samples	# Detected Concentrations	# Non-Detections
799	604	193	2	791	8
% of Total:	75.6%	24.2%	0.2%	99.0%	1.0%

	Mean (mg/kg)	Standard Deviation	Median (mg/kg)	# Detected Concentrations	# Non-Detections
1990	22.12	20.14	15.35	35	1
1991	71.86	82.94	37.65	36	0
1992	18.08	22.51	12.30	41	7
1993	54.01	56.43	23.10	11	0
1994	22.13	22.53	14.75	44	0
1997	51.87	53.56	34.88	165	0
1998	421.49	1586.30	47.40	19	0
1999	123.08	92.21	80.00	13	0
2000	39.77	44.61	26.90	41	0
2001	38.24	33.90	29.35	38	0
2002	20.70	28.77	12.40	30	0
2003	51.00	16.31	51.15	22	0
2005	30.93	45.12	9.42	30	0
2007	144.00	118.80	83.15	18	0
2008	22.81	32.78	14.00	227	0
2009	51.04	20.61	47.00	21	0
Overall	48.29	250.54	20.40		

Total # Samples	# Samples <= ERL	# Samples > ERL	# Samples > ERM	# Samples > LUS	# Samples > HUS
799	497	302	81	1	1
% of Total	62.2%	37.8%	10.1%	0.1%	0.1%

	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Tributaries
# Samples	22	87	91	193	265	141
% of Total	2.8%	10.9%	11.4%	24.2%	33.2%	17.6%
% Detects	100%	100%	95.6%	98.4%	99.6%	100%
Mean (mg/kg)	72.88	58.10	28.55	38.50	13.42	130.08
Standard Dev (mg/kg)	25.31	50.74	32.65	42.28	8.48	585.90
Median (mg/kg)	81.45	51.40	15.80	23.30	12.10	55.00

Total PCB Database Summary Statistics

Total # Samples	# Grab Samples	# Core Samples	# Composite Samples	# Detected Concentrations	# Non-Detections
592	441	144	7	459	133
% of Total	74.5%	24.3%	1.7	77.5%	22.5%

	Mean (ug/kg)	Standard Deviation	Median (ug/kg)	# Detected Concentrations	# Non-Detections
1990	-	-	-	-	-
1991	20.22	33.96	3.45	10	4
1992*	422.20	345.20	517.50	8	26
1993	25.98	36.76	21.24	9	2
1994	545.13	138.31	510.00	1	22
1996	41.10	53.82	14.13	7	0
1997	72.78	144.49	11.00	151	14
1998*	58.23	54.01	25.00	2	4
1999	69.46	44.53	50.00	7	6
2000	30.35	50.55	8.54	32	7
2001	49.47	93.27	13.80	79	0
2001 (?)	7.66	12.72	3.33	28	0
2002	14.61	47.74	1.52	29	9
2003*	371.73	67.53	361.00	2	13
2005*	319.14	477.77	181.00	2	26-
2007	1104.50	1735.55	305.50	18	0
2008	95.04	450.13	9.67	52	0
2009	112.80	94.66	62.06	21	0
Overall	150.16	422.29	18.12		

*Greater than 50% of the sample data were non-detect – used ½ detection limits

Total # Samples	# Samples <= ERL	# Samples > ERL	# Samples > ERM	# Samples > LUS	# Samples > HUS
592	308	284	128	124	10
% of Total	52.0%	48.0%	21.6%	20.9%	1.7%
# Non-detects at ½ DL	20	113	80	77	2
% of samples	6.5%	39.8%	62.5%	62.1%	20.0%

	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Tributaries
# Samples	25	73	57	165	143	128
% of Total	4.2%	12.3%	9.6%	27.9%	24.2%	21.6%
% Detects	100%	69.9%	71.9%	70.9%	92.3%	71.9%
Mean (ug/kg)	74.37	242.09	102.25	204.38	3.89	228.55
Standard Dev (ug/kg)	45.99	329.88	121.75	361.00	4.63	742.70
Median (ug/kg)	82.31	165.00	36.44	23.74	1.82	18.12

PCDD/F TEQ Database Summary Statistics

Total # Samples	# Samples <= ERL	# Samples > ERL	# Samples > ERM	# Samples > LUS	# Samples > HUS
24	6	18	1	0	0
% of Total	25.0%	75%	4.2%	0%	0%

Year	Mean (ug/kg)	Standard Deviation	Median
All Data - 2008	0.00482	0.00608	0.00342

	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
# Samples	0	0	2	12	10
% of Total	0%	0%	8.3%	50.0%	41.7%

Appendix E

Detailed Maps Showing the Results of the Aquatic Habitat Restoration and Suitability and Upland Beneficial Use Threshold Analyses

Appendix E: Detailed Maps Showing the Results of the Aquatic Habitat Restoration Suitability and Upland Beneficial Use Threshold Analyses