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Sediments

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Chapter 4 – Sediments

1 – Sediment Loading

Most estuaries of the world, including Delaware Estuary, are traps for sediment eroded from the watershed above the head of tide. As sea level rose at the end of the last glacial period, beginning about 18,000 years ago, the ancestral Delaware River valley was progressively inundated by the sea until the approximate boundaries of the estuary were established within the past several thousand years (Fletcher et al., 1990). During that period, extensive natural accumulation of both fine- and coarse-grained sediment occurred in the estuary, creating the three-dimensional geometry and distribution of sediments that existed when Europeans first sailed into the Delaware.

The present state of the Delaware Estuary sediment system represents a highly altered condition compared to what existed as recently as a few centuries ago. In the intervening period, land use changes in the watershed above the head of tide have affected the rate at which new sediment is delivered to the estuary. Additionally, portions of once natural estuarine shoreline have been modified by construction of bulkheads, seawalls, piers, and wharves to serve the needs of urban and industrial development. Other portions of the estuary shoreline have been diked and ditched for agriculture and related purposes. The construction and maintenance of a shipping channel through dredging and other activities also have an impact on the system. Dredged sediment has been used as fill to create new land adjacent to the waterway. However, quantitative sediment loading data are available only for the past 60 years.

1.1 Description of Indicator

Sediment loading to the Delaware Estuary occurs principally as the Delaware River and its tributaries discharge their suspended load, and a relatively smaller bed load of sediment, at the head of tide. The rate of sediment discharged depends on a number of factors, including antecedent hydrological conditions over the basin (rainfall and runoff); land use patterns, in particular the degree of disturbed land surface; the number and location of dams on tributaries, which can impound stream sediments above the head of tide; etc. Sediment loading to the estuary has been monitored quantitatively only for the past six decades. Fig. 4.1 presents the annual series of suspended sediment discharged to the estuary from 1950 through 2009. The data represent the combined inputs measured for the Delaware River at Trenton, the Schuylkill at Philadelphia, and the Brandywine at Wilmington, which together include ~80% of the total freshwater discharged to the estuary. The graph shows the large annual variability in sediment discharge, indicative of the fact that sediment discharge is highly correlated to freshwater discharge, particularly peak flow events; the drought period of the mid-1960s has relatively low sediment discharge, whereas the period from 2004 through 2006, with several large flood events in the region, shows relatively higher sediment discharge.

1.2 Present Status

The mean annual sediment discharge over the past six decades at these three locations is 1.28 million metric tons. Together the three gaged locations represent 80% of the drainage area tributary to Delaware Estuary. The remaining 20% of the estuary drainage area that is not gaged for sediment discharge includes smaller watersheds with lower stream gradients. It is concluded that the ungaged watersheds contribute an unknown but negligibly small fraction of the suspended load of the estuary. Other known but unquantified minor contributors of new suspended sediment includes storm and sanitary sewer outfalls.

Consequently, the mean annual sediment discharge to the estuary from the entire basin is estimated as 1.28 million metric tons (1.3 million rounded). For historical perspective, Mansue and Commings (1974) analyzed suspended sediment input to Delaware Estuary and their data show an average annual input from the Delaware, Schuylkill, and Brandywine Rivers of 1.0 million metric tons per year, with a total suspended solids input to the estuary from all sources estimated as 1.3 million metric tons annually. The sediment discharge data in Fig. 4.1 suggest no apparent trend of increase or decrease in sediment discharge over the period of record.

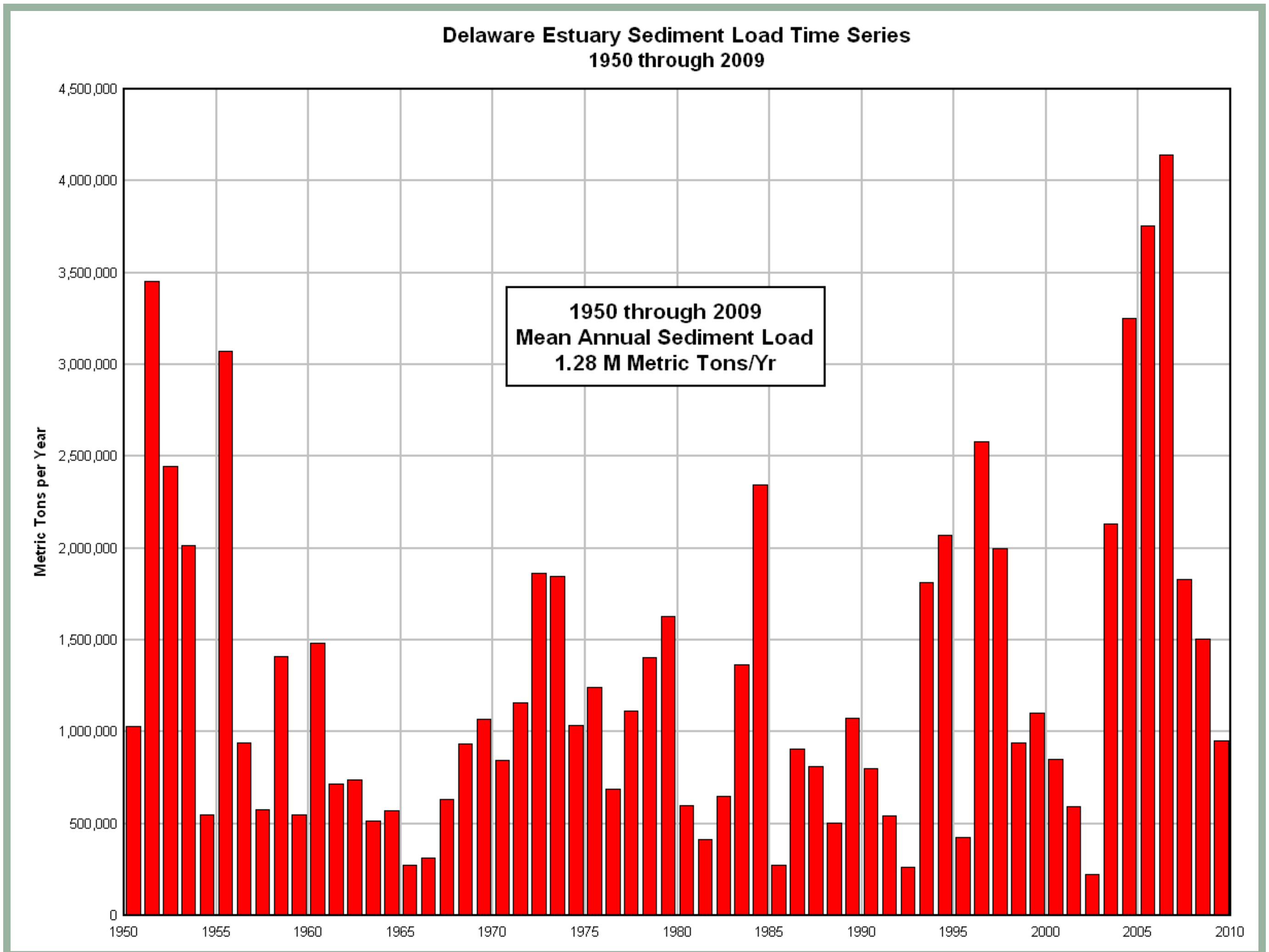

Fig. 4.1. Annual suspended load time series, 1950 through 2009

1.3 Past Trends

There is no apparent temporal trend for increased or decreased suspended sediment loading to the estuary over the past six decades.

1.4 Future Predictions

It is reasonable to expect that sediment loading in the next several decades will resemble the past 60 years. During high-flow events in the watershed, larger quantities of suspended sediment stored in and along streams will be flushed to the estuary, and the sediment load will be small in years with low inflow regimes.

1.5 Actions and Needs

Continued monitoring of suspended sediment discharge at the presently gaged locations is recommended.

1.6 Summary

The mean annual contribution of new sediment to the estuary from the watershed above the head of tide has averaged 1.3 million tons per year over the past six decades. However, the seasonal and annual variability in sediment discharge is large and reflects the underlying natural variability of the hydrologic regime of the Delaware watershed. There is no apparent trend in this record indicating either a long-term increase or decrease in sediment loading to the estuary from the watershed above the head of tide.

2 – Sediment Quantity

2.1 Description of Indicator

The most useful indicator of sediment quantity in an estuary is a spatially complete sediment budget that identifies the principal sources, sinks, pathways, and processes involved in sediment transport and distribution. In an ideal budget, all sediment sources and sinks are identified and quantified, and all processes that add, transport, and remove sediment are also identified and quantified. However, sediment transport processes are highly variable in time and space, and quantifying source and sink terms always involves a level of temporal and spatial averaging. For this reason, system-wide estimates have relatively large uncertainties associated with them. It is also important to note that a system-wide budget need not show sources and sinks being in balance. An estuary may exhibit long-term net accumulation of sediment, or long-term net loss.

2.2 Present Status

The most recent published, quantitative sediment budget for Delaware Estuary was presented in "Anthropogenic Influences on the Morphology of the Tidal Delaware River and Estuary: 1877 – 1987" (Walsh, 2004). The sediment budget data from this report is presented below as Table 4.1.

Table 4.1. 1946-1984 Estuary Sediment Mass Balance.

SOURCES		SINKS	
Bottom erosion	3.4	Maintenance Dredging	2.8
Upland Fluvial Input	1.3	Marsh Accumulation	2.6
TOTAL SOURCES	**4.7**	**TOTAL SINKS**	**5.4**

Quantities in millions of metric tons per year (Walsh, 2004)

Table 4.1 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 it can be seen that the largest category is "bottom erosion". This indicates that for the period and areas included in the analysis, scour of the bed of the estuary was observed to be the largest source of sediment available to the system, larger by a factor of 2.6 than the average annual input of "new" sediment from the watershed above the head of tide. 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 fringing marshes of Delaware Bay documented over the past 160 years, tidal marshes may accumulate as much or more sediment mass vertically than they lose to lateral retreat.

Although Table 4.1 represents the latest published sediment budget for Delaware Estuary, US ACE Philadelphia District is working with Woods Hole Group (Falmouth, MA) and Dr. Christopher Sommerfield of the University of Delaware to update this budget. In-progress findings of the sediment budget reevaluation include the following:

- Suspended sediment loading ("upland fluvial input"): 1.3 M metric tons/year
- Inorganic sediment accumulation in tidal marshes: 1.1 M metric tons/year

Additional items related to an updated sediment budget that will be completed by Woods Hole Group and Dr. Sommerfield within the next six months include:

- Suspended sediment inventory in the estuary based on University of Delaware oceanographic surveys
- Analysis of maintenance dredging records provided by US ACE
- Bottom sedimentological data (grain size and bulk density)
- Digital shoreline datasets – analyzed for shoreline change for periods of interest
- Digital bathymetric datasets - analyzed for bathymetric change over several periods

2.3 Past Trends

Previous investigators have compiled the sediment budgets for Delaware Estuary, including Oostdam (1971) and Wicker (1973). However, given the variety of data sources and analytical approaches applied in historic sediment budget research, it is not apparent that a meaningful historic trend can be derived from comparison of budgets created by different researchers at different times. However, the in-progress work by Woods Hole Group and Dr. Christopher Sommerfield, which applies a consistent methodology to several periods from 1890 to the present, will allow a meaningful comparison of estuary sediment budgets over time to identify historic and presumably future trends.

2.4 Future Predictions

[See above]

2.5 Actions and Needs

Sediment budget research in Delaware Estuary has evolved substantially in the past decade in terms of sources of historic data, analytical approaches to the subject, and also instrumentation to directly measure relevant hydrodynamic and sediment transport parameters. Continued efforts to improve our understanding of sediment transport phenomena and the estuary sediment budget in general are recommended, including a reevaluation of localized contribution of suspended sediment from storm and sanitary sewer discharges.

2.6 Summary

Sediment quantity is an indicator that is best represented by an estuary sediment budget. The latest published sediment budget for the Delaware Estuary indicates that the bed of the estuary has eroded at a rate that exceeds the average annual rate at which new sediment is supplied from the watershed, and that maintenance dredging is the principal mechanism by which sediment is "permanently" removed from the estuary. Ongoing research to be completed in the next six months will allow a significant quantitative improvement in identifying the processes and terms of the sediment budget.

3 – Sediment Organic Carbon

3.1 Description of Indicator

Sediment total organic carbon (TOC) is the sum amount of carbon that is bound to organic material. Organic carbon is both natural and anthropogenic in origin. Natural sources include leaf litter, plant and animal waste. Examples of anthropogenic sources of organic carbon include pesticides, municipal and industrial wastewater. It has an affinity for fine-grained sediment particles and its concentrations typically correlate with the percentage of silt and clay in the sediment.

Studies have indicated that the initial increase in organic carbon provides food to the benthos. Too much organic carbon can create an environment where opportunistic species dominate the area. If this occurs over a substantial amount of time, evidence suggests that bacterial mats will dominate the area. Elevated concentrations of TOC commonly suggest greater potential of contaminants to accumulate and impact the aquatic food web. Although the Delaware does not exhibit the typical signs of eutrophication (e.g. fish kills, algal blooms, etc.), TOC remains a useful indicator of contamination by organic pollutants.

3.2 Present Status

Data exists for TOC in two different matrices: sediment and water column. Sediment TOC data was collected and reported in Chapter 3 of the 2007 EPA National Estuary Coastal Condition Report. The existing data indicate that the concentrations of TOC in the Delaware Estuary were rated as "good" for sediment TOC. Sixty-seven percent of the estuarine area was rated "good" for this component, with 19% rated "fair". No portions of the Delaware were rated poor although it must be noted that data was unavailable for 14% of the estuary. In addition, the spatial distribution of sediment TOC was measured in sediment samples obtained in 2008 as part of the Delaware Estuary Delaware Estuary Benthic Inventory (DEBI) effort. The DEBI sample locations are included as Fig. 4.2. TOC sediment data had not been collected in this comprehensive fashion before the DEBI project in 2008 or since. In the Delaware River Watershed Source Water Protection Plan, data collected from 1993 to 2006, indicates that water column TOC are at their lowest in decades. Slight annual fluctuations were noted, especially in the maximum value of TOC detected, but the mean and median values indicated an overall decline in TOC concentrations in mg/L over the course of the last 13 years.

3.3 Past Trends

There isn't enough data regarding sediment TOC to determine a trend. For water column TOC, past trends indicate that TOC was present in greater concentrations than in the past. The system is typically turbid, and the greater the TSS, there is a greater chance of elevated TOC concentrations, especially when the sediment entering the Delaware Estuary is silty in origin. Improvements to wastewater treatment, stormwater control, and the creation of low impact development are a likely to reduce TOC in the water column.

3.4 Future Predictions

Continued improvements in wastewater treatment, storm-water management and smarter land use planning are projected to reduce the amount of TOC delivered to the Delaware Estuary. In addition, total maximum daily loads (TMDLs) associated with nutrient reduction or TSS would also help reduce the amount of water column TOC. Predictions regarding sediment TOC cannot be made at this time.

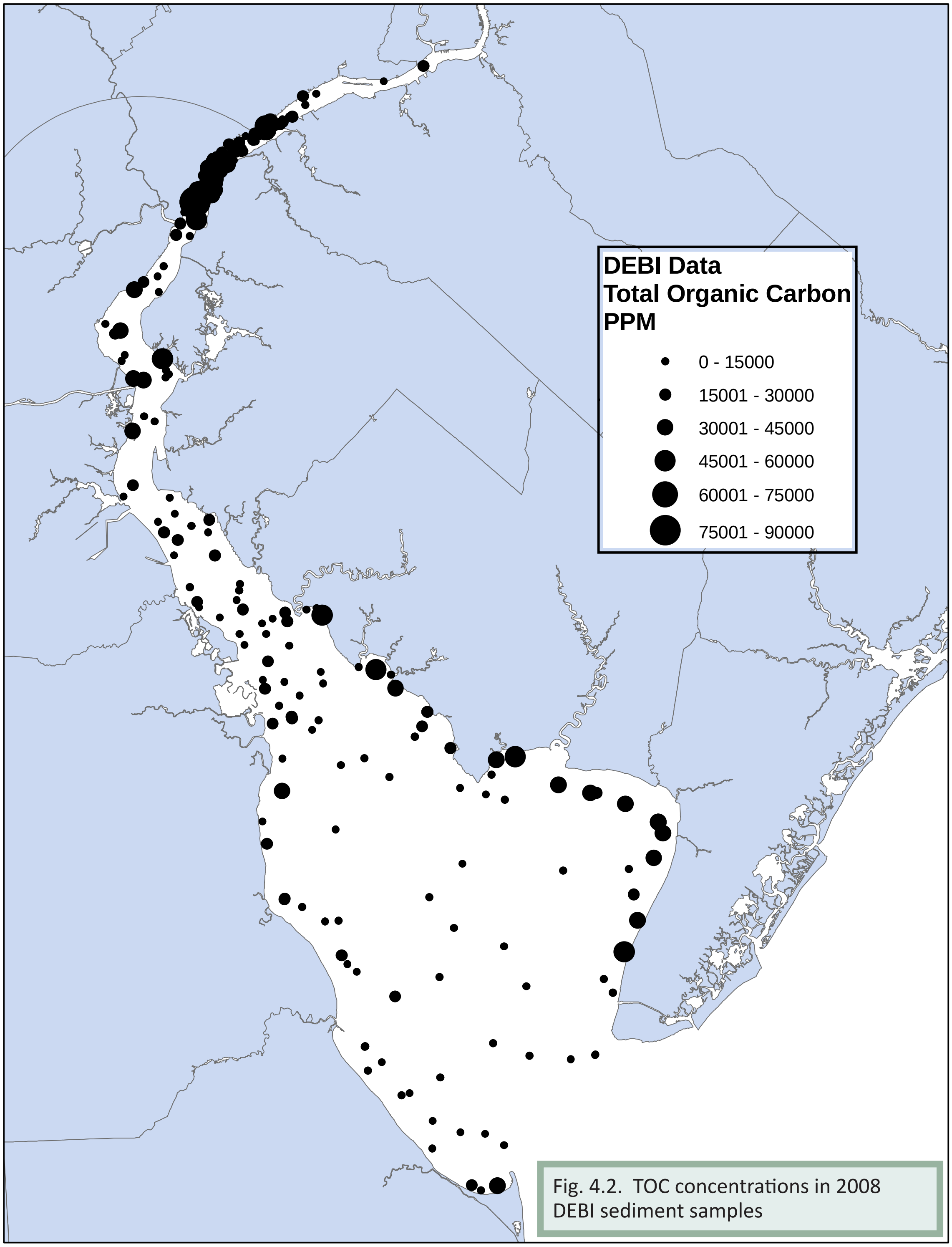

Fig. 4.2. TOC concentrations in 2008 DEBI sediment samples

3.5 Actions and Needs

It is stated in the 2007 National Estuary Program (NEP) Coastal Condition Report that the "regional NEP programs have found that the problems associated with eutrophication are dwarfed by problems from other water quality stressors". This does not mean that eutrophication is not an issue in the Delaware Estuary. It simply implies that greater concerns, such as industrial inputs to the system (i.e. PCBs) are a higher priority at this time. There are still areas of the Delaware Estuary with levels of dissolved oxygen (DO) less than 5mg/L. Although the hydromorphic features of the Delaware are favorable in creating a well mixed system, low DO levels, along with levels of nitrogen and chlorophyll a comparable to the Chesapeake Bay system insinuate that additional data regarding TOC should be collected to better understand the system.

3.6 Summary

TOC is currently being measured in the sediment and water column. A decreasing trend is associated with water column concentrations due to improvements in wastewater treatment and storm water management, while trends in sediment TOC cannot be determined until more data is collected.

4 – Sediment Grain Size

4.1 Description of Indicator

Sediment grain size in the Delaware Estuary varies across a wide range, from gravel to clay. The grain size of sediments on the estuary bottom is an ecological indicator to the extent that many benthic organisms show a preference for specific types of bottom sediments. It is natural, and expected, that different areas within the estuary will exhibit different kinds of bottom sediments. Thus, sediment grain size acts as one of the primary factors influencing the distribution of various benthic organisms and ecological communities. Another way in which grain size is an indicator is that fine grained sediment (i.e. sediment with high TOC) tends to correlate positively with elevated concentrations of industrial contaminants. Thus the spatial distribution of grain sizes contributes to the spatial distribution of contaminants.

4.2 Present Status

The present spatial distributions of sand and silt-clay content are presented in Fig. 4.3 and 4.4, respectively. The sediment grain size samples were obtained in 2008 as part of the Delaware Estuary Program DEBI (Delaware Estuary Benthic Inventory) effort. The two plots indicate the obvious inverse relationship between sand and silt-clay ("mud") fractions of Delaware Estuary sediments. The plots also indicate the heterogeneity of sediment types and patchy distribution at many locations within the estuary, particularly in the reach from Wilmington to Liston Point. In this segment of the estuary, the dominant bottom sediment type is mud whereas downstream of Liston Point, the bottom is dominated by mixtures of sand and gravel with lesser amounts of mud. 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.

4.3 Past Trends

Although sufficient data do not exist to assess the degree to which sediment grain size distribution may have changed over time, the 2008 DEBI data are broadly comparable to the bottom sediment distribution that is depicted in Biggs and Church (1984), Fig. 4.1.

4.4 Future Predictions

Although it is plausible to predict that sediment best management practices (BMPs) in the watershed will eventually lead to reductions in suspended sediment supply to the estuary, there is no evidence (see Fig. 4.1) of this reduction having occurred over the past six decades. It is therefore probable that there will be no significant changes in sediment grain size distribution in the estuary within the next few decades.

4.5 Actions and Needs

Sediment grain size data should continue to be collected and archived in future studies and conducted concurrently with other benthic research.

4.6 Summary

Sediment grain size is not intrinsically an indicator of estuary health. There are organisms and ecological communities that productively inhabit the full range of bottom sediment classes that exist in the estuary. Although fine-grained sediment can potentially have higher concentrations of adsorbed pollutants than sand and gravel, fine grained sediment bottom is a natural component of all estuaries and can support a range of "normal" benthic communities.

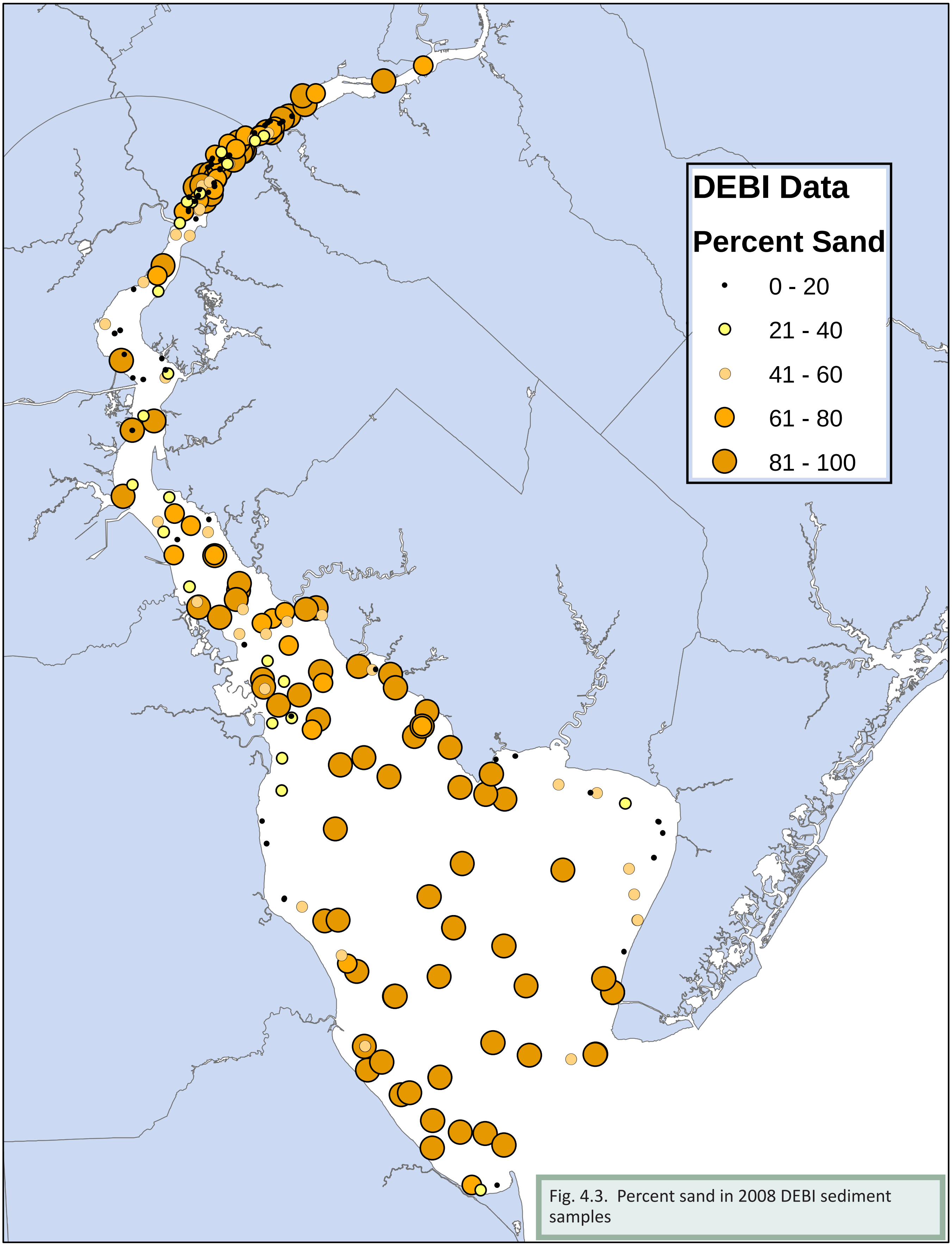

Fig. 4.3. Percent sand in 2008 DEBI sediment samples

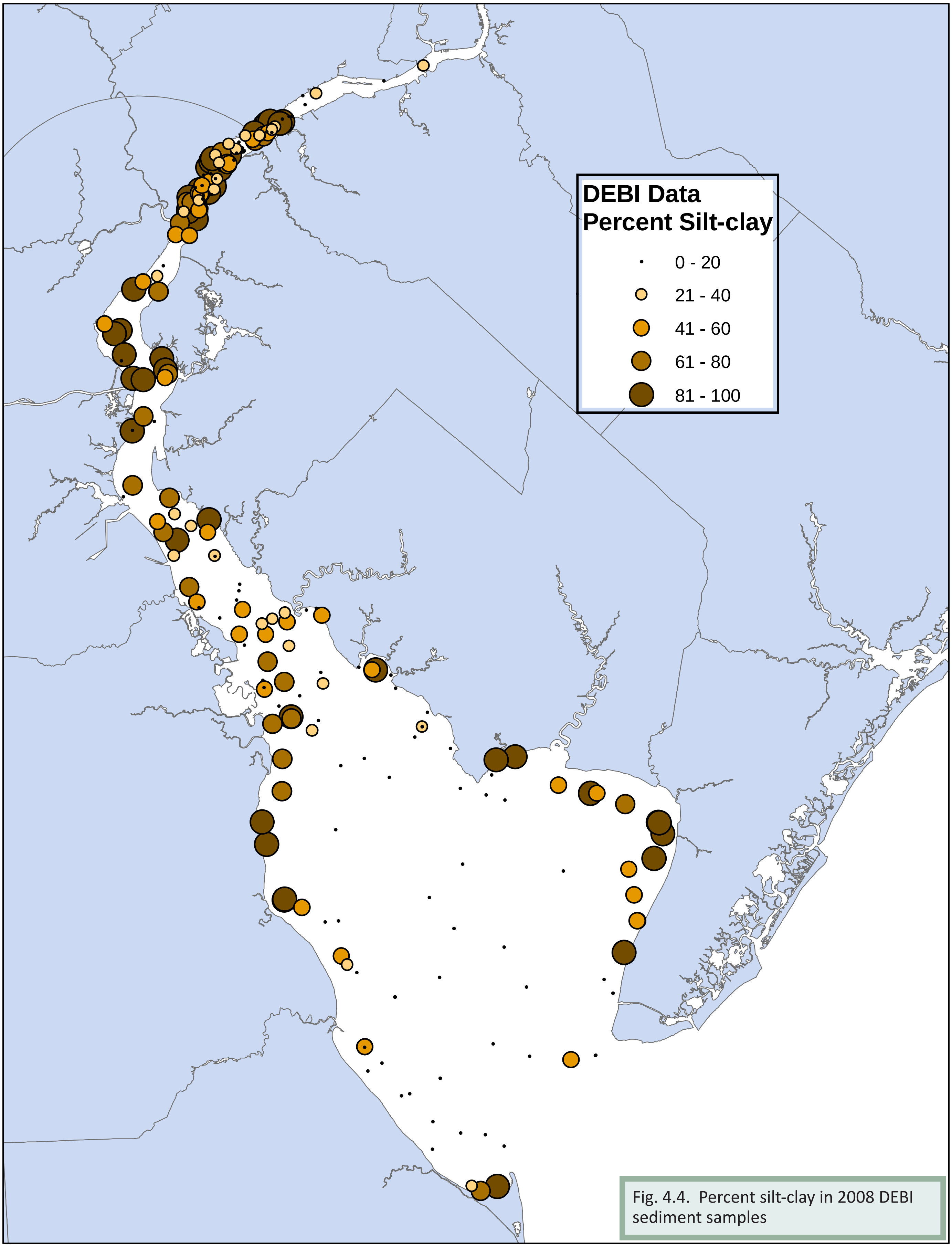

Fig. 4.4. Percent silt-clay in 2008 DEBI sediment samples

5 –Dredging Activity

5.1 Description of Indicator

As shown by the sediment budget information presented in Section 2 of this Chapter, maintenance dredging constitutes a significant component of the source and sink terms of the budget. The earliest navigation improvements within Delaware Estuary that involved dredging began in 1890 in order to meet the growing needs of waterborne commerce in the region. The US ACE has been the principal agency responsible for the construction and subsequent maintenance dredging of federal navigation projects authorized by Congress. The first project was the construction of a 7.9 meter (26 ft) deep channel from Philadelphia to naturally deep water in the bay. Between 1890 and 1942, the Delaware River, Philadelphia to the Sea channel was incrementally deepened to 9.1 meters (30 ft); 11.0 meters (36 ft); and finally to the existing channel depth of 12.2 meters (40 ft). Congress authorized the deepening of this channel to 13.7 meters (45 ft) in 1992, and a portion of that work has been initiated as of 2011. Each successive channel deepening has created a quantity of "new work" dredging. Following completion of dredging to a specified depth, "maintenance" dredging is performed periodically to remove shoaled sediment from the channel in the interest of navigational safety and efficiency. Other deep-draft navigation projects in the estuary include: Delaware River, Philadelphia to Trenton; Wilmington Harbor, Christina River, DE; and Schuylkill River, Philadelphia, PA. The Delaware River, Philadelphia to Sea channel is the longest and deepest of all navigation channels in the estuary, and correspondingly has required the largest dredging effort, approximately 74% by volume, of all Delaware Estuary dredging over the past decade.

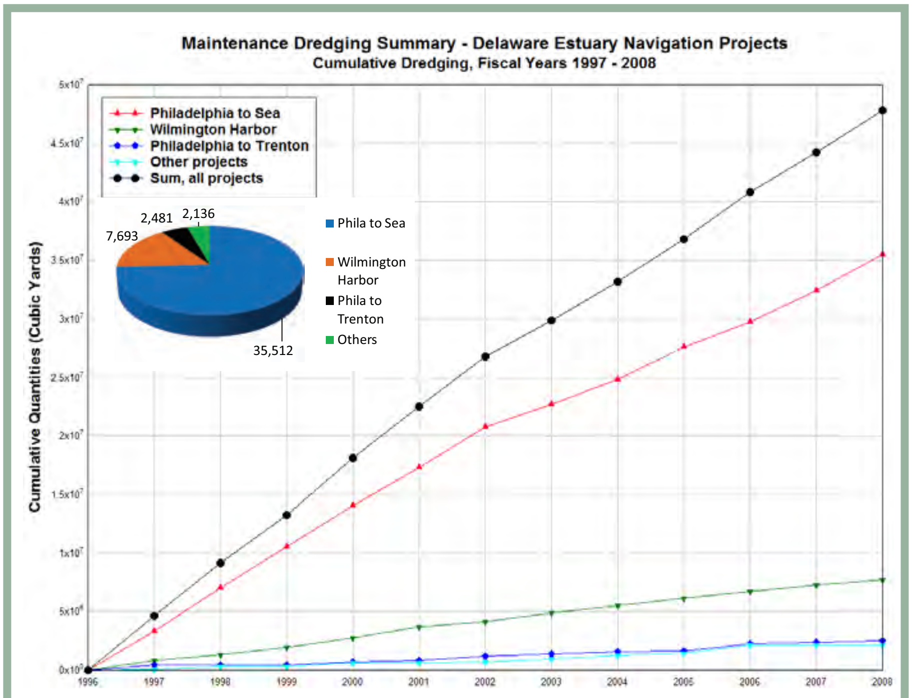

Fig. 4.5. Cumulative maintenance dredging, Federal navigation projects in Delaware Estuary, 1997 – 2009

5.2 Present Status

The cumulative maintenance dredging from all Federal navigation projects in Delaware Estuary for the period 1997 through 2008 is presented in Fig. 4.5, and illustrates the relative portion of Delaware Estuary dredging associated with each project. The average annual total of all Delaware Estuary dredging in this period is 3.1 million cubic meters (4.0 million cubic yards) per year. Channel shoaling, and hence channel dredging, is a highly localized phenomenon. There are four high shoaling-rate locations in the estuary within a 30 km reach between the C&D Canal and Marcus Hook (including the Wilmington Harbor project) that together necessitate about 80% of all maintenance dredging within the entire estuary. Note that since 1955, essentially all sediment dredged from the estuarine system has been placed in upland dredged material disposal sites.

5.3 Past Trends

Maintenance dredging quantities have been compiled in a number of US ACE reports. A 1937 report (US ACE, 1937) states "maintenance dredging amounting to about ten million cubic yards annually" was required over the preceding 25 years. Subsequent US ACE reports (US ACE 1967, US ACE 1984) also present estimated annual navigation project dredging in the estuary. Fig. 4.6 presents the annual dredging rates from these four dates (1937, 1967, 1984, and 2009). Where data were reported for projects in addition to the Philadelphia to Sea channel, these are included in

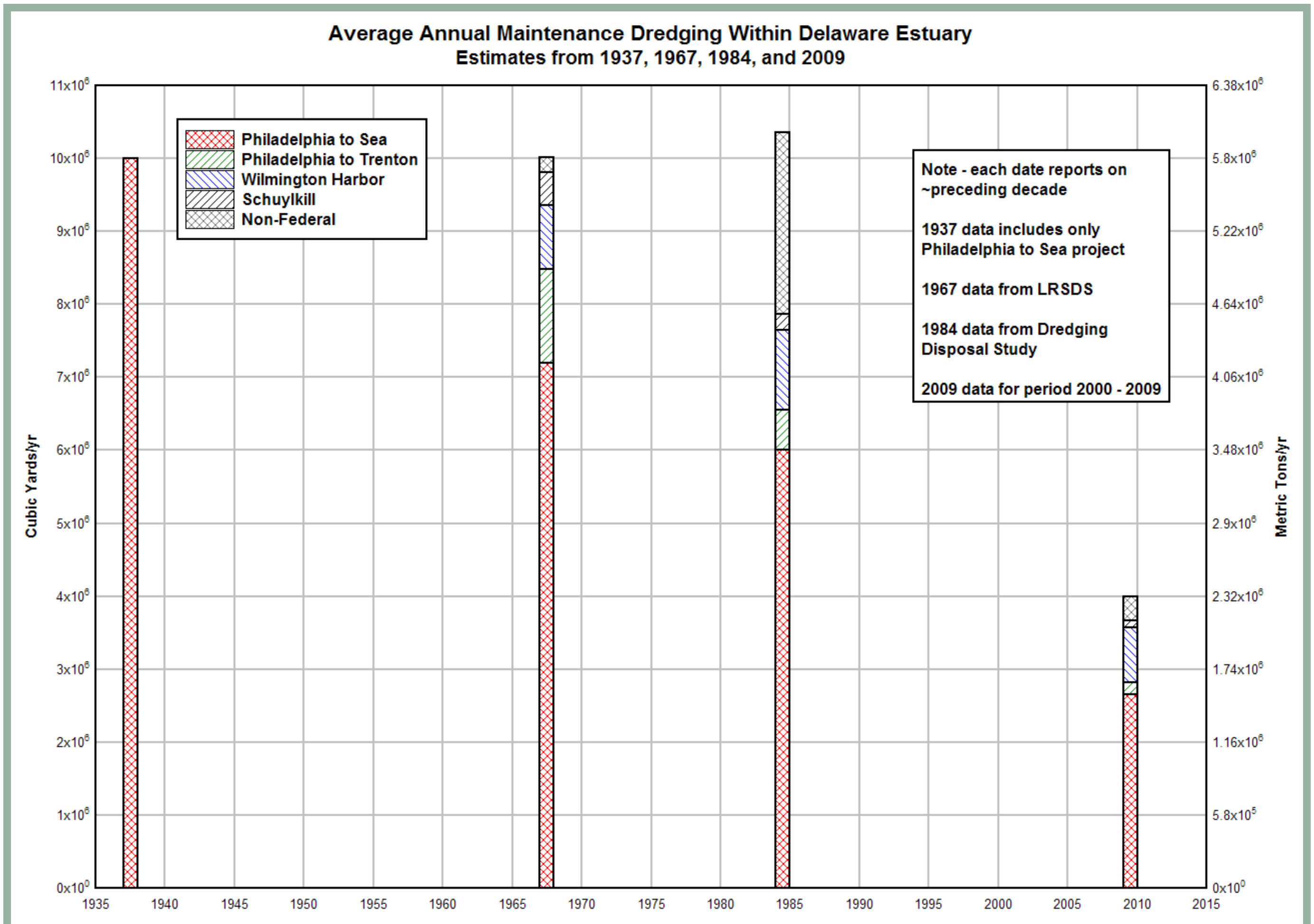

Fig. 4.6. Historic maintenance dredging rates in Delaware Estuary

Fig. 4.6. 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/m3 (see Walsh, 2004). The quantities display the trend of reduced maintenance dredging over the past several decades.

5.4 Future Predictions

The deepening of the Delaware River Main Channel from 12.2 meters (40 ft) to 13.7 meters (45 ft) is expected to lead to approximately a 20% increase in annual maintenance dredging.

5.5 Actions and Needs

Continued monitoring and reporting of maintenance dredging quantities is a routine function of US ACE. It is recommended that future work on all aspects of Delaware Estuary sediment management and sediment budget investigations include regular coordination with US ACE regarding dredging quantities.

Beginning in 2009, US ACE and several other organizations began to work collaboratively to develop a Regional Sediment Management Plan. Prior to this, there had been no systematic approach to dealing with the challenges and opportunities associated with sediment management in the Delaware Estuary region. The Regional Sediment Management initiative is intended to broaden local knowledge and facilitate watershed collaboration about how, where, and when to manage parts of the sediment system differently and more beneficially than has been previously practiced. The Plan is currently under development.

5.6 Summary

Dredging activity is not a conventional ecological indicator. It is a direct measure of the degree to which sediment shoals within navigation projects must be removed in the interest of safe and efficient navigation. The historic trend over the past five decades has been for diminished average annual dredging quantities, but the cause of this decline has not been rigorously investigated to date.

Chapter 4 - References

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