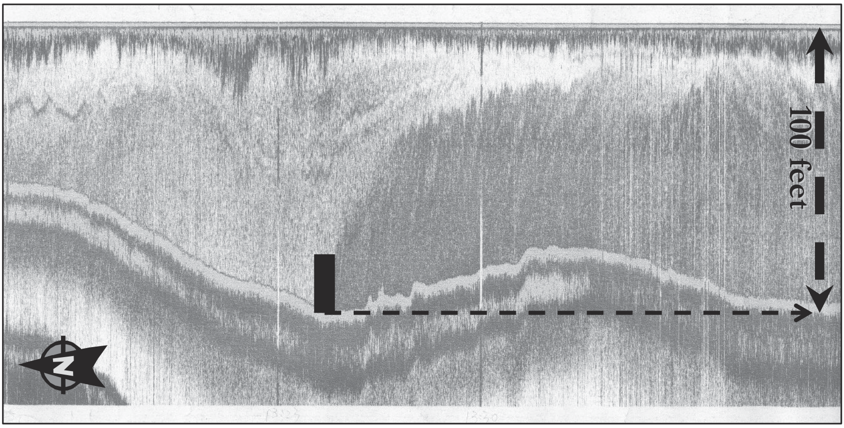

Figure 2. Salt wedge on spring ebb current at Verrazano Narrows, 3/28/91.

A somewhat similar temporary structure was constructed in 1988 and 1999 in the Mississippi River about 48 km south of New Orleans (Anonymous 1999). The salt wedge moved progressively further up river in those years due to drought, threatening the fresh water supply of that city. A 9 m high dike some 518 m long was constructed on the river bed to inhibit gravitational flow of salt along the bottom. This successfully protected the drinking water supply. However, as freshwater flow increases as the drought dissipates, the dike erodes. The U.S. Army Corps of Engineers now replaces the sill, as needed, based on salinity measurements in the lower Mississippi (Anonymous 1999).

Long Island Sound also experiences estuarine gravitational flow with fresher water at the surface and saltier water at depth. The net flux of water is from LIS to the harbor, the net flux of salt water is from LIS to the harbor, but the net flux of fresh water is from the harbor to LIS (Jay and Bowman 1975; Blumberg and Pritchard 1997).

A vertical salinity section from Upper Bay through the East River to Whitestone is shown in Figure 3. The Hudson River clearly is depicted near The Battery. The saltier LIS bottom water is indicated near Whitestone where another vertical structure simulating a storm surge barrier has been placed on the bottom in the figure. Again, it is evident that with the ebbs and floods of the current, the flux of salt into the harbor would be restricted.

Collectively, with barriers in the Hudson and East Rivers, the harbor would be freshened. Ecologically, is this acceptable?

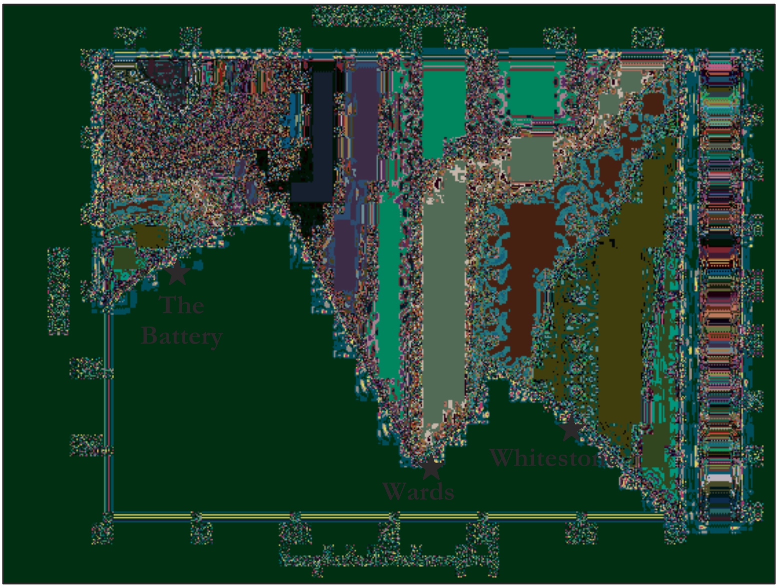

Figure 3. Salinity section from Upper Bay of New York Harbor through the East River, 1959.

Disruption of Sediment Transport

In addition to altering the salinity regime, flow fields will be modified. Tidal current velocities at the storm surge barriers will increase while the barriers are open, as the same volume of water that now makes up the tidal prism is forced through a smaller cross-sectional area. While closed, of course, the velocities through the barriers would be zero.

These changes will alter the transport of sediment throughout the protected area and upstream and downstream as well. Bokuniewicz and Ellsworth (1986) developed an estimated sediment budget for the harbor estuary noting that there were numerous uncertainties. They point out that there is a net flux of inorganic fine-grained sediment entering Lower Bay from the ocean (Fig. 4). Their estimates include an up-estuary flux of 378 to 1,016 metric tons/yr. through The Narrows and 75 metric tons/yr. into the Arthur Kill from Lower Bay. There is also a flux of 71 metric tons/yr. into Upper Bay from the East River. Much of the influx to Upper Bay is transported up the Hudson, removed by dredging, and dumped on the sea floor in the New York Bight.

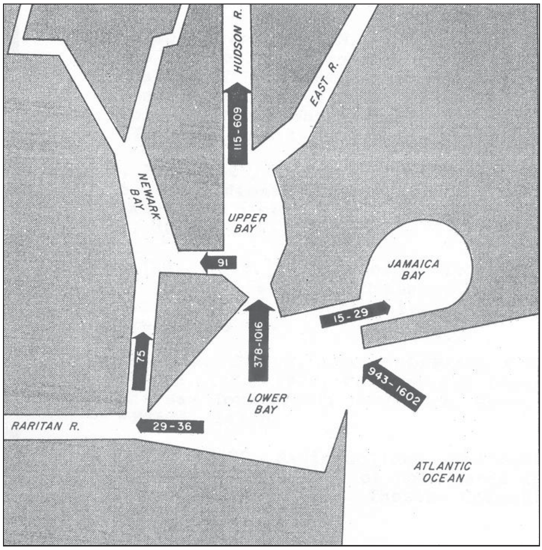

Figure 4. Sediment movement in New York Harbor, thousands of MT/yr. of inorganic, fine-grained particles. Source: Bokuniewicz and Ellsworth (1986). Used with permission.

All three of the proposed barriers would reduce the sediment flux to Upper Bay since the sources are largely from the ocean or LIS and transported at depth with estuarine flow. Upper Bay in the future may become sediment-starved relative to today, perhaps reducing the need for navigational channel dredging there but increasing the need for dredging in the vicinity of the storm surge barriers.

The sediment characteristics in Lower Bay will be changed as well. According to Bokuniewicz (1988), the sedimentation rate is 1 to 2 cm/yr. and sediment is translocated considerably prior to being permanently deposited. With changes in the velocity field and physical barriers to sediment transport, one can expect that sedimentation rates and distribution patterns will be modified. See the extant sediment distribution diagrammed in Figure 5.

Altered Habitat for Fishes and Shellfishes

Changes in the salinity distribution throughout the harbor as a consequence of constructing storm surge barriers will impact the entire ecosystem at some level. However, the anadromous fishes such as river herring (*Alosa pseudoharengus and Alosa aestibalis)*, American shad (*Alosa sapidissima*), Atlantic sturgeon (*Acipanser oxyrhynchus*), and striped bass (*Morone saxatilis*) all inhabit the Hudson/Raritan Estuary during their early development and at spawning (Mackenzie 1992). With the exception of shad and striped bass, all the other species mentioned are identified by

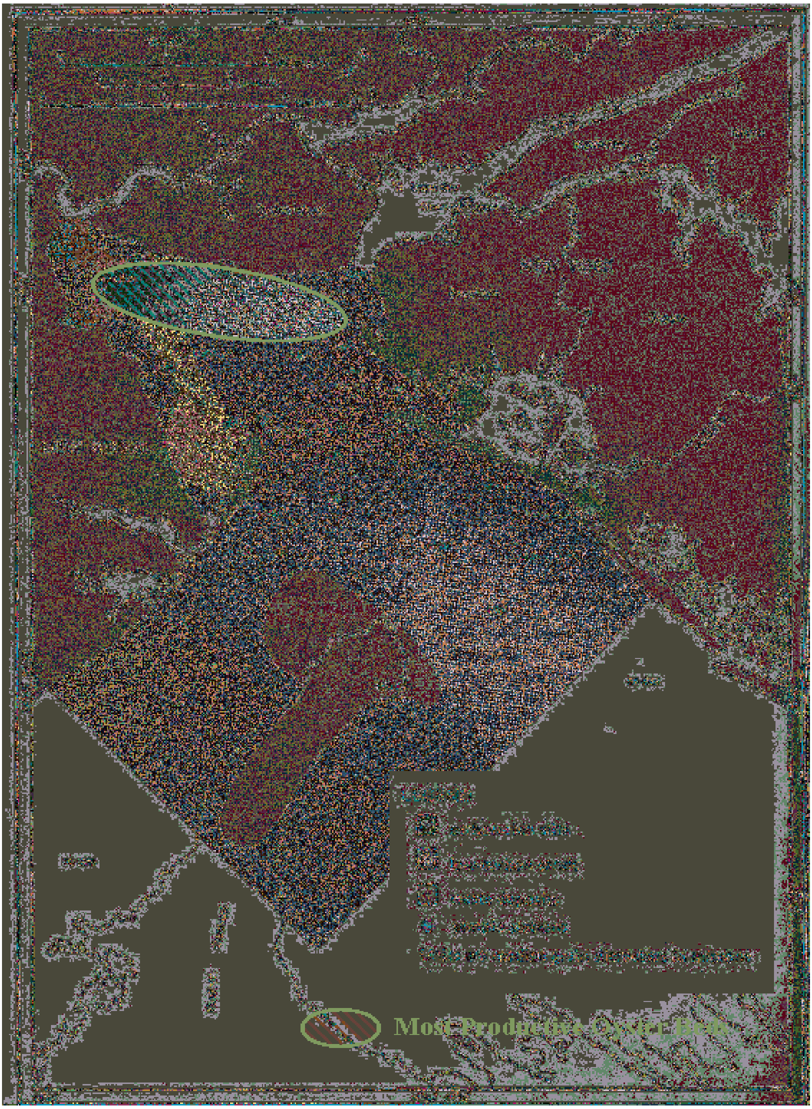

Figure 5. Surficial sediment deposits with most productive oyster beds, Raritan Bay. Source: Data from Studholme (1988). Base map from Gross (1976); used with permission from New York Sea Grant.

the National Marine Fisheries Service as being "species of concern." These fishes return to the rivers and streams where they spawned, sometimes many years after. Should the "homing" signals for the spawning fishes be altered, they may not be successful in navigating to their respective historic spawning grounds. Year classes, if not populations, of spawning fish could be lost. Physical structures are also known to hinder migration and thus cause lost spawning. Shad are particularly noted by Studholme (1988) in this regard.

Raritan Bay historically has been an important area for the shellfish industry, particularly oysters (*Crassostrea virginica*). Hard clams (*Mercenaria mercenaria*) and soft clams (*Mya arenaria*) have been important as well (Mackenzie 1992; Studholme 1988). Because of poor water quality, many of the shellfishing grounds are closed for harvesting for immediate consumption. However, New York and New Jersey both allow shellfish to be relayed to "clean waters" where they live for three to four weeks prior to harvesting and following pumping of contaminants from their systems. This new shellfish harvest approach is revitalizing the economics of the industry in the bay. The bay has been a prolific shellfish ground largely because of the character of the bottom. Compare the historic distribution of oysters (Studholme 1988) with sediment distribution (Fig. 5). Will the changes in sediment distribution due to construction of storm surge barriers hinder or improve the shellfish populations of the bay?

Attention must also be paid to possible changes in wetlands along the Staten Island shoreline. Wetlands, of course, are valued as nurseries for marine organisms. They also help mitigate the impact of storm surge. They may expand or experience loss if sediment distribution or nearshore currents are modified as a result of reducing the cross-sectional areas of the respective waterways at the sites of protection. To keep wetlands healthy and functioning, sediment accumulation must keep pace with sea level rise.

Concentration of Sewage, Sewage Effluent, and Marine Debris

There are some 5.7×10^9 L/d of secondarily treated sewage effluent discharged into the harbor estuary (Fig. 1). At times, sewage is released untreated due to combined sewer overflow (CSO) events or treatment plant malfunctions. The proposed storm surge barriers in an open position may alter the residence time of the wastes in the harbor, most likely increasing it because the estuarine flow will be reduced due to inhibiting the flow of salt water into the harbor from both LIS and the Atlantic Ocean. This could reduce the water quality in Upper Bay over the long term.

The U.S. Army Corps of Engineers captures about 5,500 metric tons of marine debris each year from New York Harbor. Will the storm surge barriers be accumulation points that perhaps ease the collection process or hinder the barrier operation?

However, when the storm surge barriers are closed, raw and/or treated sewage effluent will be trapped for hours. Opening and closing the barriers will most likely take a period of hours, so that releasing stored water, sewage (raw or treated), and marine debris as a function of tide will likely be impractical. For example, there is a phase shift between high tide in LIS and The Narrows. If the gates could be quickly opened and closed, water and wastes could flow out alternately during the storm to LIS or Raritan Bay. The reality is that once the gates are shut, they will likely remain shut for the duration of the storm event.

To which water body will the stored harbor effluvium be flushed? Will there be some equitable way to distribute the stored water and wastes? Besides affecting coastal communities, are there marine resources more at risk at one end of the protected region relative to the other?

Social Issues

There is little doubt that one of the biggest social issues will be that of the distribution of stored sewage. Residents of New Jersey expressed reservations about tide gates, which have been proposed for reducing sewage effluent from reaching LIS from New York City. Their concern is that New York will be excessively flushing on New Jersey and its seaside communities. The concept is that the gates in the vicinity of Whitestone would be closed as water flows toward LIS. This would reduce the volume of water contaminated with sewage effluent entering the sound. When the tide reverses, that effluent would be transported to Upper Bay and then to the Atlantic Ocean (Bowman 1994).

Equity—who gets protected, who doesn't—is perhaps a more contentious issue than any ecological issue. The approximately 7.5 m elevation of the tide gates must meld into the topography in order to be an effective barrier (Fig. 1). This means that a considerable portion of the population around Jamaica Bay will not be protected from storm surge of a Category 3 hurricane. The Raritan River watershed will be excluded as well, but perhaps this is best as the river apparently is the primary source of water that floods communities such as Bound Brook. An outlet for the river may be essential.

New York City's Office of Emergency Management has a hurricane evacuation plan for all boroughs including many residents of Brooklyn and Queens. So the number of people protected through evacuation and storm gates will be greater than existing plans. That reality will unlikely overcome the belief of people outside the barriers that they are being discriminated against.

How will decisions be made as to what segment of the population is to be protected and what segment won't? Is protection of infrastructure of Manhattan more important than residents of Queens? If public monies finance the gates, equity is a concern and, hopefully, protection is afforded to others than the affluent.

Conclusion

If the effort to construct storm barriers is to move forward the support of the residents of the metropolitan region of New York City is essential. The project will be a huge cost and the population must understand how they will benefit. It cannot be viewed as a project that is designed to benefit the wealthy residents of Manhattan or the interests of Wall Street. The project must be understood to be in the nation's interest. Credible advocates are required, not the U.S. Army Corps of Engineers: perhaps the American Society of Civil Engineers and a respectable environmental organization.

The public must be brought into the decision-making process at the earliest possible time—now. The support of community boards, civic organizations, and environmental groups is imperative. It is time to begin such discussions, for ultimately these are the voices that will sell the project to the politicians. The Broadwater LNG project in LIS was killed because the public and environmental community found the logic behind the proposal unconvincing and the environmental/social analysis misrepresented.

Education and public outreach are clearly needed, endeavors that go beyond climate change and engineering feasibility. The environmental analysis and risk assessment studies associated with environmental review must be more than superficial, more than an obvious attempt to justify the project. Alternatives must be thoroughly explored and arguments concerning them convincing.

In the late 1970s, it was proposed that the West Side Highway along the west side of Manhattan was to be reconstructed. Part of it would have been built on fill dumped along the banks of the Hudson. The U.S. Army Corps of Engineers (USACE) essentially dismissed the environmental argument that striped bass habitat (a fish species that was under stress) would be destroyed, further endangering the species. The Federal Court for the Southern District of New York found that USACE had not adequately considered the impact on the fishery habitat and thus ruled against Westway's construction. The Westway Project was killed by the striped bass (Suszkowski and D'Elia 2006).

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Chapter 10

Geotechnical Aspects of Three Storm Surge Barrier Sites to Protect New York City from Flooding

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Abstract

The intent of this paper is to address the geotechnical aspects and challenges to the engineering of proposed storm surge barriers in the waters surrounding New York City. The geologic, bathymetric (water depth) and topographic conditions at each of the following three sites will be explored: The Narrows, Long Island Sound, and the Arthur Kill. The paper will explore the general options for foundations that could be utilized for various different basic types of surge barriers, including

- navigable lock and dam (ubiquitous);
- fold flat buoyant floating gate (venice);
- rotating type (london, thames river);
- swinging hinged gate (netherlands and elsewhere); and
- others.

The apparent suitability and applicability of various foundation options, for each of the three sites, given the geologic and bathymetric conditions at each site, will be evaluated. A conceptual assessment of other considerations such as navigation, sedimentation, scale and scope, and such will be touched upon as they relate to the foundation and geotechnical aspects of the barrier design.

Introduction

A case has been made for the need for storm surge barriers to protect New York City from coastal flooding as the rising sea level accelerates and the intensity of storms increases. The scientific consensus had been that sea level is rising along the Eastern Seaboard at about 1 ft. per century, but more recent predictions by NASA scientists at the Goddard Institute for Space Studies in New York City say that with climate