Flood Risk Mitigation for the Jamaica Bay Area

Project Jamaica Bay

Projectteam Jamaica Bay

Technische Universiteit Delft

Project Jamaica Bay

Royal HaskoningDHV
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Challenge the future

FLOOD RISK MITIGATION FOR THE JAMAICA BAY AREA

PROJECT JAMAICA BAY

by

Projectteam Jamaica Bay

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Abstract

Project Jamaica Bay is a response to super storm Sandy, occurring in October, 2012. The storm was a disaster for New York City, causing around 50 billion US dollars of damage. Research shows that 75% of the expected annual damage in New York occurs around the Jamaica Bay area. Another problem that has been going on for several decades is the disappearance of marsh islands. Due to human interference and effects of climate change, the bay area has been altered in such a way that the sustainability of the mashes is in dispute. This research combines the two problems and gives a comprehensive overview of measures that can be taken to improve both flood risk mitigation and the sustainability of marsh islands. The report focuses on an open Jamaica Bay. This means that scenarios in which a hydraulic barrier is implemented in the inlet is not researched. The study gives an answer to the question which perimeter measures could be implemented to improve flood protection for the Jamaica Bay area. Furthermore, it elaborates on the best way to improve marsh islands within Jamaica Bay and to what extend these islands have an effect on incoming storm surges.

The Jamaica Bay area is characterized by a dense residential area, an estuarine ecosystem and several key infrastructure assets. The bay is surrounded by Brooklyn and South Queens, New York's two boroughs with the highest population. The boroughs are vulnerable to flooding, and current SLR projections add to that danger. The area lacks a comprehensive system of coastal protection measures. In addition, uncontrolled structural erosion is to be found. The waters and wetlands of the bay serve as breeding grounds and are a critical migratory stopover for a surprising diversity of birds. The bay is also of great importance to a great variety of butterflies, visiting seals, sea turtles and other species. The bay area needs to be shared with one of North America's most important air transportation hubs, namely, John F. Kennedy International Airport. In 2012 JFK handled almost 50 million passengers. The area is also host to several infrastructure assets, which greater parts of the city rely on, e.g., land and water routes and water pollution control plants.

The system of measures is designed for a storm with a return period of 100 years. This is according to the policy currently implemented in the USA. The governing water conditions during such a storm for the Jamaica Bay area have been subtracted from FEMA Preliminary Work Maps. For the Atlantic side of Rockaway Peninsula the governing storm surge level is 5.18 m and the governing wave height is 3.35 m. Within Jamaica Bay these values are respectively 4.27 m and 2.8 m. The design lifetime for the measures is 50 years, which means that the measures to be implemented still have to prevent flooding due to a 1/100 year storm in 2065. Sea Level Rise has been approximated to be 0.65 m in 2065 with the use of the IPCC (2013) report.

When looking at the safety of the Jamaica Bay area as a whole, it should be noted that the same boundary conditions should be used for all of the measures. Also, the measures should be connected in a way that guarantees the safety of the hinterland. The area analysis shows that there is a variable amount of space to implement a coastal protection measure throughout the Atlantic side of the peninsula. Therefore, because of its size, a dune alone would not suffice. Both the energy impact of the storm and the hydraulic level is taken into account. However, it is possible to combine safety, aesthetics and ecology to protect this area. Also, when the bay side of the Rockaway Peninsula is taken into account, the area analysis shows several different situations. It is found that there is a limited amount of space available for measures. Therefore, raising Beach Channel Drive is one of the proposed measures in this particular area. The proposed solutions integrate multiple functions or take up a small amount of space, e.g. flood walls. When looking at further perimeter measures, the report also accounts for solutions for JFK Airport. The boundary conditions show that within a one mile radius no bird habitat can be constructed. Furthermore, because pilots need a clear vision of the runway, no measures can be taken that permanently reach above ground level. Therefore, temporary measures like self-closing flood barriers are proposed. The Jamaica Bay area encompasses a lot of infrastructure which disrupts the continuation of the shorelines. Hence, there are a couple of exceptions when looking at perimeter flood protection measures. The report briefly gives possible solutions for all of the exceptions within the area. The different creeks are elaborated on as well as Floyd Bennett Field and Broad Channel. For each of these exceptions, different options of protection are given and sketches are made on how they would look like. It can be concluded that it is possible to secure the whole perimeter of the Jamaica Bay area to protect the inland form flooding during 1/100 year storm surges.

A part of the research is analyzing the effectiveness of vegetation on wave height reduction. Reduction in wave height enables a reduced levee height. Also a hardened revetment would not be required resulting in a more ecological solution. From this research can be concluded that vegetation suffices in reducing wave height. The stems of the applied vegetation (i.e. Spartina Alterniflora) are modeled as vertical rigid cylinders, based on an article of Mendez and Lodosa (2004). Due to the drag between the cylinders and the current velocity induced by the waves, the wave height is reduced. An important parameter is the vegetation density. The research states that a steeper living shorelines slope leads to a lower mean water depth. The lower water depth results in a larger wave dissipation. For the Canarsie Pier area the reduction of vegetation based on the current slope is 40 % and the reduction for a steep slope is 75 %. However, it should be noted that constructing a steep slope requires a lot of landfill and, therefore, is an expensive activity. Therefore, another approach is advised for the Howard Beach area. For this area the current shoreline slope will suffice in reducing wave energy. At Howard Beach the large available space results in a wave reduction of 75 % over 350 m.

Aside from perimeter measures, the influence of dimensions of the bay are researched. Shallowing is preferred regarding flood risk mitigation. The results show that shallowing the inlet and/or the channels in the inner-bay can contribute significantly regarding the expected storm surge level in the bay. Shallowing the inlet results in the highest storm surge reduction. On the other hand, restoration of wetlands hardly show any influence in surge. However, wetlands can have a positive effect on wave height reduction.

Looking at the sustainability and ecology of wetlands in Jamaica Bay, several remarks and design directions can be formulated. In the last century the area has shown dynamic features. To address the exhaustiveness of the area, the study area is analyzed with an equilibrium theory for the outer delta, basin and inlet. The approach complies with measures and changes in the bay, which have occurred in the past. Therefore, it is advised to apply a system approach for restoration of the bay, instead of the current strategy of local measures. In practice this means that wetlands can be created in a more efficient way, by carefully thinking about their placement. Also the study shows that many channels are deeper then needed, eventually, shallowing these channels can have a positive effect regarding sustainability. In conclusion, restoration of marsh islands improves ecology and could improve sustainability.

Delft3D is used to evaluate the results of the storm surge mitigation and the sustainability of the system. A high resolution, small scale model with a high resolution (70m) curvilinear grid is forced at the boundaries by Sandy conditions to simulate a '1/100 year storm'. Results from the model calculations are discussed.

The three most important conclusions of this study are given below:

1. It is advised to implement a system approach
2. Restoration of marsh islands improves ecology and could improve sustainability but hardly affects flood risk mitigation
3. Shallowing the channels is preferred regarding both flood risk mitigation and sustainability

PREFACE

This report is written in context of the course "CIE4061-09", which is part of the Master curriculum Hydraulic and Structural Engineering at Delft University of Technology. The purpose of this project is to solve an actual and recent civil engineering problem in a multidisciplinary team, integrate several studies and designs into a coherent study, based on knowledge, understanding and skills acquired in the preceding educational years. In this case, research is conducted regarding the Jamaica Bay area. The Jamaica Bay is an important resource for the City of New York. Its variety of wildlife, ecology and recreation contributes to a densely inhabitant area. The focus of the project will be on flood risk mitigating challenges in this specific area. It will tackle the issue of how various engineering features can be further leveraged to provide flood risk reduction benefits within the Jamaica Bay. Specific focus will be on innovative solutions integrating infrastructure, nature and society in new or alternative forms of engineering: building with nature. Comprehensive design directions are given to protect the Jamaica Bay area from inundation. Also the disappearing marshlands will be a key part of the study. Both the sustainability of the mashes and the consequence of different marsh configurations on storm surges are researched.

We would like to thank our supervisors for the opportunity to participate in such a vastly energetic city, where the momentum for taking measures is at its peek. We hope that eventually the momentum will results in a safer New York City and therefore Jamaica Bay area. We would also like to thank the ARCADIS Long Island City office for the wonderful time.

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New York City, December 2013

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Introduction

1.1. Motivation

New York City is one of the largest cities of the world. The city includes a large National Park with a wide variety of wildlife, recreation and communities: Gateway national Park. The largest part is this park is Jamaica Bay. The changing climate is a threat to the Jamaica Bay area and its inhabitants. Super storm Sandy was an example of how these changing conditions can impact the area.

According to PlaNYC (2013) [2] the impacts of climate change are likely to increase over time, more floodings, more damage and more erosion are likely to occur in New York City as well. Especially within Jamaica Bay where the flood hazard is the greatest. In response to these challenges, New York City has to protect its coastline and coastal zone. The emphasis of this study lies on mitigating the effects of sea level rise and reducing the effects of storm waves and storm surge significantly. Generally, New York City's coastline does not have purpose-built coastal defenses, many of the features that serve this function do this coincidentally, rather than by design (PlaNYC, 2013 [2]).

The southern coastline of the Rockaways has to be strengthened to withstand future storms. This coastline experiences inundation, destructive waves and erosion on daily basis. In general there are several options to be considered to protect the areas within the Bay, i.e. an open alternative and a closed alternative. In this the open alternative (option 2) will be considered and the other two will be neglected. To make a measured decision about what should happen with the Jamaica Bay area also the other two, and maybe more, options should be investigated. In the following paragraphs the different options are shortly described.

1.2. Base options

One can distinguish three base options for this study. Below the three options are shortly described.

1. **Closed alternative**
   A storm surge barrier at the inlet of the Jamaica Bay can be constructed which keeps the water from storm surges out of the bay and therefore away from the adjacent coastlines within the Jamaica Bay. Under ordinary circumstances, the closure gates would have navigable channel openings, allowing ship traffic and water to flow through. During storm events the gates would be closed, blocking surge waters. Next to the barrier, Rockaway Inlet and the Atlantic side of the Rockaways should have additional protection. This option will not be considered during this study.

2. **Open alternative**
   The open alternative assumes that there will be no barrier at Rockaway Inlet and all banks have to be improved. To mitigate the risks of storm flooding, several options can be considered to keep water from storm surges out of the vulnerable neighborhoods and away from critical infrastructure within the Jamaica Bay area. See section 1.3 for the coastal protection measures for an open solution.

3. **Strategic retreat**
   In 1983 FEMA (Federal Emergency Management Agency) released their Flood Insurance Rate Maps (FIRMs). These FIRMs represent the Federal government's assessments of coastal flood risk. These maps divide the coastal areas into several zones of vulnerability. The Jamaica Bay area lies in the highest risk zone (i.e. Coastal A Zone). Therefore an answer to the flood hazards could be a complete retreat from the shore. Furthermore, it is expected that the 100-year floodplain will continue to expand due to sea level rise at a steady pace over the course of the next decade and beyond, eventually covering 24 percent of New York City in 2050. However, this option will not be considered during this study.

1.3. COASTAL PROTECTION MEASURES FOR OPEN ALTERNATIVE

As shown before, several solutions for the area can be considered. During this study an open solution will be elaborated. Listed below possible measure are defined.

1. Inner bay
   (a) Improving/designing levees: Hardening levees with armour revetments can protect the levee against erosion caused by storms/currents/wave action and Sea Level Rise (SLR). Moreover, other measures can be considered as a second line of defence.
   (b) Elevated homes: Site elevation often proved effective in protecting buildings from waves and flooding to reduce the sensitivity concerning storm surges. Elevated developments, such as Battery Park City in Lower Manhattan and Arverne By The Sea on the Rockaway Peninsula, survived Sandy with minimal damage, particularly compared to other nearby locations that were not elevated.
   (c) Bulkheads: Although the bulkheads were overtopped by the water during Sandy, they helped to disperse wave energy.
   (d) Living Shorelines: Living shorelines are coastal edges that incorporate a combination of breakwaters, forests and tidal wetlands to reduce wave action and erosion. These shorelines also increase the water quality.
   (e) Geosynthetic tubes: Geosynthetic tubes are geotextile elements filled with sediment, sand or sludge. The Rockaway Peninsula and the bay are believed to be subject to a erosion problem. Geosynthetic tubes could be a solution in this case, because erosion could not take place through the textile. The tubes will be loaded on tensile strength. According to Deltares [3] some of the advantages could be the use of local sediment for filling and that this type of solution is relatively cheap compared to more conservative options. Furthermore these geosynthetic tubes could function as wetland creation.
   (f) Restoration of the Bay: Restoration of the marsh islands could have a positive impact on reducing the inundation risk of the Jamaica Bay area. Marsh islands can shorten the fetch length and reduce wave impacts.

2. Outer bay
   (a) Beach nourishment: Beaches are a critical part of NY's coastal defense network. Regular wave action and the natural sediment transport process (the ongoing movement of sand following the dominant wave direction) continue to erode beaches over time. Storms accelerate this process. Beach nourishment, adding large quantities of sand to widen and elevate beaches frequently, is critical to ensure that city beaches continue to serve their vital coastal protection function.
   (b) (Offshore) breakwaters: Storm waves, which are increasing in size and strength over time, threaten to cause neighbourhood damage, erosion and the loss of beach sand in vulnerable areas. To address this risk, one has to do research to provide significant dispersion of wave energy (knock down waves or diminish their velocity) both off and onshore before they reach inhabitat areas. This eventually will reduce damage to structures, erosive forces on the shoreline and protect infrastructure.
   (c) Dunes: Dunes help to break waves and keep floodwaters away from inundating inhabitat areas.

(d) Groynes: Groynes are structures placed perpendicular to the shoreline. They can help retain sand from beach nourishment and also serve to break waves and absorb wave energy. On the other hand, groynes are disrupting the natural alongshore sediment transport.

Because of the complexity and the size of the area in combination with the length of the stay, beforehand the project team, in consultation with the supervising committee, has chosen measures to be researched out of the list above. The considered area will be divided into two different parts, i.e. the Bay and the Atlantic side of Rockaway Peninsula. The team will strive for a total solution which will prevent Jamaica Bay from flooding during a 1/100 year storm. The main focus will be on the prevention of flooding. Furthermore the focus will be on ecology and spatial feasibility.

Generally the current bank protections within the Bay can be split up into two different measures. The bank in the eastern part of the bay, where the JFK airport is situated, and at Floyd Bennett Field is reinforced with armor stone (riprap revetment). The rest of the bank within Jamaica Bay is mostly covered with grass. On the other hand the southern coastline of the Rockaways consists of small dunes.

Taking feasibility and spatial integration into account, several solutions will be investigated. The project team has chosen the following bank- and shoreline protections (exceptions are the areas that have to be considered separately):

1. Living shorelines
2. Studying current revetments/levees at JFK Airport
3. Innovative, bulkhead-like measure for the bay side of Rockaway Peninsula
4. Nourishment-like measure for the Atlantic side of Rockaways Peninsula
5. Exceptions
6. Marsh islands restoration

See figure 1.1 for the locations of the different measures (note that for readability the marsh island restoration is not shown in this figure, obviously this will be done within the bay).

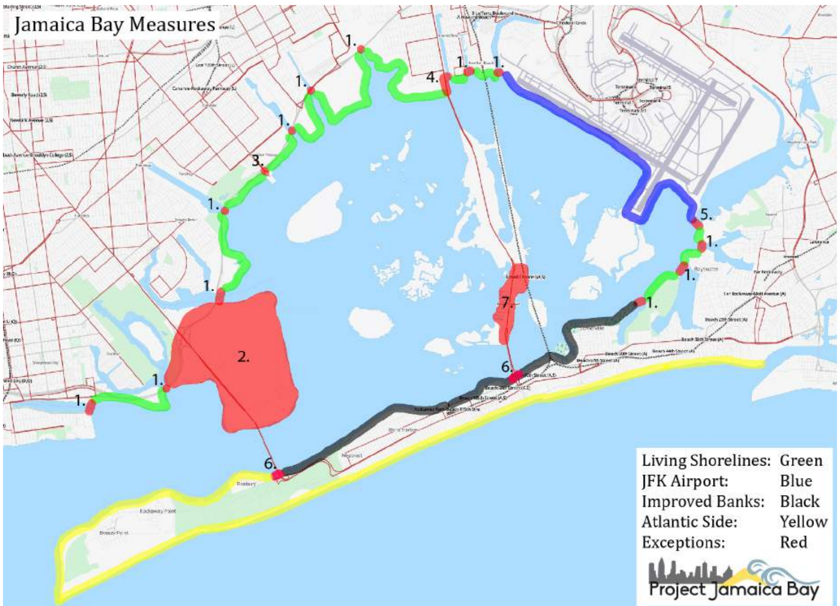


Figure 1.1: Locations of different measures

The effects and consequences will be modeled with Delft3D. With this software one can also conclude what the effects are of the different proposed coastal solutions together and if/how the different solutions interact with each other. Delft3D is a flexible integrated modeling suite, which simulates two-dimensional and three-dimensional flow, sediment transport and morphology, waves, water quality and ecology and is capable of handling the interactions between these processes.

1.3.1. RESEARCH QUESTIONS

To obtain the stated project targets, several questions will be formulated and answered during this project.

RESEARCH QUESTIONS

Which measures at the perimeter could be applied to improve flood protection of the Jamaica Bay area?

What is the best way to improve the marsh islands in Jamaica bay and what are the effects on flood risk mitigation?

1.3.2. METHODOLOGY & READING GUIDE

This section will elaborate on the methodology that has been followed during this study. The following sections will be the phases that will be followed.

LITERATURE

To really get to know the area and to find out what already has been done in the past, a literature study has been conducted. A list of articles and reports has been read and summarized. From these summaries a report has been written. This literature study can be found in Appendix C.

LOCATION ANALYSIS

Field visits and the literature study have been used to come up with a full overview of the project area. The focus is on available space, important infrastructure, important areas and boundary conditions. Chapter 2 shows the Location Analysis.

REQUIREMENTS, BOUNDARY CONDITIONS AND WISHES

From the literature study and locations analysis the requirements, boundary conditions and wishes have been subtracted. They form the base from where designing started, as they determine important features like design height, available space, regulations, etc. The full motivation for each requirement, boundary condition and wish can be found in chapter 3, a and a summarized list can be found in section 3.4.

METHODOLOGY JFK AIRPORT, ROCKAWAY PENINSULA AND EXCEPTIONS

For the areas JFK Airport, Rockaway Peninsula (improved banks and Atlantic side of Rockaway Peninsula) and exceptions (see figure 1.1) the measures are discussed in mainly a qualitative way. Firstly a short area analysis is given for the area that is discussed, then different possible measures are discussed in a qualitative way and with rule of thumb calculations and in the end an evaluation and recommendation is given based on these findings. JFK Airport, the bay side of Rockaway Peninsula, the Atlantic side of Rockaway Peninsula and the Exceptions will be discussed in respectively chapters 6, 5, 4 and 7.

METHODOLOGY LIVING SHORELINES

Living Shorelines

Living shorelines can have a positive effect on the required height of the integrated levee because of the reduction of the wave height. Also, vegetation can be used in controlling erosion and boosting ecology. The following steps will be followed:

1. Location analyses
2. Reference projects
3. Consideration building with nature
4. Inventarisation of usable vegetation
5. Conceptual designs

6. Wave energy dissipation calculations
7. Conclusions

The results can be seen in chapter 8.

Methodology Marsh Islands

The marsh island restoration will be discussed in more detail. The focus is on the sustainability of the system and on the effects on storm surge mitigation.

Sustainability for Jamaica Bay Because of the degradation of marsh islands within Jamaica Bay the sustainability of the system is studied in chapter 10. The theory of the tidal basin system is used. The qualitative results are compared with the results from the Delft 3D model.

Storm Surge Control for Jamaica Bay
The use of marsh islands for storm surge mitigation is studied in chapter 9. The influence of marsh islands on wave height and wind set-up are researched in a theoretical manner. Furthermore, the influence of shallowing the inlet and decreasing the area of the basin are studied with the use of the rigid column approach.

Delft 3D Model

A Delft3D small scale, high resolution model will be made to test considerations regarding storm surge mitigation due to marshlands and sustainability of the marsh islands. The boundaries of the small scale model will be forced by a water level of Superstorm Sandy from a bigger basin model. Measures will be implemented in Delft3D, calculations will be run and results will be processed and discussed.

2

THE JAMAICA BAY AREA

2.1. GEOGRAPHICAL LOCATION

The area of interest is Jamaica Bay. Jamaica Bay is located in the southeast of New York City, on the west coast of the United State of America, see figure and figure 2.1. Although, this part of New York City is easily overlooked by the lively island of Manhattan, which is also the economic hart of the city, it is enclosed by two major boroughs, namely Brooklyn and Queens. In this part of the city the most residents are situated. The bay itself has a diameter of approximately 7.5 kilometers and has a surface area of 100 square kilometer. On the southwest end of the bay a inlet of about 1 kilometer is formed by the former airport Floyd Bennett Field at the north side and the peninsula called the Rockaways on the south side. The Rockaways face the Atlantic Ocean on the south side and the Jamaica Bay on the north side. This peninsula has an averaged width of approximately 500 meters and is a combination of parks, houses and beaches. Several communities are based in this area. In overall, the surroundings of the bay has been subject to urbanization in the last decades, however the bay itself is a designated National Park. Some controlled by the NPS (National Park Service) and some by the City.

Figure 2.1: Location of Jamaica Bay in New York City (Google)

2.2. ELEVATION NEW YORK AREA

New York is a coastal city. Coastal cities all around the world have to cope with problems regarding sea level rise (SLR). Other than a lot of cities in coastal deltas, like big parts of the Netherlands for instance and some cities in Asia, New York City lies above sea level. This can be seen from the Most parts of New York City and its surrounding area are even located at fairly high altitude. But the coastal deltas with barrier islands are low lying areas like you would expect. Jamaica Bay is one of those deltas. Both the elevation of the New York area and the Jamaica Bay area can be seen in figure2.2. The plots in this figure are created using ArcGIS software. The data used for the greater New York area is a digital elevation model (DEM) from the National Elevation Dataset of the United States Geological Survey (USGS, 2007 [4]; USGS, 2002 [5]). The data used for the Jamaica Bay area is a DEM made by the Federal Emergency Management Agency (FEMA) for the determination of the new floodmaps and was provided to the project team by ARCADIS US (FEMA, 2011 [6]). More explanation on the DEM of Jamaica Bay can be found in the chapter on modeling and Delft3D, for which the DEM is an important input parameter, see chapter 11.4.

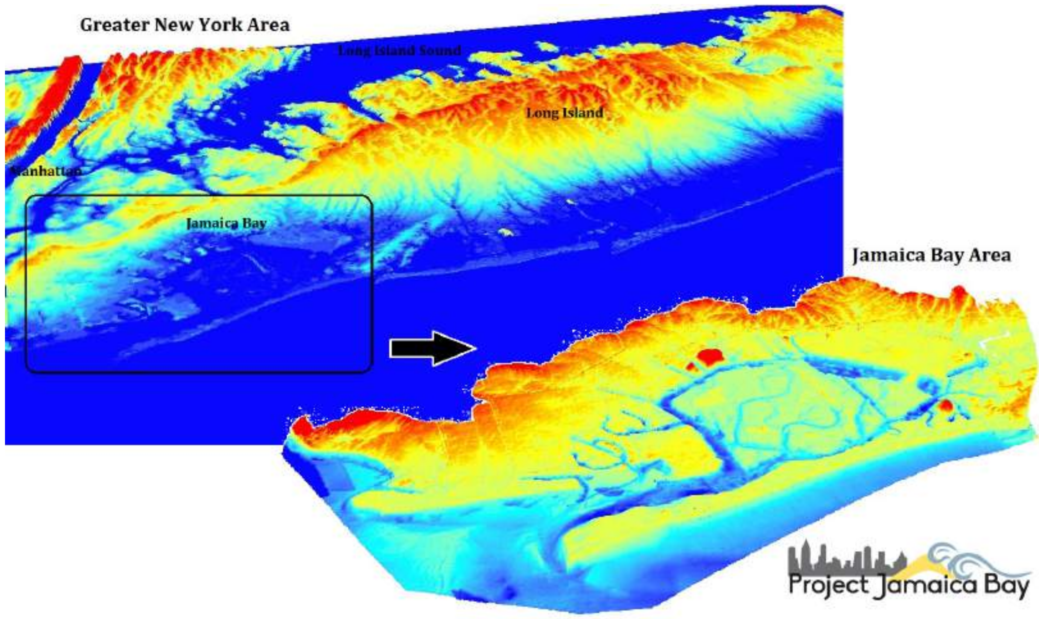


Figure 2.2: Bird's-eye view of elevations of New York & Jamaica Bay (USGS, 2007 [4]; USGS, 2002 [5]; FEMA, 2011 [6]))

It is important to notice that most part of the New York area are not subject to danger of high waterlevels due to storms or even SLR, because they lie at high altitudes (yellow and red colors in the figure on the left). But the Jamaica Bay area, surrounded by the framework on the left and enlarged on the right, is a low-lying area. Most elevations are just above mean sea level, indicated by the dark blue colors in the left picture (darkest blue is the reference color, equal to mean sea level). Jamaica Bay and its surroundings are vulnerable for floodings now, and certainly in the future with the current SLR projections.

The plot for the specific Jamaica Bay area on the right of figure 2.2 uses a different scale factor, therefore the colors are different than in the big picture. Dark blue stands for the lowest elevation and red stands for the highest elevation. Clearly can be seen that the bay itself is very shallow, except for the channels. The inter-tidal marshes in the middle of the bay are very shallow and the shore around the perimeter, which used to be only wetlands as well is shallow. Furthermore the depth of the channels and borrow pits in front of JFK Airport and in Norton Basin are interesting subjects to see as well as the high elevations of the Fountain Avenue Landfill in the north, the Rockaway Community Park in the southeast and Floyd Bennet Field in the west.

2.3. NOR'EASTERS & HURRICANES

GENERAL

According to Aerts et al. (2012) [7] the Atlantic hurricanes are affected by climate variations including the El Nino-Southern Oscilliation (ENSO). ENSO is the warming of the ocean surface that occurs every 4-12 years at the western coast of South America. During the El Nino phase, tropical vertical shear increases due to stronger upper-atmosphere westerly winds, suppressing the development and growth of Atlantic hurricanes. Although hurricane doesn't occur often in the NYC area, their impact can be huge, i.e. high storm surges and rain damage. In general, hurricanes occur between July and October in this area. A direct hit, like Sandy last October, may cause economic damage, hence Aerts et al. The Hurricane Evacuation Zones provided by the NYC Office of Emergency Management show that large parts of the city are potentially vulnerable to surge flooding. Another recent study, from Aerts and Bozen [8], to estimate the direct flood damage in NYC, revealed that for a category 1-3 hurricane, the total value of exposed assets varies between US$ 18 bn and 34 bn. The maximum potential damage to these assets varies between US$ 6 bn and 11 bn.

The storm surges occurring in NYC are mostly caused by two types of events, i.e. Nor'easters (Northeasters) and hurricanes. Especially low-lying areas of NYC are prone to flooding due to storm surges. Furthermore, storm surge can be responsible to waves which can lead to (sudden) erosion of shorelines and banks. On the other hand, stated in this report, gradual hazards are those hazards that slowly develop in time in contrast to the previous mentioned hazards. Coastlines are shaped and modified over time by winds, waves, tides and currents. These processes gradually erode soft shorelines and move sediment from one place to another, reshaping the landscape. One of the main gradual hazards is the rise of the global sea levels. This increase can cause flooding to low-lying areas on a daily basis and therefore the risks that NYC faces will only intensify.

*Note: This subsubsection comes partly from the literature study, see section [**?**].*

NOR'EASTERS

The New York State basically has to subdue two main kind of storms, being frequent nor'easters and occasionally hurricanes. A nor'easter is a storm which is generated at sea either in the Gulf of Mexico or off the East Coast in the Atlantic Ocean, but can also come from other parts of the ocean, and passes along the East Coast of the States, including New York. The name is associated with the wind direction the marco-scale storm has. Nor'easters are most frequent during September till April, during winter they impose the heaviest magnitude.Because these storms are quiet common, they can pose a real threat regarding wind, surge levels, erosion and precipitation. Sometimes windgust exceed hurricane wind speeds. Also, heavy snowfall is to be expected during the colder months. [9]

HURRICANES

Hurricanes are less common, but are still a yearly phenomenon for the New York State. Occasionally, causing substantial damage (Sandy 2012 was such an event). Hurricanes are usually formed in the Caribbean or the Atlantic. A hurricane needs warm waters (found at the equator) from which it will feed energy, the atmosphere must be rich in moisture. Due to the Coriolis effect, all hurricanes rotate counterclockwise in the Northern Hemisphere. When hurricanes become cooler while traveling North, they loose strength. [10]

New York has experienced several hurricanes since the early 1800's, all with a variety of ways. Some hurricanes make landfall at high tide (or even almost spring tide like Sandy) while other do not even make landfall at all. Although Sandy was the most costly hurricane to have struck New York, it was not the most powerful. For example "The Long Island Express" in 1938 and "Donna" were a category 3 hurricane, while Sandy was 'only' a category 1 hurricane. Special features, like making landfall during high tide, of superstorm Sandy made it such an costly event (New York City Office of Emergency Management, 2013 [11]).

2.4. ECOLOGY AND RECREATION AREA

Greater Jamaica Bay-Rockaway Parks is a 41 km^2 wetland area in Brooklyn and Queens that consists of a maze of islands, waterways, meadowlands and beaches. It is the largest intact estuarine ecosystem in NYC, serving as a home to hundreds of species, including 80 species of butterflies, visiting seals, sea turtles and 100 types of finfish. The waters and wetlands of the bay and the upland habitats surrounding the bay serve as breeding and wintering grounds and as a critical magratory stopover for a surprising diversity of birds, hence the

American Littoral Society Friends of Jamaica Bay. At least 335 species of birds, from as far north as the Arctic and as far south as South America, have been documented at the Jamaica Bay Wildlife refuge and the other areas contiguous to the bay including Fort Tilden, Breezy Point, the Rockaway Inlet, Plum Beach, Dead Horse Bay, Floyd Bennett Field and Spring Creek Park. Thousands rest and feed here during migrations along the Atlantic Flyway. The bay is the site of comprehensive wetland, oyster-reef and eelgrass restoration projects. This littoral society states that the Jamaica Bay's rebirth as an ecological treasure for NYC comes from the efforts of both private organizations like the American Litterol Society and the Jamaica Bay EcoWatchers and the efforts of and/or funding from public agencies such as the USACE, DEP, NOAA, DEC and NPS to reduce water pollution, remove marine debris and restore salt marshes and dunes.

The NPS declares that the recreation area is a great waterfront park with outstanding recreational facilities for fun and self-expression. It is possible to do ocean swimming, sailing, kayaking, canoeing, sunbathing and fishing. Off the beach and water, more than 32 km of greenway and open space for hiking, biking, overnight camping and birding make this area unique in all of New York. A natural recreation area so close to a metropolis. One can visit historical areas that explain the defense of New York harbor, the growth of aviation of Floyd Bennett Field and the building of navigational airds that have guided ships in the harbor for centuries. At the Jamaica Bay Refuge it is possible to learn about ecosystems, shoreline dynamics, plants and animals.

2.5. AREA DESCRIPTION

Jamaica Bay is located on the southern side of Long Island and adjacent to the boroughs Brooklyn and Queens. A smaller part is touching Nassau Country, New York. Furthermore is the bay closed in the southern part by the 11-mile-long Rockaway Peninsula. Behind this Peninsula there are 31 square miles of water that compromise Jamaica Bay. Compromising an area almost equal to the size of Manhattan, the bay remains one of the largest and most productive coastal ecosystems in the northeastern United States and includes the largest tidal wetland complex in the New York metropolitan area, hence the Gateway National Recreation Area (2007)[12]. The area is dominated by urban residential, commercial and industrial development. The bay itself has been disturbed by different engineering modifications over time, i.e. dredging, filling, including the construction of JFK airport and Floyd Bennett Field. For an historic overview of the bay see section...... Most of Jamaica Bay are part of the Gateway National Recreation Area. This area embraces an area known for over a century as the 'Gateway to America'. Covering over 26000 acres, the park extends from Sandy Hook, New Jersey, along the south side of Staten Island to Jamaica Bay and Breezy Point in New York. The parkland is managed by the National Park Service and NYC Parks as an urban national Park. Smaller areas in the upland buffer around the bay and on the Rockaway Peninsula remain in private residential or commercial ownership.

At the north-east part of the Jamaica Bay area the John F. Kennedy International Airport is situated, which is owned by the city of NY and operated by the Port Authority of New York and New Jersey. This airport was created in April 1942 when NYC began placing hydraulic fill over the marshy tidelands of Idlewild Golf Course. Today, JFK is the national's leading international gateway, with more than 80 airlines operating from its gates. More about the history of JFK International Airport can be found in section 6.

2.5.1. DENSELY POPULATED AREA

Questions about how to handle flood risk in densely populated areas are as old as many human settlements. Water supply has always been an important factor in the search for eligible settlement locations throughout history. Given the high spatial concentration of people and infrastructural assets in coastal cities, the damage of inundations in those cities is very high.

New York City is and will always be a waterfront city. The majority of NYC's coastline is situated in the southern part of the city, like for example South Queens. According to Aerts et al. (2012) [13], socioeconomic developments, such as population and economic growth, will probably increase the potential consequences of flooding. NYC's population is projected to continue to grow to 9.1 million in 2030. At this moment about 300.000 people live in the 1/100 flood zone. Furthermore 33.000 buildings (assets which represent US$18.3 bn) are located in the same 1/100 flood zone of which 252 properties are considered to be critical infrastructure, i.e. schools, power plants, police stations and airports. More information about flood zones see section C.7.2.

Note: This subsection comes from the literature study, see section [?].

2.5.2. DAMAGE ASSESSMENT

Aerts et al. (2013) [7] state that NYC is one of the most vulnerable cities to coastal flooding around the globe, in terms of probability of hit by a major storm surge and the potential consequences. In this report the flood risk is quantified by the probability of flood events and their potential consequences and is usually expressed in a monetary term such as US $/year. First, low-probability surge events for NYC are selected form the synthetic data set by Lin et al.[14] However, available historical data about hurricanes making landfall is very scarce. Therefore, hurricane surge events for NYC are often modeled with a Monte Carlo simulation. The hurricane surge events for NYC generated by Lin et al. -a Monte Carlo set of 5000 events- are modeled by coupling a statistical/deterministic hurricane model with the hydrodynamic model SLOSH (sea, lake and overland surges form hurricanes) and ADCIRC (advanced circulation model). Slosh is a 2D tropical storm surge model, developed by the Techniques Development Laboratory of the National Weather Service, for real-time forecasting of hurricane storm surge. The accuracy of the surge predicted by the models is approximately 20% when the hurricane is adequately described. Furthermore is ADCIRC a finite element model for the purpose of simulating hydrodynamic circulations along shelves, coasts and within estuaries. The resolution of the applied mesh varies from 70 km to several hundred kilometers offshore to as high as 10m around NYC, hence Lin et al.[14] A few results of this modeling is shown in figure C.30. Climate change projections indicate that the zone that is currently expected to flood, on average, each 100 year (the 1/100 year flood zone) may flood approximately four times as frequently by 2080 (Aerts et al. (2012) [13]).

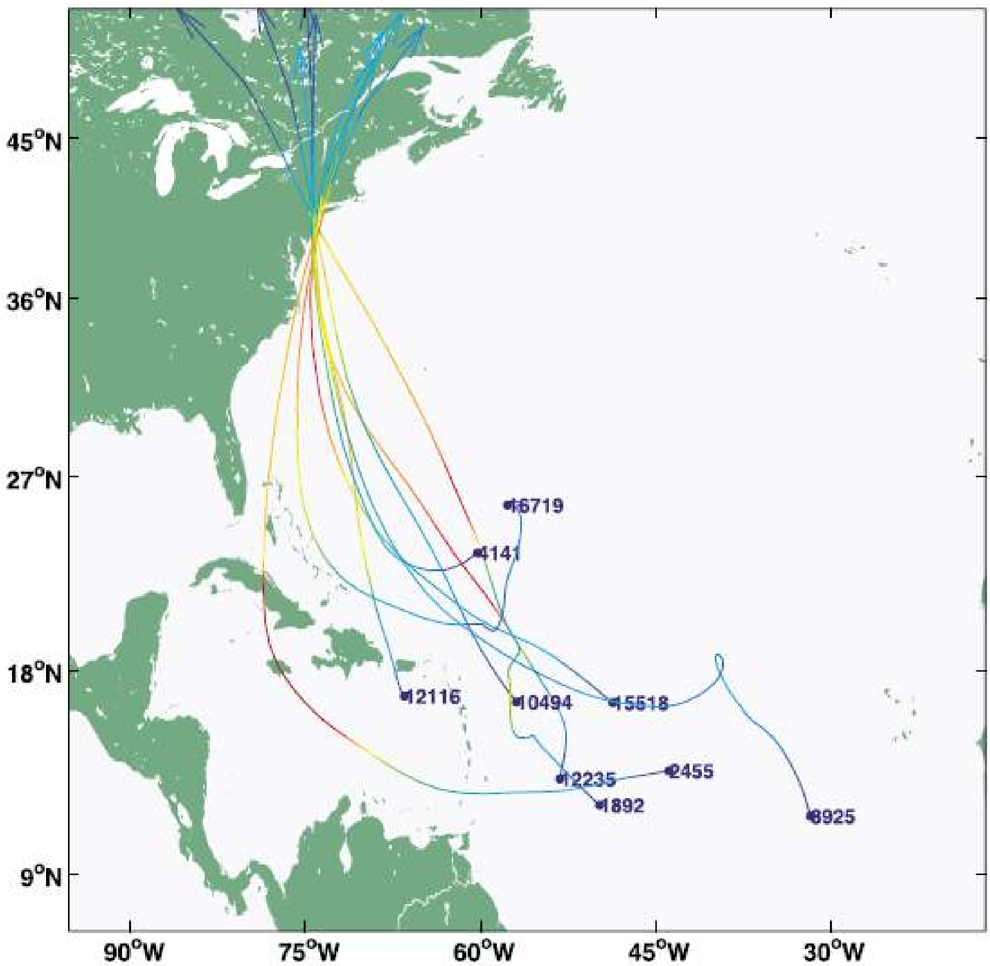


Figure 2.3: The 9 (of the 7555) synthetic storms that generate the highest surges at the Battery in the SLOSH simulations

The second step [7] for each event is the projection of the simulated coastal surge heights on a digital elevation model (DEM) to create inundation maps. The elevation data are available via the database of the National Elevation Data (NED) with a resolution of approximately 10 x 10 m^2. However, this modeling does not include levees or dunes that protect areas from inundation. Third, Aerts et al. combined the created inundation maps with information of the exposed assets to generate a set of flood damage maps using different stage damage functions, which produce high, medium and low estimates of damage. Subsequently, each grid cell (10 x 10m) describes the relation between flood depth and potential damage. In this modeling other physical characteristics, such as flow velocity or duration of the inundation, are neglected. Another risk-management approach developed by NPCC is called Flexible Adaptation Pathways (figure C.31) which is partly based for the update of the Thames Barrier in London on climate change, hence Rosenzweig et al. [15]. The goal of this approach is to enhance climate change responses as understanding of climate change and that reflect local, regional, national and global economic and social conditions.

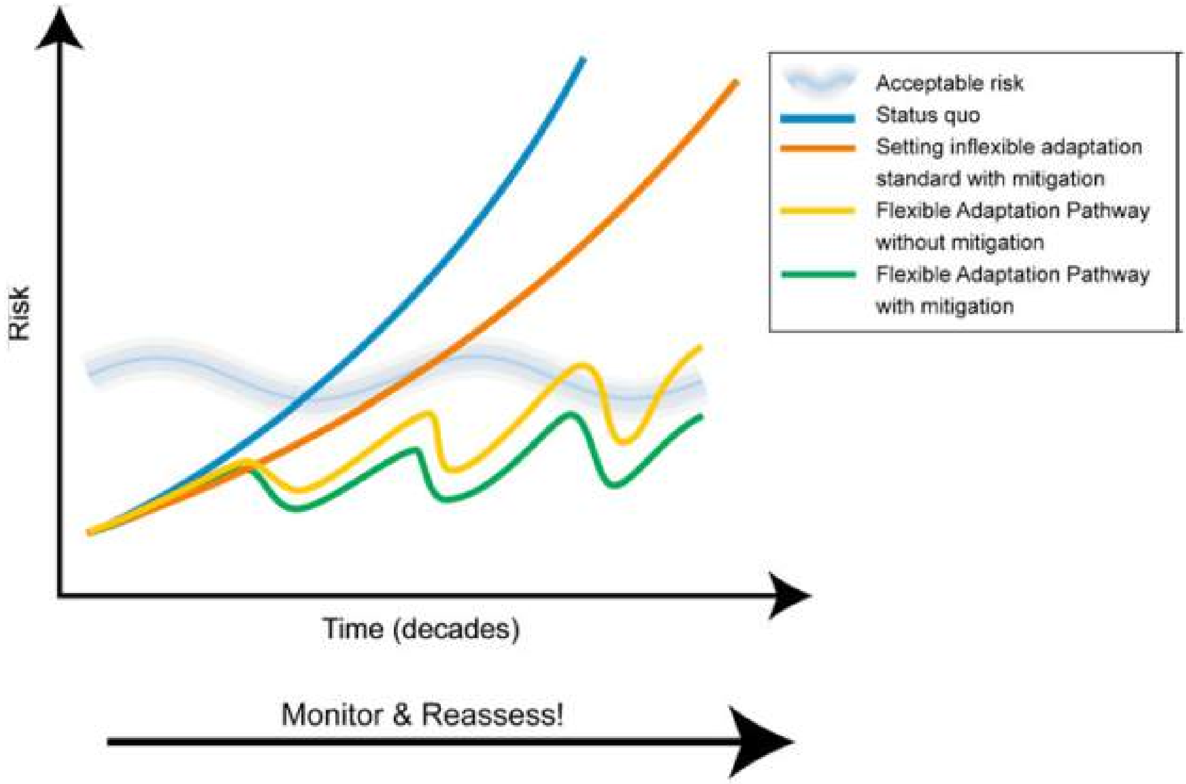


Figure 2.4: The Flexible Adaptation Pathways Approach

RESULTS

Aerts et al. [7] conclude that for the most extreme storms (probability<1/5000) the total damage varies roughly between US$ 14bn and 26 bn. The total damage caused by a 1/100 year storm (the design frequency applied for engineering features in the US), is US$2 bn to US$5 bn. Furthermore for a 1/500 year storm, the estimaties lie within US$5 bn to US$11 bn. According this research, Brooklyn and Queens are the most vulnerable areas. When analyzing the damage in the FEMA 1/100 and 1/500 surges, the damage increases relatively quickly in Brooklyn and Queens. This implies that quite a few buildings in these boroughs, which are currently in the 1/500 year flood zone, are located in the potential future 1/100 year flood zones due to for instance sea level rise. Flood-risk management policies could be first prioritized to these areas. The Jamaica Bay is one of these areas, hence Aerts et al. The expected annual damage for New York City lies between US$59 to US$129 million per year. Although climate change will exacerbate existing urban challenges and environmental stressors, it also provides an opportunity for cities like NYC by encouraging infrastructure investments and improving urban planning and regulation.

Note: This subsection comes from the literature study, see section [?].

2.5.3. BOROUGHS

Brooklyn is New York's borough with the highest population. It has approximately 2.5 million residents. Queens is the largest borough of New York City and the second most populous with a population of over 2.2 million. The two boroughs are shown in figure 2.5. As part of Queens Rockaway Peninsula, more commonly referred to as The Rockaways, is the most vulnerable urban area. The peninsula, with a population of about 130.000, has direct contact to the Atlantic Ocean. This stresses why the area should be protected against storm surges and why this project is important.

Figure 2.5: Boroughs Brooklyn and Queens

BROOKLYN

Canarsie is historically a working class neighborhood with approximately 200,000 residents. Canarsie has the highest home ownership rate (about 58%) and the second lowest poverty rate in Brooklyn. In the past most residents were Jewish and Italian, but since the 1990s this changed into African- and Caribbean-Americans. The residents were targets for predatory loans during the housing boom causing all sorts of trouble today. During 2011, about 3,000 residents received pre-foreclosure notices, being the highest of any New York City neighborhood. More than half of them lived within Canarsie's flood zones determined by FEMA (Brooklyn Bureau (2013) [16]).

The most important infrastructure to get in or out of Canarsie is Belt Parkway, the A-train starting in the Northeast of Canarsie and Linden Boulevard. Belt Parkway is the biggest road and connects Canarsie to the other neighborhoods surrounding Jamaica Bay, JFK Airport and even the other NYC Boroughs. The L-train goes all the way to Manhattan.

On the border between Brooklyn and Jamaica Bay, Belt Parkway can be found, see figure 2.15. This highway functions as one of the main highways surrounding Brooklyn and Queens, also providing access to JFK International Airport. From exit 11, at Floyd Bennett Field, it more or less follows the perimeter of the bay, until Howard Beach in Queens. In between, a bridge is crossed over the Mil Basin Drawbrdige into Brooklyn Beach, another bridge from Brooklyn Beach gets the highway to Canarsie. Two bridges after, and Spring Creek Park, will reach Howard Beach.
As the highway is really close to the water and wetlands on one side, and urban residents at the other, both have to be taken into account to let it highway fit in terms of accessibility, capacity and environmentally. Several projects have already been initiated to the bridges by the DEP and DOT, in consultation with DPR [**?**],

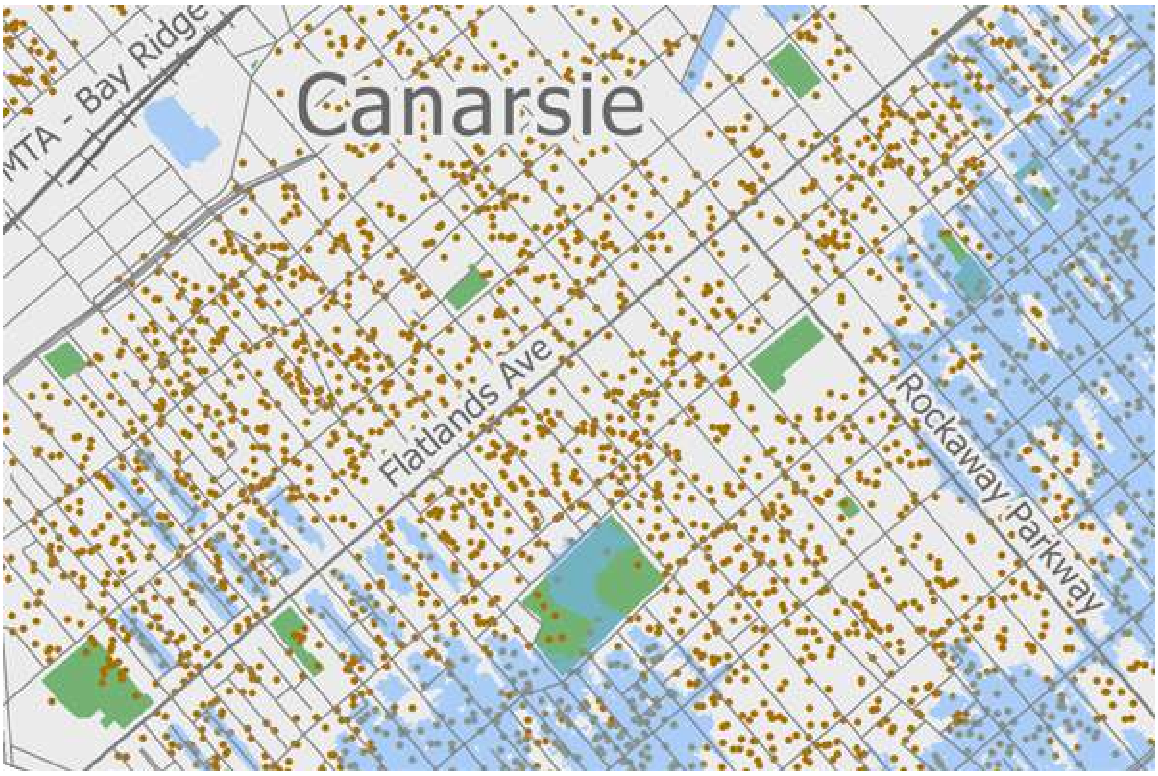


Figure 2.6: Blue shows the reach of the water during Sandy. The dots represent houses that have received pre-foreclosure notices over the past three years (prepared by Center for New York City Neighborhoods)

integrating capture zones for CSOs and vegetation, leading to so called green infrastructure. Although, a integral solution for whole section which follows the perimeter of the bay not within the scope of these projects. Inundation caused by Sandy was significant in the hinterland of the highway, namely in Bergen Beach and Canarsie. Some houses are elevated, but not sufficient for such an event. The Belt Parkway has potential to offer more then just a highway. Already, the bridges are being upgraded into green infrastructure. However, a combination of function can even lead an integration of coastal protection.

At the east side of Brooklyn, south of Bergen Beach and east of Gerritsen Beach, a former naval airport serves as a National Park: Floyd Bennett Field (FBF)2.7. The park has a 1,358 acres surface and also incorporates several municipal services on the southeastern side of the field, such as New York City Department of Sanitation (NYCDS), the Metropolitan Transit Authority (MTA), the NYPD and the United States Marine Corps (USMC) (Columbia University, 2007)[**?**]. The NYCDS stores sanitation vehicles at FBF, the NYPD provides its driving training to its employees, and the USMC has a base for the 6th Communication Battalion. Besides the municipal activities, FBF hosts a diverse array of informal programs, such as parasailing, bike racing and model airplane flying. On the western side of FBF, Flatbush Avenue is located. The road provides a main entrance to the Rockaways and is connected to the Marine Parkway Bridge. This bridge is located at the narrowest part of the Jamaica Bay inlet between FBF and the Rockaways. On the northwestern side of the Field, Belt Parkway provides access to Brooklyn.

The area on which FBF lies used to be partially a barren island and partially intertidal marshes. Because of the developments throughout the 20th century, these marshes were filled forming a large area on which an airport was realized. To be able to construct Flatbush Avenue, the original waterway splitting the field in half formally called Deep Creek was also filled. These fillings meant that the inlet to the Jamaica Bay was reduced to the south side of FBF. Because of the Navy having a base on FBF, the inlet was dredged to make navigation possible. At the south eastern side of the field, quay walls were placed for the ships to dock and to decrease the level of erosion.

Because of FBF being filled, it has been suffering from erosion (National Park Service, 2009)[17]. The north-

Figure 2.7: Aerial Overview of Floyd Bennett Field

ern part of the field mostly consists of a beach shore. A small part is protected by a revetment. Were the northeastern side of the field also consists of a sandy shore, the southeastern side is partially protected by revetments. Old sheetpiles were cut off at mean low tide and backfilled with armor stone at approximately a 45 degree angle. Because of the runoff occurring due to Sandy, the smaller stones were flushed away while the larger stones remained intact. Also several different erosion protection measures have not been maintained and have come apart. Further to the south an old Navy quay wall is situated. On the south side of FBF there are remainders of gas docks and industries. This part of the field has been filled mid-20th century.

SOUTH QUEENS

South Queens consist of Far Rockaway, Belle Harbor, Broad Channel, New Howard Beach, Old Howard Beach and Hamilton Beach on the Bay's north side. A common geomorphological feature of this neighborhoods is that they have the lowest elevation of New York City. Therefor, they are highly vulnerable to inundation in case of a (super) storm. This area's coastline is constantly changing due to the (hydro)dynamic loads. The natural movement of sediment from east to west along the Rockaway Peninsula formed what is today the community Breezy Point at the tip of the peninsula in the southwest.

South Queens has 130.000 residents, hence the area is predominantly residential. Most buildings in area are constructed of lighter structural components, such as wood. Far Rockaway is an exemption, this is built in slightly elevated ground which makes its less vulnerable to inundation. This part is also protected by groins and the Long Beach barrier island.

West from Far Rockaway the peninsula extends. This part of South Queens is referred as the Rockaways, consisting of the five neighborhoods: Arverne, Somerville, Edgemere, Rockaway Park and Rockaway Beach. Notable, Arverne was relatively protected against a super storm like Sandy, thanks to a dune system on the beach which could absorb wave impact. Also, a special drainage system and elevated homes mitigated the overall damage. In front of Somerville lies Brant Point Wildlife Sanctuary in the bay. This mostly undeveloped marshland is believed to serve as protection against a flood event, PlaNYC (2013) [2].East from Arverne lies Rockaway Park. A photo taken at the beach,see figure 2.11, it can be clearly seen that there is little to no

Figure 2.8: Technical Details of Floyd Bennett Field

protection against wave impact or surge levels. The beach provides a slight elevation of a couple meters. The next neighborhood to be found is Belle Harbor. Sea walls protecting the area at the bay side were easily over topped by high surge levels. See figure 2.10. On the sea side the insufficient dune structure was completely lost in the storm. With hydraulic loads from both the sea side and the bay side of the peninsula, numerous people claim that the 'ocean met the bay', with flood height up to 3 meters. At the tip of the peninsula two private communities can be found, Roxbury and Breezy Point. They set their own rules governing construction and maintenance, hence flood protecting measures. Most of the residential buildings are made from wood and are not elevated. The area is poorly protected against a super storm. In these areas high velocity waves struck the unprotected structures facing the ocean. Even a year after the event, a lot of sand can be found in the streets which is due to intruding floodwaters into the neighborhood. The bay side is not protected in such a way that it protects along the banks. A few measures are to be found, which do not complement each other. Surprisingly, on the seaside there is plenty of room for coastal measures. Aside from the extreme surge levels which a super storm can generate, strong winds can also have devastating impact. Fires which broke

Figure 2.9: Erosion Protection Eastern Side FBF

Figure 2.10: belleharborbayside

out in Breezy Point were spread out by the wind, leading to loss of residential structures.

In the middle of Jamaica Bay the island of Broad Channel hosts a small community in the southern end. The northern end is occupied by the Jamaica Bay Wildlife Refuge. Although most of the buildings along the banks of the island are slightly elevated on wooden piles, residents have stated that during super storm

Figure 2.11: Beach at Rockaway Park, it can be clearly seen that there is little protection for sea facing structures.

Sandy the water level rose to the second floor, devastating homes and infrastructure. Local measures against inundation are to be found, but none are consistently along the banks or of sufficient height, see figure 2.12. Furthermore, a breach had occurred in the one of the freshwater reservoirs in the National Park in the North of Broad Channel. Subsequently, salt water had intruded the area, destroying flora and fauna, jeopardizing biodiversity.

North of Broad Channel, on the Northern side of the bay, you will find New Howard Beach, Old Howard Beach and Hamilton Beach. New Howard Beach is relativity elevated compared to the other two. However, this area is very likely to flood, as shown by Sandy. Many docks in narrow basins are to be found in the neighborhoods of this area.

The average poverty rate in South Queens 18 percent. This is comparable with the rest of New York City, which is about 20 percent in 2012 [18]. However, the socioeconomic state differs much between different neighborhoods. Broach channels being the among the most wealthiest, 1 percent, and the Rockaways the poorest, 22 percent. It goes without saying that there is little to no incentive for communication between the communities to collaborate in area development.

2.5.4. IMPORTANT INFRASTRUCTURE

There are several key infrastructure assets to be found in South Queens and Brooklyn these. Some serve, not only the surrounding area, but also a greater part of the city. Four major Water Pollution Control Plants purify wastewater from the two boroughs. John F. Kennedy International Airport serves as one most important air transportation hubs in North America. Also some smaller infrastructural assets that are directly facing the waterline are of high priority. Aside from their seemingly primary function, let it be a road or a beach, they have to provide coastal protection as well. In many cases these places do not have a sufficient coastal protection measures, like dunes, groins or seawalls, which can withstand a 1/100 year storm.

NAVIGATION CHANNELS

Jamaica Bay accommodate the needs of its surrounding inhabitants. Both in an ecological perspective as noted before, as in human recreation and activities. Currently the region is dominated by urban residential, commercial, and industrial development. A lot of local residence have boats, which is most probably one

Figure 2.12: broadchannel

of their main reason to live around Jamaica Bay. They rely on the available navigation channels in the bay to maneuver in-between the salt marsh islands. A map of this navigate able channels is provided by NOAA (2011) [**?**], see figure 2.14. To preserve these channels, dredging operations are being carried out consistently. Thanks to a deep circular channel that lines the outer edge of the bay, the area is separated into two different distinct area's. Within this circle are the remainder of the marsh islands, the shoreline has highly constructed parts like Floyd Bennett Field and John F. Kennedy International Airport. Some fairways are up to 15 meters deep. As indicated by Hartig, et al (2001) [19], the continues dredging and regulating of the channels can influence the morphodynamics of the bay, hence the sediment transport. The channels can, subsequently, be a great contributor in the erosion problem the bay is facing. There is no large harbor in the considered area that can be used by relatively large vessels (like oil tankers or containers ships).

LAND TRANSPORTATION

Because the area is only partly accessible by subway, most transportation is on land/road. In red the main transportation routes are highlighted in the following figure 2.15.

JOHN F. KENNEDY INTERNATIONAL AIRPORT

John F. Kennedy International Airport (JFK) is located on the eastern border of Jamaica Bay. It lies in the borough of Queens and is owned by the City of New York and operated by the Port Authority of New York and New York (PANYNJ). The PANYNJ has a long term lease to run this airport, and has extended its lease in 2004 with an additional lease of 50 years. JFK is one of North America's busiest airports, leading this list in international passenger traffic in 2010[20]. In 2012 the JFK handled almost 50 million passengers. The airport is operated by more then 90 airlines, and is a major international gateway hub for American Airlines and Delta Air Lines. Although, initially named New York International Airport, the airport was formerly known as Idlewild Airport.

Figure 2.13: Map showing neighbourhoods

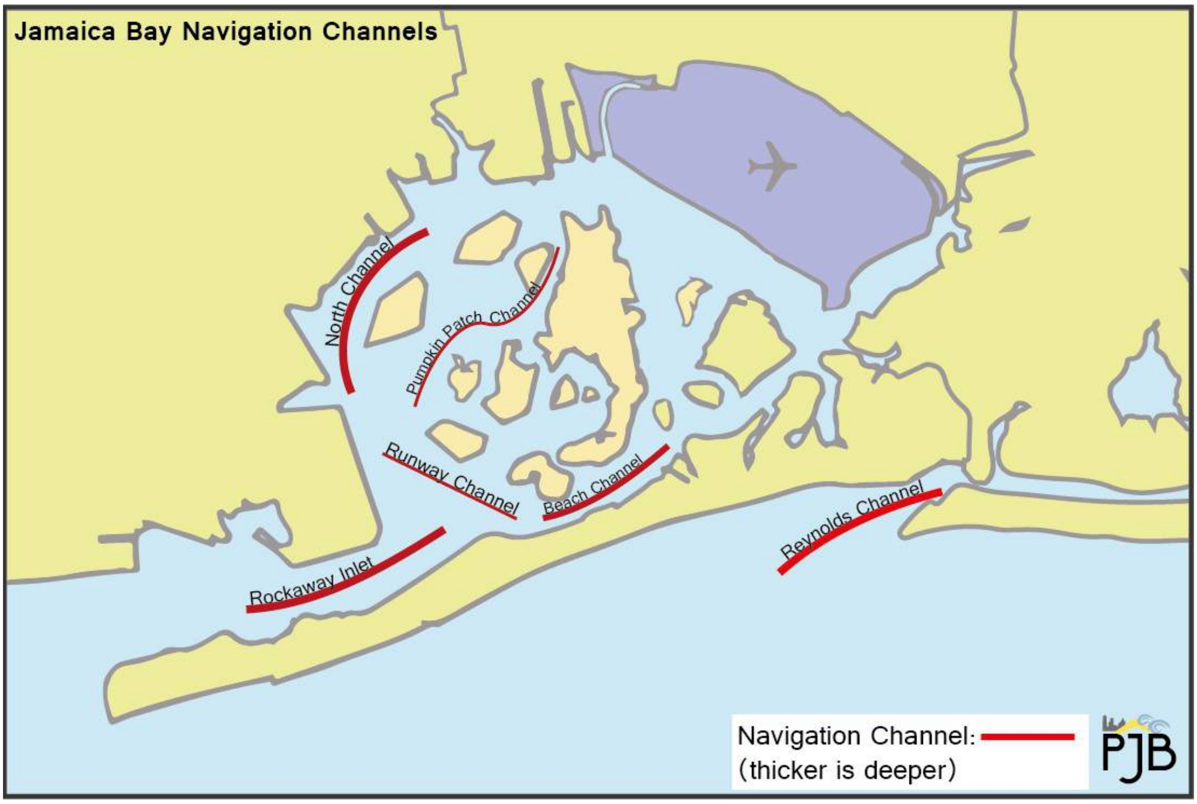


Figure 2.14: Main navigation channels

Figure 2.15: Main highways on land

In 1963 the airport was renamed to its current in memory of 35th president of the United States of America. As can be seen in the aerial figure 2.16, the area is hardly natural. A lot of landfilling has been done during the construction of JFK. Nearly all boundaries are hardened.

According to the PANYNJ, Sandy impacts on the airport where relatively minimal compared to other areas in New York. Because the JFK is a bit elevated, flooding was reduced. Stating, the area flooded near the borders of JFK, only being subdued to a couple of feet of water. The flood impact did relatively not cause that much damage because of the precautions that were taken. The majority of the damage during Sandy was caused by the interaction between the salt water and the electrical equipment. The airport's resiliency is being praised, being operational only 3 days after the super storm struck.

Regarding its current coastal protection, there isn't any substantial structure present, only a riprap bank revetment to reduce the erosion. This current revetment is built in 1947/1949. So way before the knowledge of climate change came about. However, there is an extensive drainage system constructed in the subsurface of JFK. This drainage system has a sufficient discharge capacity during high tides and storms.

If a modification to the airport's surface is to be made, it has to comply to certain rules, mainly imposed by the Federal Aviation Administration (FAA). Any structure that will affect the runway, is not safe enough regarding flight safety standards. The higher you build (like for example a levee structure) the more trouble you cause. Pilots must have a clear sight over the runway, i.e. they need to see the lamps that are situated next to the runway. The Federal Aviation Administration (FAA) regulates the aviation in the US and makes those rules.

Another legislation of the FAA is that it is not allowed to build marshes or wetlands within 5 miles of the runway. The marshes or wetlands can attract birds, which can fly into a jet engine. However, the 5 mile radius is not really that black and white, it is more an advice of the FAA. There is some flexibility, e.g. the Joco marsh is situated within this 5 mile radius, you have to deal with that and you cannot change that. On the other hand, the 1 mile radius is a very strict rule.

Other boundary conditions are imposed by the Department of Environmental Conservation. Because JFK is surrounded by wetlands, it is not allowed to build in the water front of the airport. To get permits, for such an activity, would be extremely difficult. If new infrastructure were to be build that would affect the wetlands, mitigation regarding those wetlands (e.g. create new wetland area somewhere else) should at least balance the negative effects.

Figure 2.16: jfkairport source: USGS digital orthophoto via MSR Maps (formerly TerraServer-USA)

WATER POLLUTION CONTROL PLANTS

Each day, 250 million gallons (946 million liters) wastewater is treated in four waste water pollution control plants (WPCPs). The four WPCP's are highlighted in figure 2.17: 26th Ward, Coney Island, Jamaica, and Rockaway Plants. Coney Island Wastewater Treatment Plant is to be found in the western part of the bay. 26th Ward Waste Water Treatment Plant is in East New York, Brooklyn. Jamaica Water Pollution Control Plant is situated directly adjacent to JFK airport. And finally, Rockaway Plants is about in the middle of the peninsula in, south of the bay. Large parts of Brooklyn and Queens are in the capture zone of these WPCPs. Before waste water can be discharged into open water, it needs to be cleansed. Cleansing is needed to comply to the water quality standards set by the DEC. Without cleansing, high concentrations of pathogens, nitrogen, sulfide, silica and carbon loadings will be released in the surface water. This could effect water quality tremendously, and subsequently ecological value will be lost and public health can be jeopardized. There has been a lot of debate whether the WPCPS are endangering the total ecological state of the bay, for instance loss of natural habitat and disappearing of salt marshes. To mitigate the impact of treated waste water, several updates and modifications have been taken in to account at the various WPCPs in the past decades. Also, the DEP has stated that the Rockaway Plants WPCP its capacity is in fact twice then the current demand (the ratio demand/capacity is about $\frac{25\ million\ gallons}{50\ million\ gallons}$), therefore, combined sewerage overflows rarely occur at the Rockaways. John F. Kennedy International Airport's sewerage is directly connected to the adjacent the Jamaica WPCP according to the Port Authority.

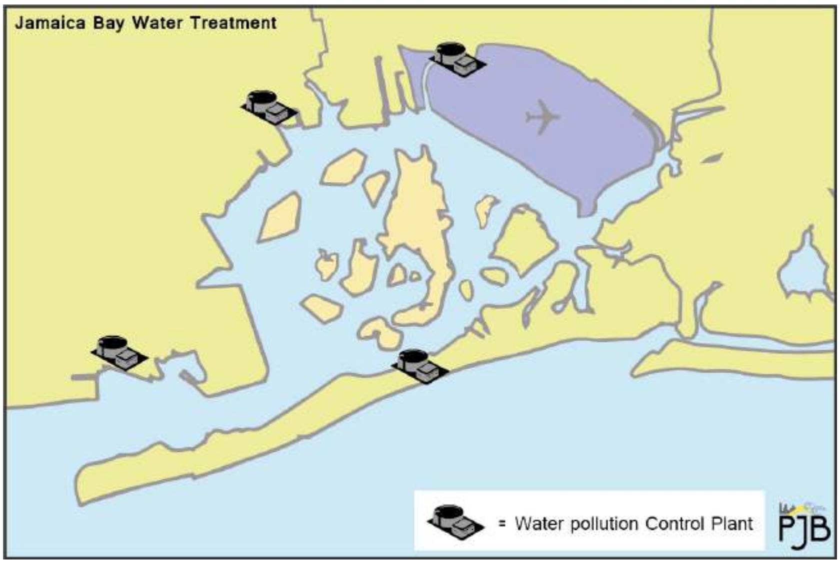


Figure 2.17: Four Water Pollution Control Plants around Jamaica Bay

2.6. MARSHES

A study was conducted by the Gateway National Area, National Park Service, U.S. Department of the Interior and the Jamaica Bay Watershed Protection Plan Advisory (2007) [?]. For this report, the conductors made use of field observations, satellite imagery and aerial photography 2003 obtained by GNRA, and aerial photography obtained from DEC for the years 1951, 1974, 1989, 2003, and (for selected marshes) 2005. The research has pointed out that a decrease of 63 percent of vegetated salt marsh islands can be noted between 1951 and 2003, see table 2.1. To put this figures into perspective, the rate of marsh island loss has been computed in the next table, table 2.2. In the periods 1951-1974 and 1974-1989 the rate of loss was 17 acres/year and 18 acres/year respectively. For the last period 1989-2003 this was 33 acres/year. What can be concluded is an acceleration of marsh island loss in the past 60 years, especially in the period 1989-2003. This infers that this rate is not nearing an equilibrium, and might however result in total loss of marsh islands. Even sooner then the previously projected 2024. See also figure 2.18 for an aerial overview on marshland loss.

	Time Period			
	1951	1974	1989	2003
Vegetated Marsh (Acres)	2347	1610	1333	876

Table 2.1: Jamaica Bay Marsh Islands: Total vegetated Marsh

	Time Period		
	1951-1974	1974-1989	1989-2003
Average Rate of Loss (Acres/Year)	17	18	33

Table 2.2: Jamaica Bay Marsh Islands: Rate of Marsh Loss

A definite cause to sediment deposition, resulting in disappearing salt marsh islands, remains unknown. However, several developments have been addressed as processes which could have influence in the overall state of the Jamaica Bay. When compared to the earliest data of the bay some differences in activities and usage of the bay can be pointed out. Landfilling, dredging, hardening of the bay's perimeter, residential and commercial development, channeling of overland flow through storm sewers and combined sewer overflows

(CSO's), little to know freshwater supply and water pollution are all loads the bay has coped with in the past, or is still subject to. A redistribution of sediment is therefore more then likely.

For a comprehensive overview on the disappearance of salt marshes of Jamaica Bay, please read chapter 4.4 of the Literature Study Report in the appendix.

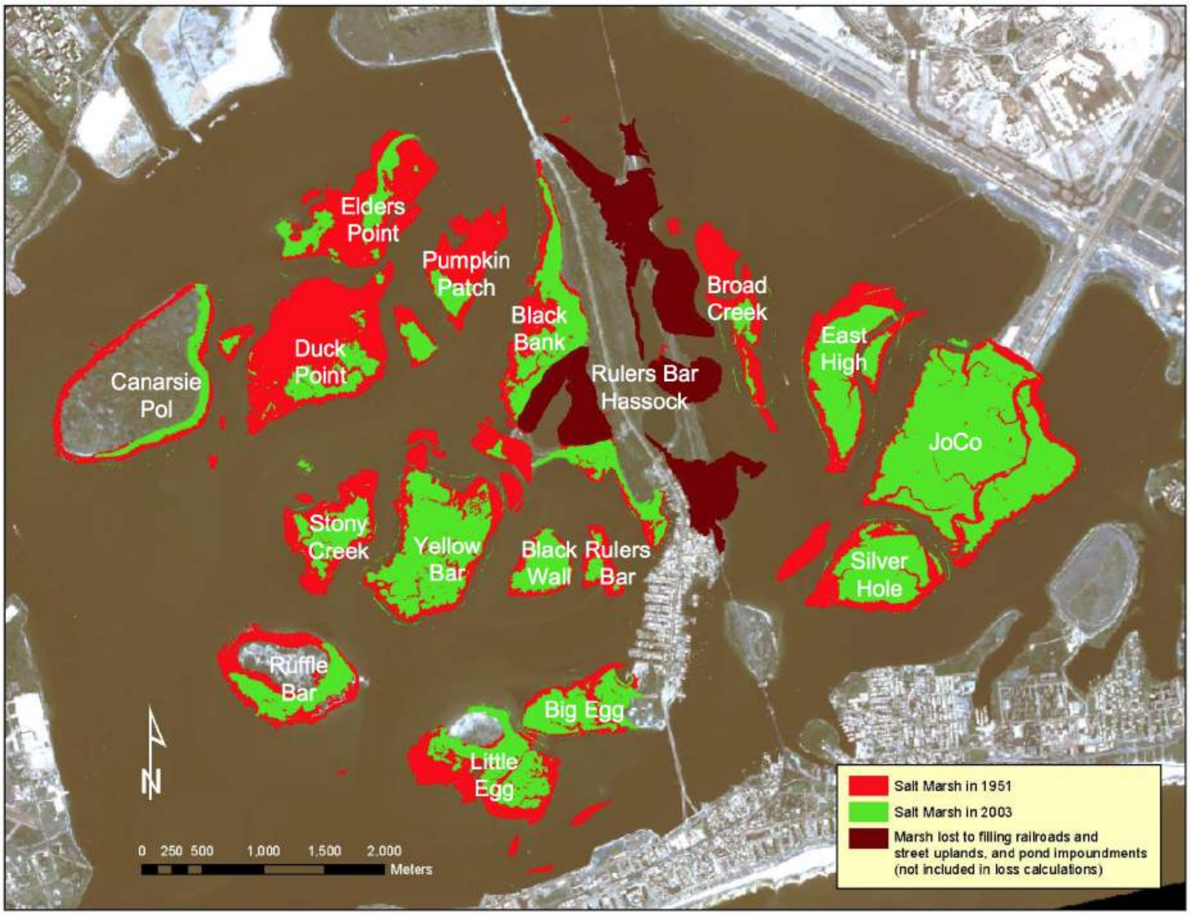


Figure 2.18: Overview of salt marsh island loss between 1951 and 2003

2.7. WATER QUALITY

The bay is subjected to variety of loads concerning water quality. A brief history of the water quality within the bay can be found in chapter 3.2 in the Literature Study report. Currently, the bay has to cope with high nitrogen loadings, combined sewage overflows, a high pathogens concentration, and a lack of dissolved oxygen. As shown in figure 2.19, based on 19th century mapping [**?**], the bay used to have plenty of freshwater input from the surrounding tributaries. A lot of tidal wetlands (green) and tidal flats (gray) can be seen. However, this is not the case anymore. Almost all of the formely tributaries and wetlands along the perimiter of the bay have been reclaimed for ubanization. The only freshwater conveyed is that from the sewerage plants around the bay. Each day, 250 million gallons (946 million liters) of treated wastewater containing thirty to forty thousand pounds of nitrogen are discharged by the the four city water pollution control plant (WPCP). This study was conducted by the Gateway National Area, National Park Service, U.S. Department of the Interior and the Jamaica Bay Watershed Protection Plan Advisory (2007) [**?**].

However, a water quality study done by the New York - New Jersey Harbor (2012) [**?**] showed that surprisingly the estuary's health is much better than it was 30 years ago, but many problems remain. The fact sheet they made summarizes a few aspects, including pollution. Nutrient pollution in the estuary has decreased, thanks to investments in better wastewater treatment. Excessive nutrients in the waters enable microorganisms to grow and consume dissolve oxygen, stressing or even killing valuable aquatic wild life. Therefore, an increase is to be found in dissolved oxygen in bottom waters. Pathogens relating to bacteria to found has decreased, and PCB's as well. For a visual representation see figure 2.20. Improvements in WWT infrastructure have generally resulted in cleaner waters. In overall, it can be said that the water quality has vastly improved over the last couple of decades.

Figure 2.19: The Historic Tidelands of Jamaica Bay, this composite maps is largely based on 19th century U.S. Geological Survey Topographic maps

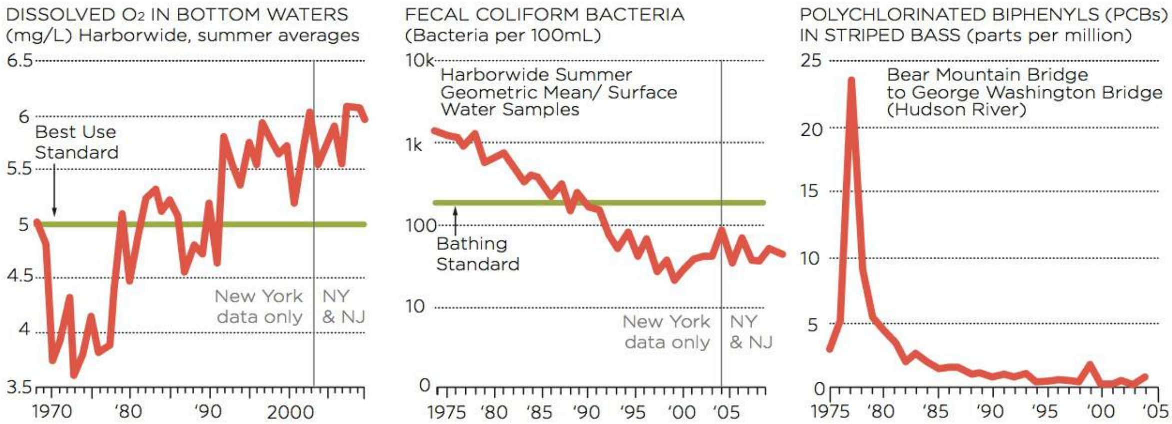


Figure 2.20: Pollution monitoring in past 35 years, New York - New Jersey Harbor (2012)

When looking at the tidal movement within the Jamaica Bay, with each semidiurnal cycle, tidal currents are estimated to exchange one third of the volume of the bay (Rhoads et al. (2001) [4]) An effect of the deepening of Jamaica Bay through dredging, the residence time of fresh water streaming into the bay is approximately 30 days. A model made by Isleib (2006) ,see figure 2.21, shows in visual way the age and extend of surface water mixing. This model roughly corresponds with the prediction of Rhoads, et al. (2001). What can be concluded from this is that contaminated fluids or solids which are discharged into the bay are sometimes hard to wash out, regarding there place of impact. Also, Pickerell (2007) pointed out, during his study for eelgrass restoration in Jamaica Bay, that turbidity increases further you go into the estuary (from inlet to estuary end). Subsequently, this has an significant influence on the light penetration, see figure 2.22. What clearly can be seen is that vegetation is highly dependable on sufficient exposure to sunlight for photosynthesis. Water quality monitoring from the Gateway NRA (2006) also shows differences in turbidity throughout the bay, figure 2.23. Low valued Secchi depths represent low turbidity, as high valued depths represent high turbidity. This study done by the Gateway NRA complies with the eelgrass observations.

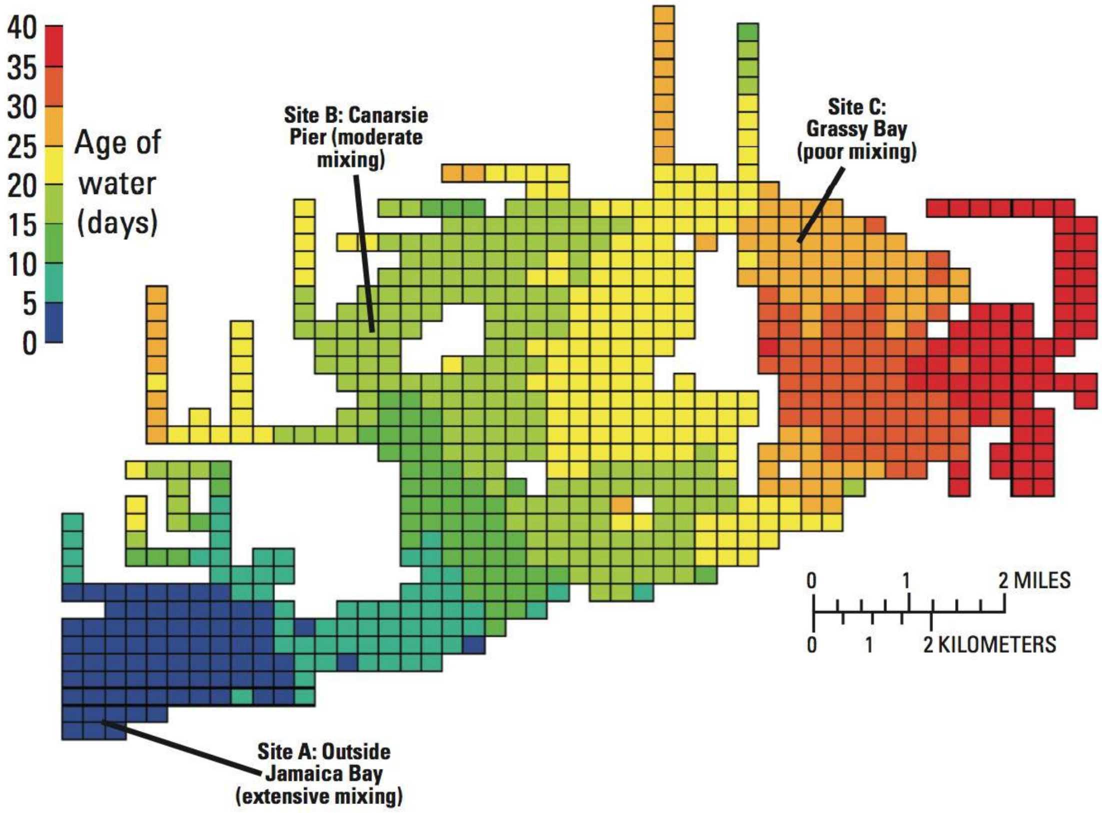


Figure 2.21: Age and extent of surface-water mixing at three sites on Jamaica Bay, Long Island, N.Y., as defined by a coupled hydrodynamic/water-quality model (From Richard Isleib, HydroQual, Inc., written commun., 2006).

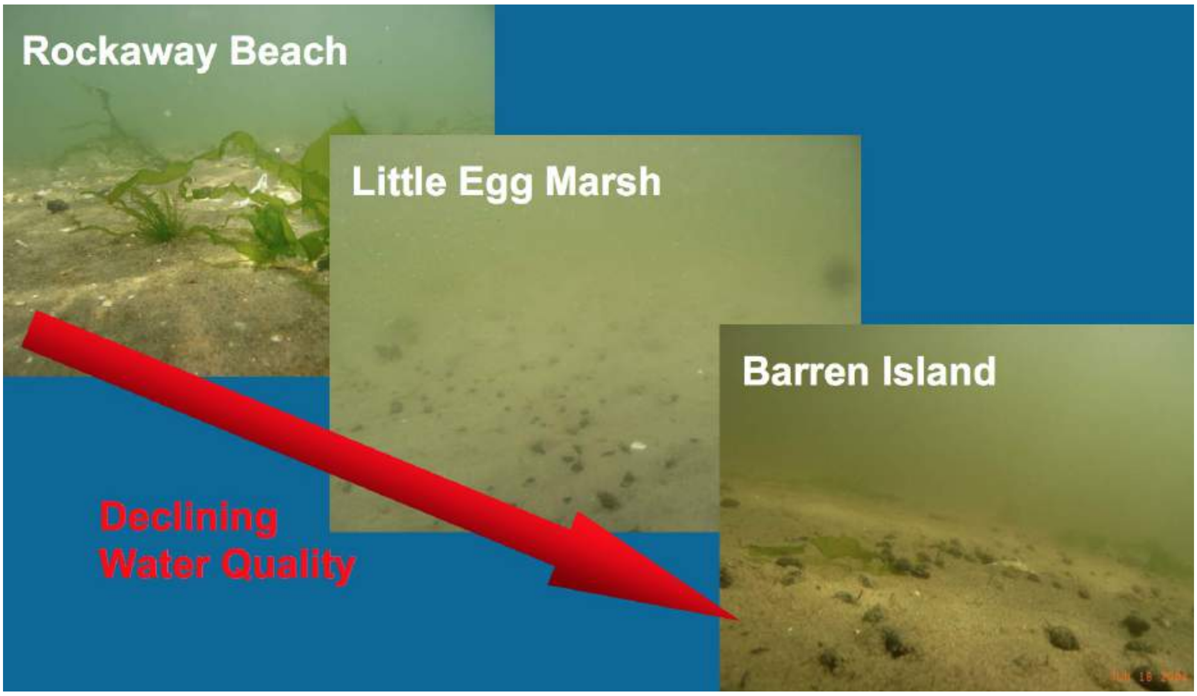


Figure 2.22: Declining water quality [21]

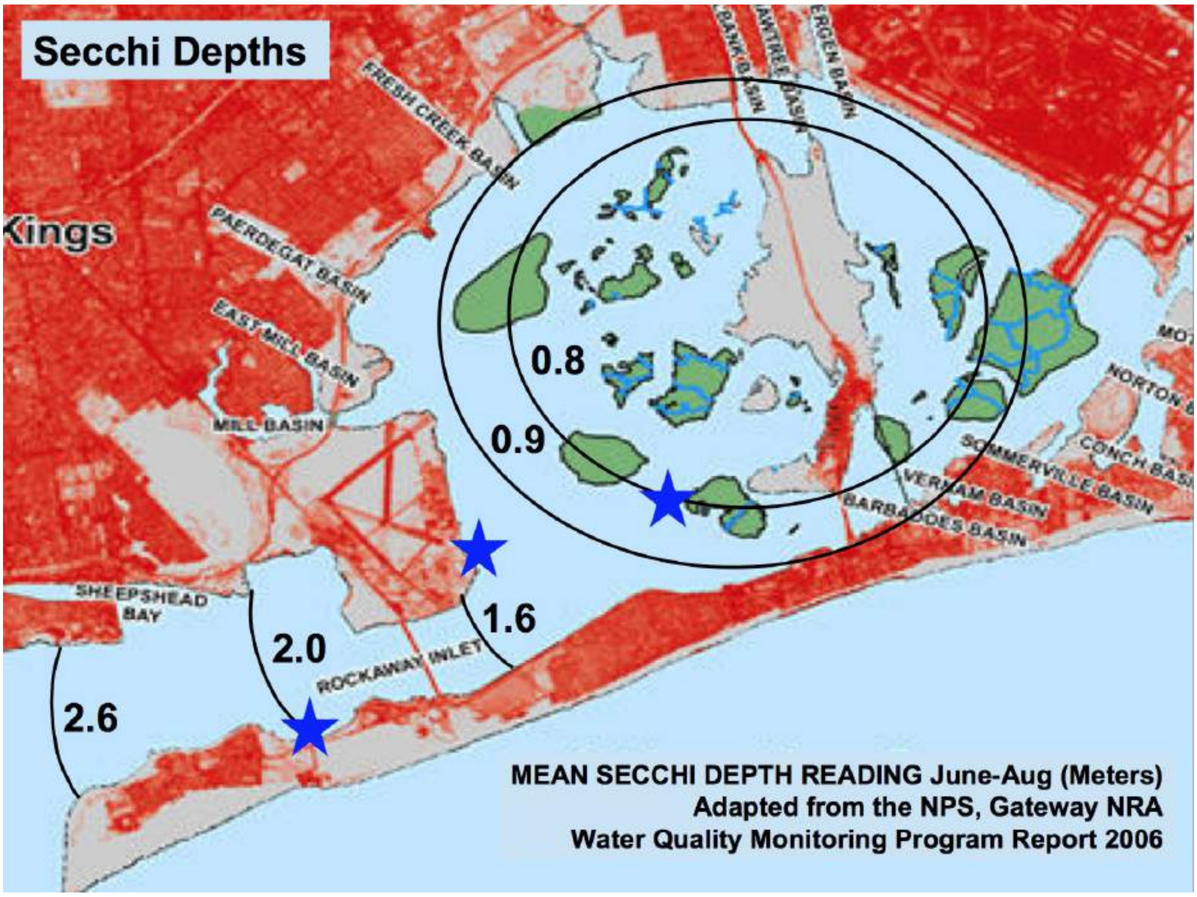


Figure 2.23: Secchi depths in Jamaica Bay [21]

2.8. SPECIFIC ELEVATION JAMAICA BAY

The elevation of New York and Jamaica Bay was shown in section 2.2 with a 3D visualization in figure 2.2. This section will elaborate more on the specific elevations for Jamaica Bay. The DEM with certain point in and around the bay is shown in figure 2.24. The units of the elevations are in feet. Elevations in these points will be extracted from the DEM using ArcGIS software.

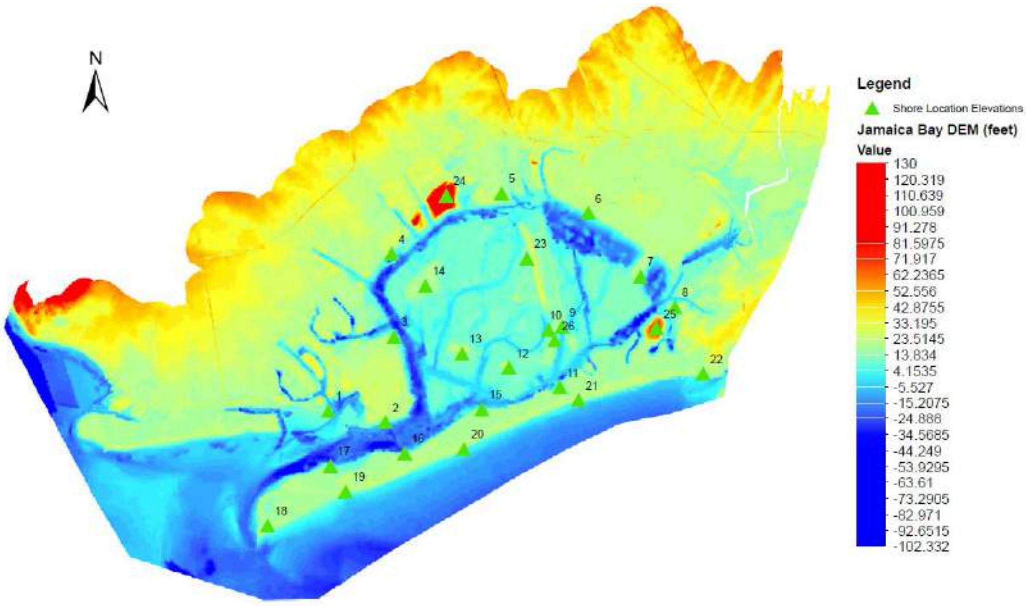


Figure 2.24: DEM of Jamaica Bay with locations for elevation extraction (source DEM:[6])

Table 2.3 shows the result of this extraction from the DEM. The locations are put in order of lowest to highest elevations. These elevations will be used for the design of several measures in the design phase.

Interesting to see is that indeed the channel in the bay is deep (about 50 feet at most) and that there are several borrow pits in the east of the bay (some are even 60 feet deep). Furthermore are the Rockaway Peninsula and Broad Channel very low-lying areas and thus the most vulnerable for flooding. Scour channels north of the Rockaway Peninsula near the inlet can be seen, which could be the result from ever changing tidal movement in the bay due to human interference. Also JFK Airport is not very well elevated. Two landfills in the north and east are situated at high altitudes. Far Rockaway is fairly high elevated, which can also be concluded from the lower amount of damage during Sandy. Three high marsh islands in the bay are at high elevations as well.

2.9. AREA SPECIFICATION

In this section several areas of our interest are defined. Each distinct area has different characteristics which will be highlighted, and in a later stage measures will be elaborated. In the below figure 2.25 an overview can be seen.

2.9.1. SEA SIDE OF ROCKAWAYS

This side of the peninsula has some specific features, which makes it a distinct area. The area specified in the below picture, see figure 2.25, extents from the inlet at Reynolds channel along the shoreline to the Marine Parkway Bridge. From that point on, the embankment changes significantly, which evokes a different approach. The main reason for the specification along the seaside coast would be the difference in hydraulic loads, which are high energetic waves from the Atlantic Ocean, compared to other parts of the bay. Subsequently, the area suffers from consistent coastal erosion. The former recreational area is struck hard by Sandy 2012, destroying the boardwalk, which used to be an iconic feature. An attractive and recreational solution is preferable from that point view. The coast is in a sandy beach state at the moment, with residential houses

Number	Location	Latitude	Longitude	Elevation (feet)	Elevation (meter)
1	Plumb Beach	40,58	-73,91	1,10	0,33
2	Floyd Bennett Field	40,58	-73,89	2,79	0,85
23	Broad Channel	40,63	-73,83	2,97	0,91
9	Broad Channel	40,61	-73,82	4,00	1,22
10	Broad Channel	40,61	-73,82	4,00	1,22
26	Broad Channel	40,60	-73,82	4,43	1,35
14	Canarsie Pol	40,62	-73,87	6,00	1,83
15	Bay side Rockaway Peninsula	40,58	-73,85	6,00	1,83
18	Breezy Point	40,55	-73,94	6,07	1,85
11	Bay side Rockaway Peninsula	40,59	-73,82	6,56	2,00
20	Ocean side Rockaway Peninsula	40,57	-73,86	7,93	2,42
4	Canarsie Pier	40,63	-73,89	8,00	2,44
7	JFK Runway	40,62	-73,79	8,00	2,44
17	Bay side Rockaway Peninsula	40,56	-73,91	8,00	2,44
19	Ocean side Rockaway Peninsula	40,56	-73,91	8,00	2,44
6	JFK shore	40,64	-73,81	8,19	2,50
21	Ocean side Rockaway Peninsula	40,58	-73,81	8,33	2,54
16	Bay side Rockaway Peninsula	40,57	-73,88	8,82	2,69
8	Bayswater National Park	40,61	-73,77	9,54	2,91
3	Floyd Bennett Field	40,60	-73,89	10,00	3,05
5	Howard Beach	40,65	-73,84	10,00	3,05
13	Ruffle Bar	40,60	-73,86	10,00	3,05
22	Ocean side Rockaway Peninsula	40,59	-73,76	11,81	3,60
12	Little Egg	40,59	-73,84	13,89	4,23
25	Rockaway Community Park (Landfill)	40,61	-73,78	65,80	20,06
24	Fountain Avenue Landfill	40,65	-73,86	76,33	23,26

Table 2.3: Elevation of certain locations in and around Jamaica Bay, in order from lowest elevations to highest

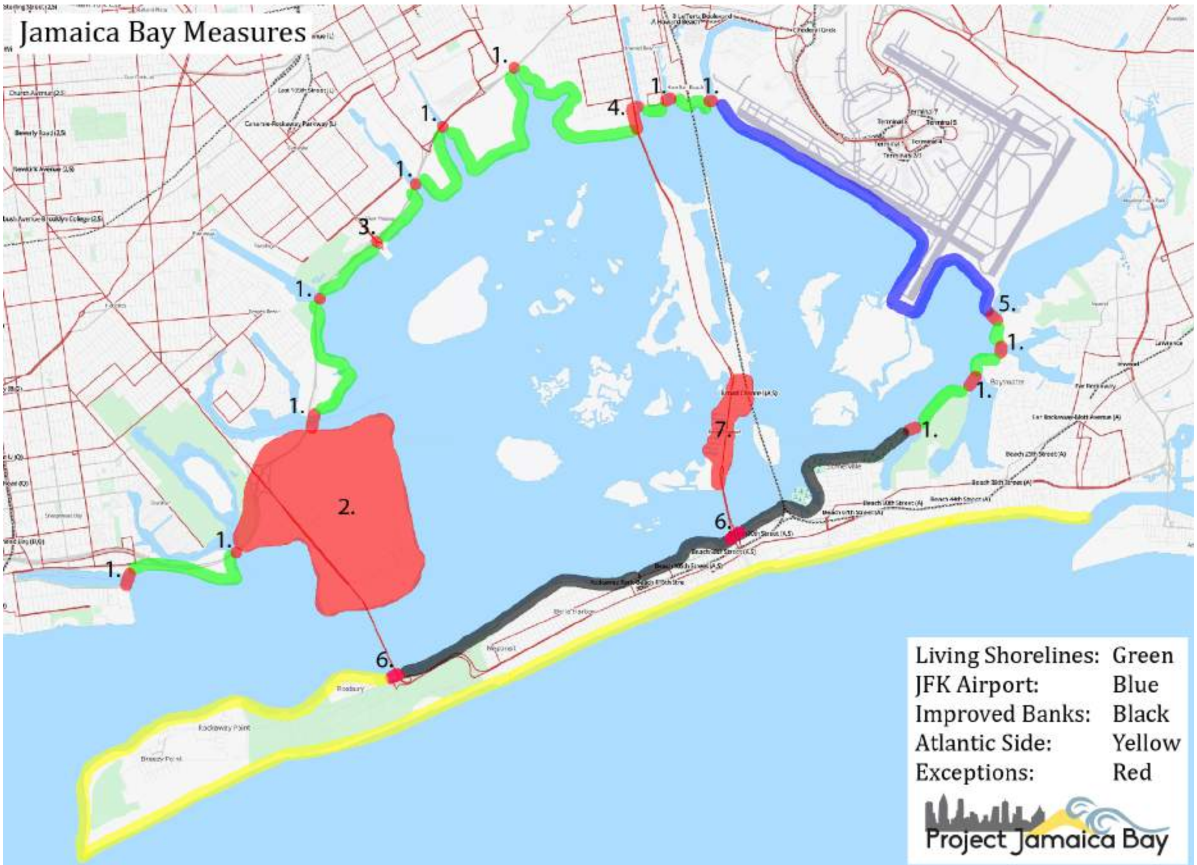


Figure 2.25: Jamaica Bay Area Map

built closely to the seaside. No sufficient coastal protection measure is to be found (yet), although there is space for conventional methods, like levees or dune like structures. The focus should be on a restoration of the beach, integrating coastal protection against erosion and surge levels.

2.9.2. JOHN F. KENNEDY INTERNATIONAL AIRPORT

This part of Jamaica Bay has been extensively described in section 2.5.4. The main points we briefly be highlighted here. The area is slightly elevated compared to other more vulnerable areas surrounding the bay. Damage to be expected due to a flooding is mostly salt water intrusion causing electrical equipment to fail. Currently, only riprap bank revetments, constructed in 1947/1949, are in place to prevent erosion from the landfill. Also, an extensive drainage system constructed in the subsurface of JFK. If a modification to the airport's surface is to be made, it has to comply to certain rules, mainly imposed by the Federal Aviation Administration (FAA). Any structure that will affect the runway, is not safe enough regarding flight safety standards. Another legislation of the FAA is that it is not allowed to build marshes or wetlands within 5 miles of the runway. The marshes or wetlands can attract birds, which can fly into a jet engine. However, this rule is somewhat flexible, because it is hard to comply to in such a differs area. Other boundary conditions are imposed by the Department of Environmental Conservation. Because JFK is surrounded by wetlands, it is not allowed to build in the water front of the airport. To get permits, for such an activity, would be extremely difficult. If new infrastructure were to be build that would affect the wetlands, mitigation regarding those wetlands (e.g. create new wetland area somewhere else) should at least balance the negative effects.

2.9.3. BAY SIDE OF ROCKAWAYS

The bay side of the Rockaways introduces some spatial fitting challenges. This area spans from Marine Parkway Bridge to Rockaway Community Park, then is extended along the banks to Barbados Basin, see figure 2.25. Of great concern is the limited amount of space where a measure can be situated. Aside from the busy Beach Channel Drive which runs along the most part of the perimeter of the northern side of the peninsula, one has to integrate the rapidly increasing of water depth perpendicular to the banks. The navigation channel "Beach Channel" does not allow for a lot of landfill extension into the bay. A solution should incorporate the navigational demand in both on land and water means. The current Beach Channel Drive is far from attractive, and could even be considered dangerous for pedestrians (or any kind of traffic for that matter) thanks to speeding cars and alike. Therefore this area calls for overall improvement.

2.9.4. LIVING SHORELINES

Because the bay is a National Park and an important ecological area it has been decided to pursue natural, ecological, "building with nature"-like solutions. Living shorelines are an ecological measure to prevent banks from eroding and wave impact. To protect the hinterland from the surge a levee-like structure has to be combined, either within the living shoreline or behind it. Because a living shoreline usually consists of a gentle sloped bank with vegetation and sand, it cannot be applied for all banks within the bay. The locations where enough space is available living shorelines will be designed. Non-living shoreline measures are designed for locations where it is impossible to have living shorelines, either because of limited space or another reason (e.g. FAA regulations near JFK Airport). So it is striven for to use this measure on all possible locations within the bay. Living shorelines can be integrated into the surroundings, making it a measure that does not interfere with the ecology and that can even improve the current ecological state. The Belt Parkway drive bridges over the creeks on the North West side of the basin are currently being improved in a ecological way. So applying living shorelines in this region will amplify the results. All green marked banks in picture 2.25 will get living shorelines because there is enough space and no restricting regulations.

The tracing for the living shorelines will start North of Floyd Bennett Field, protecting the banks as far as JFK (with exceptions (see subsection 2.9.6 to connect them). Furthermore they will be applied in the South East corner of the bay for the parks and on Plumb Beach (in the Inlet).

2.9.5. MARSHES

Within the bay the restoration of the marsh islands will be evaluated. These are not indicated in figure 2.25. The reason is that multiple configurations will be evaluated in a later stage. The islands can not be placed anywhere because of the navigation channels that have to be open. The islands will only be placed within the bay, meaning East from Marine Parkway Bridge. Furthermore, because of the FAA regulations it is prohibited to restore bird breeding grounds withing a 5 mile radius from JFK Airport. This means that most of the wetland restoration will be done West from Broad Channel.

2.9.6. EXCEPTIONS

Exceptions are locations where none of the proposed measures is a good solution. The locations will be shortly discussed in this subsection.

1. Inlet creeks
   The perimeter of the contains a number of creeks around the bay. To protect the people living next to these creeks something has to be designed around the perimeter of the creeks or in the inlets. The creeks are being used for navigation by pleasure boats.

2. Floyd Bennet Field
   Floyd Bennet Field is treated as an exception because there is a number of possibilities for it. The most important aspect is to protect Belt Parkway Drive, as it is one of the few evacuation routes for Brooklyn residents.

3. Canarsie Pier
   At Canarsie Pier the living shorelines are interrupted. An exception has to be designed over here as well.

4. Cross Bay Boulevard - Shell Bank Basin
   Cross Bay Boulevard is right next to the inlet of Shell Bank Basin. So a design for the creek inlet has to be combined with a measure to protect Cross Bay Boulevard.

5. Head of Bay
   Head of Bay is a creek that is being used for professional navigation. This has to be accounted for when designing a measure to protect the Head of Bay banks and people living there.

6. Beach Channel Drive bridges
   Beach Channel Drive has two bridges, connecting Rockaway Peninsula with Brooklyn and Queens. At the junction of these bridges and Beach Channel Drive exception measures have to be designed.

7. Broad Channel
   Broad Channel is a low lying community within Jamaica Bay. Currently there is no protection for storm surges. Because this study is about a open Jamaica Bay, something has to be designed to protect Broad Channel during storms.

3

Requirements, Boundary Conditions and Wishes

This chapter will discuss the requirements, boundary conditions and wishes for the measures. Requirements are determined by the design team or client and what the design has to be capable of in the end. Boundary conditions are conditions that have to be met, for the designs to work. In general one could say boundary condition are limiting factors that cannot be influenced by the design team. Wishes are features that would be nice to strive for but are not critical to the project.

3.1. Requirements

Requirements determine for a great part what the measures will do. The requirements are usually given by the client. For this particular project the requirements are determined by the project team in consultation with the supervisors. Requirements one could think of are about the projected lifetime, the design storm, ecological requirements, etc. The coming subsections will elaborate on them.

3.1.1. Projected Lifetime of the Measures

One of the most important aspects that has to be determined in the beginning of the project is the projected lifetime of the measures. The reason is that this influences both boundary conditions and requirements, e.g. sea level rise, building materials, ground consolidation, etc. A typical design lifetime for a levee is, in for instance the Netherlands, 50 years. The longer the design lifetime, the higher the demands for the designs will be. After consulting an ARCADIS-US specialist (Wesley D. Jacobs) it has been determined that the projected design lifetime for the measures in this study is 50 years. This means that the measures still have to defend the hinterland for a 1/100 storm over 50 years (about 2065).

1. **The projected lifetime of the measures is 50 years**

3.1.2. Design Storm

May 24, 1977 Executive Order 11988, Floodplain Management was issued by president Carter. Federal agencies are directed to use HUD (now FEMA) maps to establish whether an action takes place in the floodplain and, if so, to adopt regulations and procedures from the National Flood Insurance Program which was created with the 1968 passage of the National Flood Insurance Act. This established the 100-year standard as the minimum for evaluation of Federal actions (National Academies Keck Center (2004) [22]). According to them much of the developed world uses the same 1% chance flood standard. However, there are countries, like the Netherlands, that have adopted a stricter standard. For the Netherlands this is the 10,000 year storm. One of the explanations for this can bee seen in figure 3.1. This shows that an increase in return period will have greater consequences in NYC than in the Netherlands, meaning that a increased return period is easier to maintain in the Netherlands than in the USA; an increase in return period from 10^2 to 10^3 gives in the Netherlands an increase in flood height of about 2 feet (0.61 m) while in New York City the same increase in

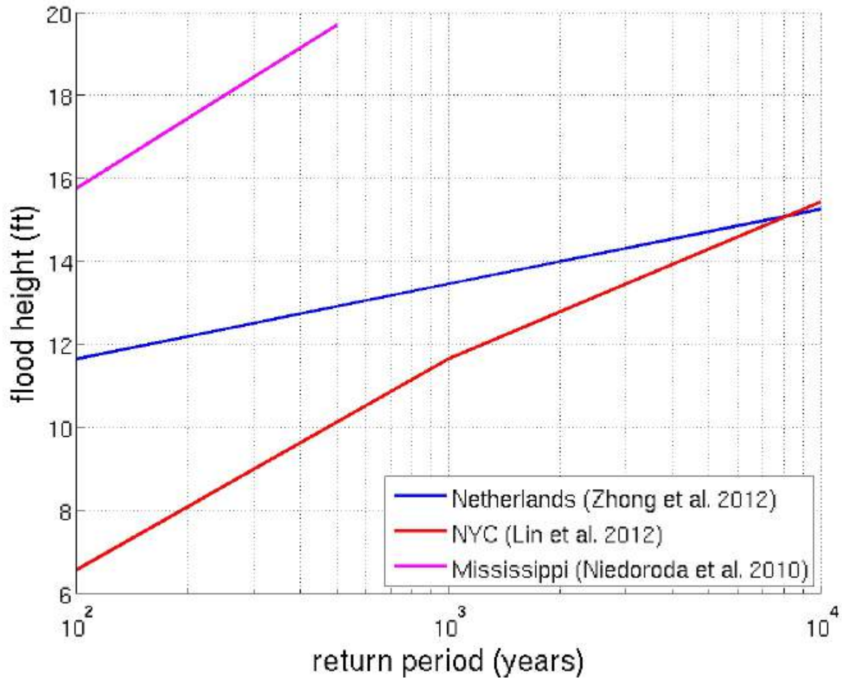


Figure 3.1: Graph showing hazards in NYC vs The Netherlands (Philip Orton (Stevens Institute))

return period gives an increase in design height of approximately 5 feet (1.52 m).

However, because of the amount of people living in the Jamaica Bay Area and the economical value of this area and of NYC in general, it can be argued that a 1/100 year design storm is not safe enough. Like stated in the literature report, written prior to this report, a child born today has about 56 % chance of facing a 1/100 year event. So it might be better to increase the return period for the design storm to increase safety and economic value of the region. Aerts et al. (2013) [7] state that the total damage for NYC for a 1/100 year flood is about $ 2.06 - 4.69 billion, for a 1/500 year flood it is about $ 5.65 - 11.55 billion and for 1/100 year it is about $ 7.52 - 15.41 billion (see figure 3.2). From this graph it can easily be seen that there is a big gap between the 1/100 year and 1/500 flooding. One could argue, based on this economical perspective, that a 1/500 year flooding would be justifiable. Furthermore climate change projections indicate that the current 1/100 year flood zones may flood approximately four times as often by 2080 (Aerts et al. (2012) [13]).

The measures designed for this study will be designed for a 1/100 year storm because this is the current USA policy. A more detailed discussion about the safety of this design level is outside of the scope of this study.

2. **The measures should protect the hinterland from inundations during a 1/100 year storm**

3.1.3. INTEGRATING INFRASTRUCTURE, NATURE AND SOCIETY

One of the goals for this study is to integrate infrastructure, nature and society. Improving the safety during storms is a great opportunity to also improve these three items. The area is a beautiful site and it plays an important role in society and nature. The measures that are designed to protect the hinterland from flooding and inundations should not affect the ecological state of the area in a negative way. Furthermore, the current infrastructural situation within the Jamaica Bay area and between Jamaica Bay and other areas is not optimal. If possible, improved infrastructure must be integrated within the measures. Lastly society impacts should be taken into account. Within the Jamaica Bay there are a lot of different communities, but there is nothing that combines these communities. Instead of being a unity, the communities are divided. By improving the area, also the society should be taken into account and improvements to be made whenever this is possible. More background information on these topics is given in the Location Analysis (section **??**).

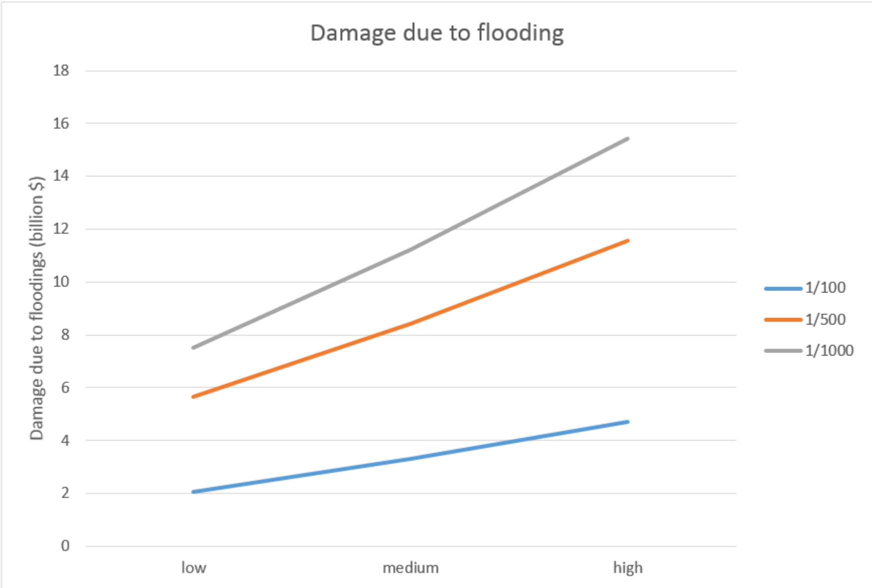


Figure 3.2: Graph showing damage for whole NYC due to flooding (data used from Aerts et al. (2013) [7])

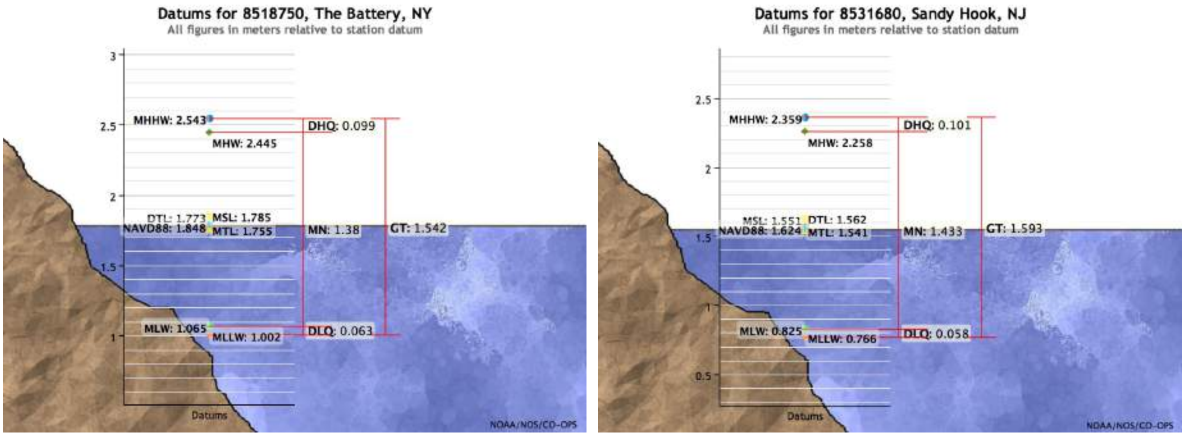
3. **Whenever possible, improvements in infrastructure, nature and society should be integrated within the measures designed for mitigating flood risk**

3.2. BOUNDARY CONDITIONS

This section will elaborate on the boundary conditions for this project. The boundary conditions usually give limitations to the measures, but cannot be influenced. One could think of water conditions, soil conditions and available space. Each of the boundary conditions will be discussed.

3.2.1. MEAN SEA LEVEL

Although a lot of gauges within Jamaica Bay measure tidal range, high tide and low tide, none specify their respectively level against NAVD88. Because most of our data regarding storm surge levels, elaborated in section 3.2.3, are with respect to NAVD88, we need to make an approximation which will suit the conditions in the Jamaica Bay. The two closest gauges that do give an accurate reading about their level with respect to NAVD88 are the ones found at The Battery (NY) and Sandy Hook (NJ). In the figure below, several datums are pointed out, these are acquired by NOAA (2001). Datums are updated every 25 years. The datums represented are measured from Station Datum, a fixed elevation from which every elevation can be measured, and therefore unique to each station. What can be seen from these figures is that in both cases NAVD88 is about 7 cm lower then Mean Sea Level (MSL). And although one could argue that Sandy Hook and The Battery offer different characteristics compared to Jamaica Bay, the same can be said between those places. In any case, this is the closest we can get to a fair approximation, and therefore it is assumed that MSL Jamaica Bay is of equal magnitude.



(a) The Battery (NY)

(b) Sandy Hook (NJ)

Figure 3.3: Datums NOAA(2001)

1. **Mean sea level is +0.07 m NAVD88**

3.2.2. TIDAL RANGE

It is important to determine the tidal range and flood levels for the Jamaica Bay area because a storm could arrive simultaneously with spring tide. For this situation the spring tidal amplitude should be added to the storm conditions. The tidal predictions for 2011 by NOAA (2010) [23] can be seen in table 3.1. Mean Sea Level (MSL) is taken at +0.07 m NAVD88 (see Boundary Condition 1), from which tide levels and flood heights relative to NAVD88 can be calculated (see table 3.2). Overall the simplified water levels are shown by the mean value of locations within the Bay. For the Atlantic side of Rockaway Peninsula the ranges for east Rockaway Inlet will be used. Figure 3.4 shows where the locations are in a map.

Jamaica Bay Locations	**Location Character**	**Mean Range (ft)**	**Mean Range (m)**	**Mean Range Amplitude (m)**	**Spring Range (ft)**	**Spring Range (m)**	**Spring Range Amplitude (m)**	**Mean tide level (ft)**	**Mean tide level (m)**
East Rockaway Inlet	A	4.1	1.25	0.62	5	1.52	0.76	2.2	0.67
Locations within Jamaica Bay									
Plumb Beach Channel	B	4.9	1.49	0.75	5.9	1.80	0.90	2.6	0.79
Barren Island, Rockaway Inlet	C	5	1.52	0.76	6	1.83	0.91	2.7	0.82
Beach Channel (bridge)	D	5.1	1.55	0.78	6.2	1.89	0.94	2.7	0.82
Motts Basin	E	5.4	1.65	0.82	6.5	1.98	0.99	2.9	0.88
Norton Point, Head of Bay	F	5.4	1.65	0.82	6.5	1.98	0.99	2.9	0.88
J.F.K. International Airport	G	5.3	1.62	0.81	6.4	1.95	0.98	2.8	0.85
North Channel Bridge, Grassy Bay	H	5.2	1.58	0.79	6.3	1.92	0.96	2.8	0.85
Canarsie	I	5.2	1.58	0.79	6.3	1.92	0.96	2.8	0.85
Mill Basin	J	5.2	1.58	0.79	6.3	1.92	0.96	2.8	0.85
Mean over all locations (within JB)		**5.19**	**1.58**	**0.79**	**6.27**	**1.91**	**0.96**	**2.78**	**0.85**

Table 3.1: Tidal ranges in feet and meter for several locations within the bay **relative to MLLW** (data from NOAA (2010) [23])

Jamaica Bay Locations	**Mean Tide Level (m) relative to MLLW**	**Mean Tide Level (m) relative to NAVD88**	**Mean Flood Level (m) relative to NAVD88**	**Spring Flood Level (m) relative to NAVD88**
East Rockaway Inlet	0.67	0.07	0.69	0.83
Locations within Jamaica Bay				
Plumb Beach Channel	0.79	0.07	0.82	0.97
Barren Island, Rockaway Inlet	0.82	0.07	0.83	0.98
Beach Channel (bridge)	0.82	0.07	0.85	1.01
Motts Basin	0.88	0.07	0.89	1.06
Norton Point, Head of Bay	0.88	0.07	0.89	1.06
J.F.K. International Airport	0.85	0.07	0.88	1.05
North Channel Bridge, Grassy Bay	0.85	0.07	0.86	1.03
Canarsie	0.85	0.07	0.86	1.03
Mill Basin	0.85	0.07	0.86	1.03
Mean over all locations (within JB)	**0.85**	**0.07**	**0.86**	**1.03**

Table 3.2: Mean tide level converted from relative to MLLW to relative to NAVD88 and mean- and spring flood heights relative to NAVD88

2. **For the tidal ranges and amplitudes within the area, the figures given by table 3.2 will be used**

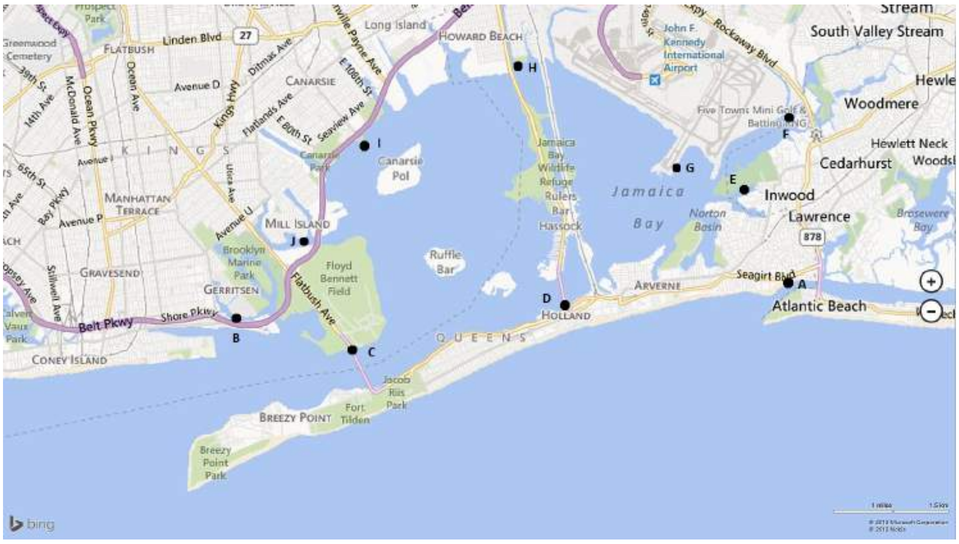


Figure 3.4: The locations for which tables 3.1 and 3.2 give the information

3.2.3. WATER CONDITIONS DURING A 1/100 YEAR STORM

The water conditions during a 1/100 year storm are one of most important boundary conditions for this study. Because of the shape, positioning and location of Jamaica Bay water conditions during a storm will differ along the banks and within the bay. The data can be seen in figure 3.5 and table 3.3. They will be discussed in the following subsections as well.

Figure 3.5: Locations of the water conditions given in figure ??

Number	Name	Location	Latitude	Longitude	100yr Elevation (feet)	100yr Elevation (meter)	Flood Zone	100yr Wave Height (feet)	100yr Wave Height (meter)	100yr Wave Period (seconds)
1	Plumb Beach	South tip	40.581628	-73.910998	15	4.57	VE	3.4	1.04	2.8
2	Floyd Bennett Field	Flatbush avenue	40.577892	-73.888374	15	4.57	VE	3.7	1.13	3.2
3	Floyd Bennett Field	North West tip	40.605539	-73.884206	14	4.27	VE	2.9	0.88	2.4
4	Canarsie Pier	Tip	40.627951	-73.883144	14	4.27	VE	3.2	0.98	2.4
5	Howard Beach		40.644845	-73.840143	14	4.27	VE	3.1	0.94	2.4
6	JFK shore		40.641573	-73.805564	14	4.27	VE	3.9	1.19	2.8
7	JFK Runway		40.621445	-73.784793	12	3.66	AE	3.1	0.94	2.4
8	Bayswater National Park		40.613301	-73.773969	12	3.66	VE	2.9	0.88	2.2
9	Broad Channel	East Side	40.605311	-73.816507	13	3.96	VE	2.9	0.88	2.3
10	Broad Channel	West side spot 1	40.605812	-73.822876	13	3.96	VE	3.1	0.94	2.3
11	Bay side Rockaway Peninsula	Cross Bay Bridge	40.588382	-73.818486	13	3.96	VE	2.5	0.76	2
12	Little Egg	On top of island	40.594566	-73.838814	12	3.66	VE	2.6	0.79	2.1
13	Ruffle Bar	On top of island	40.598835	-73.857835	10	3.05	AE	3	0.91	2.3
14	Canarsie Pol	On top of island	40.620272	-73.87345	10	3.05	AE	3.4	1.04	2.4
15	Bay side Rockaway Peninsula	Beach 127th St.	40.582112	-73.8499	12	3.66	VE	2.2	0.67	1.9
16	Bay side Rockaway Peninsula	Flatbush avenue	40.568719	-73.881357	14	4.27	VE	2.5	0.76	2.8
17	Bay side Rockaway Peninsula	Beach 201st St.	40.565162	-73.911612	15	4.57	VE	3.9	1.19	3.1
18	Breezy Point	Tip	40.542961	-73.940586	17	5.18	VE	10.2	3.11	7.8
19	Ocean side Rockaway Peninsula	Beach 193rd St.	40.557048	-73.905504	17	5.18	AE	10.4	3.17	9.3
20	Ocean side Rockaway Peninsula	Beach 142nd St.	40.569257	-73.856989	17	5.18	VE	11	3.35	9.8
21	Ocean side Rockaway Peninsula	Beach 90th St.	40.583697	-73.810662	17	5.18	VE	10.3	3.14	10.1
22	Ocean side Rockaway Peninsula	Marvin St.	40.591658	-73.760417	17	5.18	VE	8.2	2.45	9.3
23	Broad Channel	West side spot 2	40.628285	-73.831013	13	3.96	AE	3.7	1.13	2.3

Table 3.3: Water levels, wave conditions (relative to NAVD88) and flood zones during a 1/100 year storm. BAFH is Best Available Flood Hazard (data collected from FEMA Preliminary Work Maps)

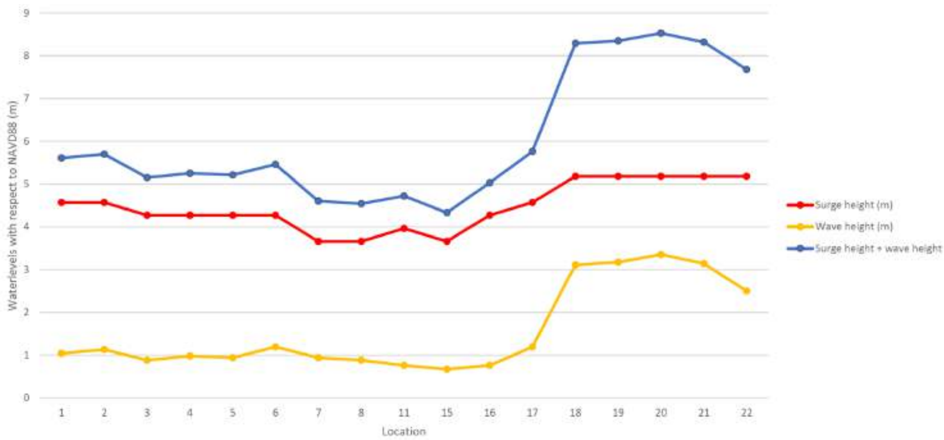


Figure 3.6: Graph of the waterlevels during a 1/100 year storm (data provided by ARCADIS-US)

Figure 3.6 shows a plot of the water levels during a 1/100 year storm. On the y-axis one can find the the water levels in meters and on the x-axis the location numbers. It starts with point 1 and then follows the banks of Jamaica Bay and the outside of Rockaway peninsula. So it is the situation at the banks if the bank was just a straight line. The locations within the bay are not shown in the graph.

STORM SURGE LEVEL

Table 3.3 shows the surge height in meters and feet for the chosen locations within the bay. From this numbers you can see that Rockaway Inlet (locations 1, 2, 16 and 17) has high surge levels in comparison with the surge levels within the bay, probably because of upsets due to funneling. Within the bay it can be seen that the Northern banks of the bay (locations 3 t/m 6) have slightly higher surge levels that the Southern banks (locations 8, 11 and 15), this is probably because of wind upset. Furthermore, surge levels on barrier islands Ruffle Bar and Canarsie Pol(13 and 14) are significantly lower than elsewhere, probably because of higher roughness. But this is not the case for location 12, possibly because of the fact that Little Egg is a lower marsh island or because of the position of the island. It can also be seen that the surge levels on both sides of Broad Channel (9 and 10) and further north on the same island are the same. As can be expected, the highest surge levels are situated on the Atlantic side of the Rockaways (18 - 22).

3. **For the surge heights within the area, the heights given by table ?? will be used**

WAVE CONDITIONS

Table 3.3 shows the wave conditions for the chosen locations within the bay. The first thing that can easily be seen is the striking difference in wave height and period between the inside of the bay and the Atlantic side of the Rockaways. The most probable reason for this is the difference in fetch length. The Atlantic side of the peninsula suffers waves coming from sea with a very long fetch length. The inside of the bay has a maximum fetch length of its width, about 10 km. But there are also a lot of marsh islands that give even much shorter fetch lengths. Furthermore there is a small difference in wave height and period between the Northern banks and the Southern banks. This has probably the same explanation.

4. **For the wave conditions within the area, the conditions given by table ?? will be used**

SEA LEVEL RISE

According the most recent publication of the Intergovernmental Panel On Climate Change (IPCC) the sea levels are rising [24]. They describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four scenarios (RCPs), namely RCP2.6, RCP4.5, RCP6.0 and RCP9.5 are named after a possible range of radiative forcing values difference of radiant energy by the earth and energy radiated back to space, hence IPCC. Global mean sea level rise for 2081-2100 relative to 1986-2005 will likely be in the ranges of 0.26 to 0.55 m for RCP2.6, 0.32 to 0.63 for RCP4.5, 0.33 to 0.63 m for RCP6.0 and 0.45 to 0.82 m for RCP8.5. However, the design life time of hydraulic structures [25] is 50 years therefore we will consider the sea level rise around 2055. In the figure below 3.7 the IPCC projections for very high emissions (RCP8.5 scenario) and very low emissions (blue RCP2.6 scenario) are illustrated.

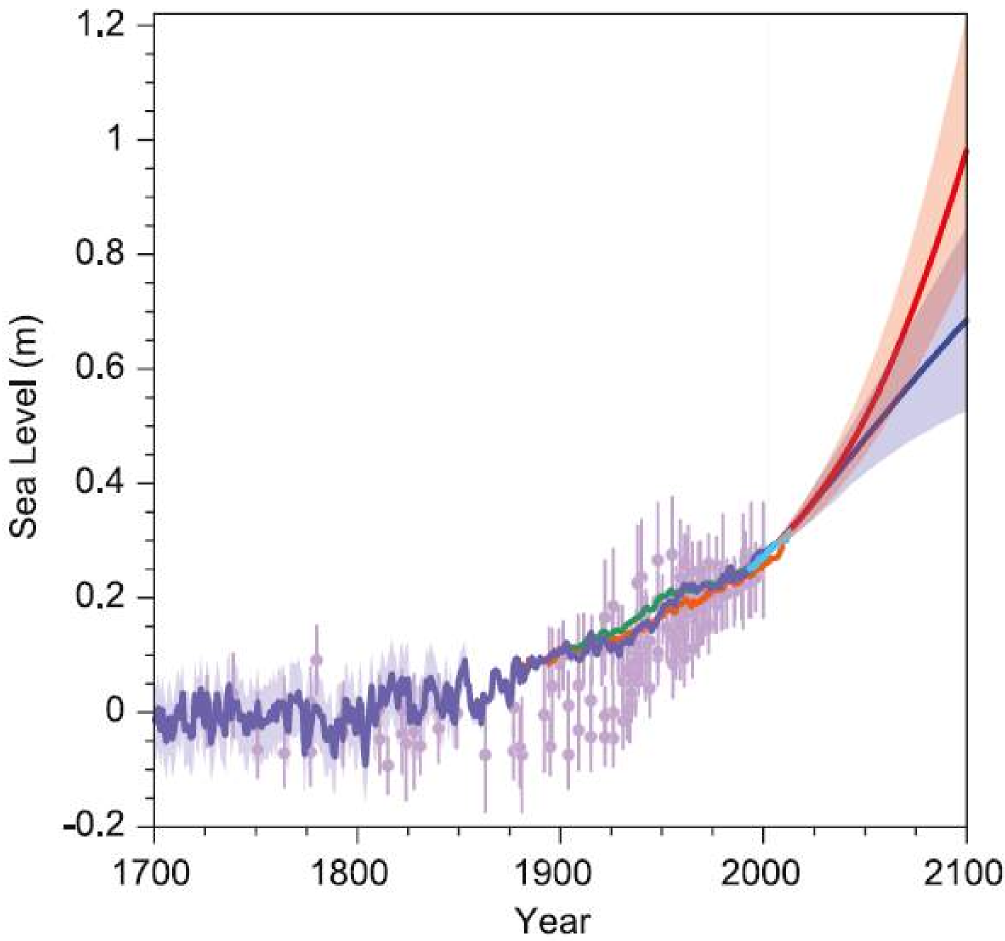


Figure 3.7: Past and future sea-level rise. For the past, proxy data are shown in light purple and tide gauge data in blue. For the future, the IPCC projectons for very high emissions (red, RCP8.5 scenario) and very low emissions (blue, RCP2.6 scenario) are shown. (IPCC AR5 fig. 13.27)

One can conclude that the projections for 2050 differ not very much. By using interpolation, we determined a (global) sea level rise of approximately 0.55 m.

Furthermore sea level rise will not be uniform, hence IPCC. The local sea level changes may differ substantially from a global average, showing complex spatial patterns which result from ocean dynamical processes, movements of the sea floor and changes in gravity due to water mass-redistribution (land ice and other terrestrial water storage) in the climate system [24]. Regional changes in sea level reach values of up to 30% above the global mean value in the Southern Ocean and around North America, between 10-20% in equatorial regions and up to 50% below the global mean in the Arctic region and some regions near Antarctica. Applying this assumption leads to a local sea level rise of approximately 0.1 m.

5. **The governing sea level rise during this study can be calculated by adding up the local rise plus the global rise, which leads to a total sea level rise of 0.65 m**

3.2.4. WIND CONDITIONS

In general hurricanes strike NYC during July and October. However, the majority of storms are northeasters (nor'easters). Although hurricanes do not occur often in the NYC area, their impact can be huge. The wind created by the hurricanes play an important role. Wind is caused by uneven pressures in the atmosphere that exist in high and low-pressure areas. The wind direction, wind velocity and turbulence in the lowest layers of the atmosphere are important in the design of hydraulic structures. The area over which strong wind blows (i.e. fetch length) correlates closely with storm surge, the rise in water level caused by the pressure difference and the force of the winds pushing against the water. By analyzing wind data and considering the fetch length, the wind set-up can be calculated. The wind velocity and the velocity of the wind gusts during Hurricane Sandy are shown in figure 3.8. The highest wind speeds are measured during 10/29/2012 23:00 and 10/30/1012 01:00. The mean wind speed during these two hours is about 25 m/s (90 km/h). The wind direction was east. This will form the boundary condition regarding wind conditions.

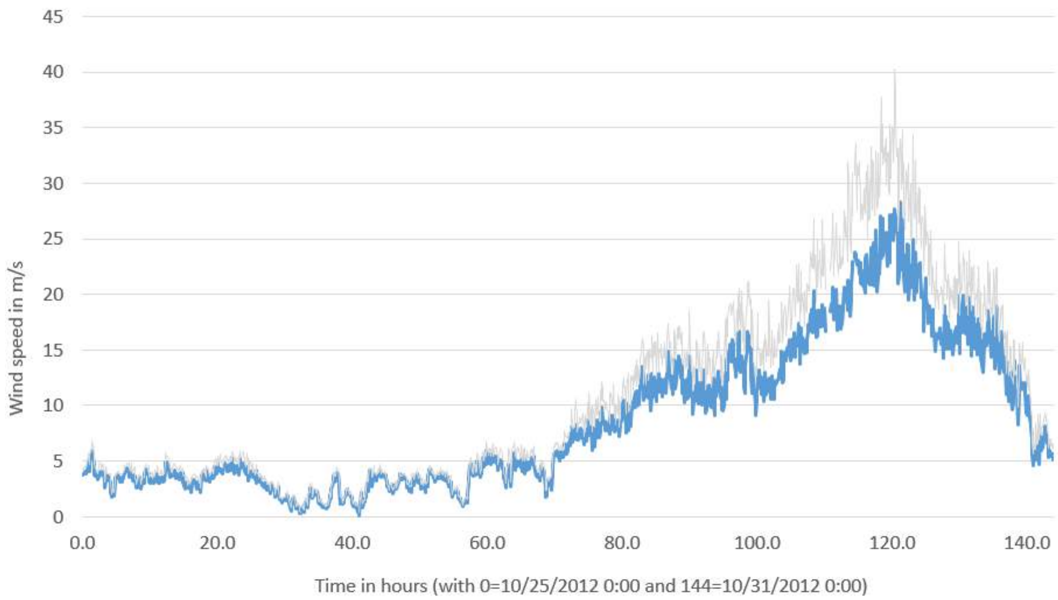


Figure 3.8: Wind speed (blue) and wind gust speed (grey) during Hurricane Sandy (NOAA [26])

6. **For this study the wind speeds will be based on the wind speeds during Hurricane Sandy. The governing (eastern) wind speed is 25 m/s**

3.2.5. SOIL AND SUBSOIL CONDITIONS

Because the designs will be preliminary designs assumptions on soil and subsoil conditions based on geological maps form the area will be made. According to Rhoads et al. (2001) [27] the Rockaway Peninsula is composed of tidal sediments and upper glacial sands. The marshes at the perimeter of the bay are characterized by dark gray clayey silt to silty clay sediments. The underlying glacial sands are Upper Pleistocene deposits. For determining the soil parameters the book Manual Hydraulic Structures by Vrijling et al. (2011) [25] has been used. It must be noted that the numbers are educated guesses and not the exact soil conditions. These guesses are good enough for this study but for more detailed studies this has to be investigated again.

7. **The soil types for the Jamaica Bay area are shown below (for soil parameters see table 3.4)**

   - **Rockaway Peninsula: tidal sediments an upper glacial sands, approximated as *clean sand with a moderate consistency***
   - **Jamaica Bay perimeter: dark gray clayey silt to silty clay sediments, approximated as *greatly sandy clay***
   - **Underlying glacial sand, approximated as *clean sand with a solid consistency***

3.2.6. NATIONAL PARK

The Jamaica Bay compromises an area almost equal to the size of Manhattan, therefore the bay remains one of the largest and most productive coastal ecosystems in the northeastern United States and includes the largest tidal wetland complex in the New York metropolitan area. Because of this unique appearance the Jamaica Bay is part of the Gateway National Recreation Area, which was created by the US Congress to preserve and protect scarce and/or unique natural, cultural and recreational resources. The areas are owned by the United States government and managed by the National Park Service. The NPS carries out its responsibilities in parks under the authority of federal laws and regulations. A large part of the circumference of the bay consists of

Parameter		Greatly sandy clay	Clean sand (moderate consistency)	Clean sand (solid consistency)
γ_{dry}	$[kN/m^3]$	-	18	19 - 20
γ_{wet}	$[kN/m^3]$	18 - 20	20	21 - 22
q_c	$[Mpa]$	1	15	25
C'_p	$[-]$	25 - 50	600	1000 - 1500
C_c	$[-]$	0.190 - 0.027	0.006	0.003 - 0.002
C'_{sw}	$[-]$	0.063 - 0.025	0.003	0.001 - 0
E	$[Mpa]$	2 - 5	75	125 - 150
ϕ'	[°]	27.5 - 32.5	32.5	35 - 40

Table 3.4: Soil parameters for the different soil types relevant to this study (Vrijling et al. (2011))

wetlands, in order to avoid possible long and short term adverse impacts associated with the destruction or modifications of wetlands, one has to follow their laws and regulations. Also as a part of the Clean Water Act, the US Army Corps issues permits for activities that result in discharge of dredges or fill material into waters of the United States, including wetlands. Regulated activities range from depositing fill for building pads or roads to discharges associated with mechanized land clearing. Furthermore the NPS is directed to take action to reduce the risk of flood loss, to minimize impacts of flooding on human safety, health, welfare and to restore and preserve the natural and beneficial values of floodplains. Since wetlands are often located within floodplains, such proposed activities may require compliance with Executive Orders [28]. The legislation concerning wetlands is elaborated in the following sections.

AVOID ADVERSE IMPACTS ON WETLANDS

In the course of developing project alternatives and implementing actions, the NPS must seek to avoid direct or indirect adverse impact on wetlands and avoid support of activities that would result in such impacts, wherever practicable.

MINIMIZING UNAVOIDABLE WETLAND IMPACTS

If a proposed action will still have adverse impacts on wetlands even after avoidance measures have been incorporated, the NPS must minimize such impacts by designing or modifying the action to reduce wetland degradation or loss.

COMPENSATING FOR WETLAND IMPACTS

After *avoidance* and *minimization* have been applied to the maximum practicable extent, remaining new wetland degradation or loss must be offset through wetland *compensation*. For the NPS, compensation refers primarily to restoring natural wetland functions in degraded or former natural wetland habitats on NPS lands. In general, it does not refer to creating wetlands where they did not exist previously.

NPS wetland compensation is required as follows:

- If the adverse impacts on wetlands from the entire project totals less than 0.1 acres, then wetland compensation is strongly encouraged
- If the adverse impacts on wetlands from the entire project covers 0.1 acres or more, then wetland compensation in the form of restoration of degraded or former wetland habitats is required

For the purpose of wetland compensation, wetland restoration proposals must, at a minimum, provide one-for-one (1:1) wetland function replacement (i.e., focus on no net loss of wetland functions, not just wetland acreage). In the absence of definitive information needed to specifically address 1:1 wetland function replacement, a minimum of 1:1 wetland acreage replacement may be used as a surrogate. In the latter case, the focus should be on replacing wetlands of equivalent type and function, to the extent practicable.

8. **The measures must meet NPS regulations**

3.2.7. BIRD HABITAT

Because of JFK International Airport (JFK) there are rules for making bird habitat within Jamaica Bay. Within a 1 mile radius from JFK it is forbidden to create bird habitat at all, there is also a guideline stating that it is forbidden to build bird habitat within a 5 mile radius from JFK. This rule is not as strict as the 1 mile radius and because this study will address wetland restoration and creation of living shorelines only the strict rule will be followed. Both areas are shown in figure 3.9.

9. **The measures cannot create bird habitat within a 1 mile radius from JFK International Airport**

Figure 3.9: The 1 and 5 mile perimeter of Jamaica Bay

3.2.8. LOCATION OF MEASURES

There is many things that have to be taken into account when deciding which measure should be design for which location. This is addressed in the Location Analysis, section Area Specification (section **??**). Figure 3.10 shows the locations for the different measures that will be designed, this was the end result of the Location Analysis.

10. **The measures will be designed for the locations given by figure 2.25**

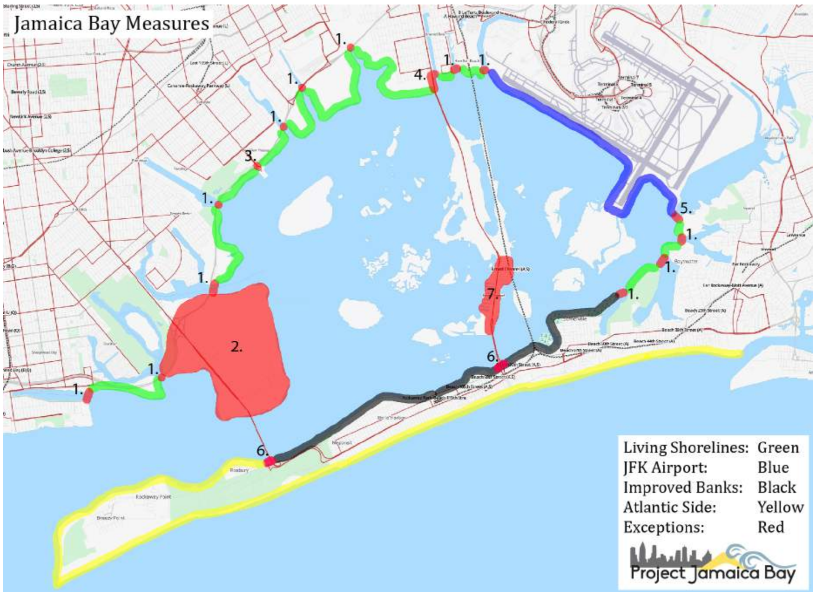


Figure 3.10: The locations for the different measures

3.3. WISHES

This section will elaborate on the wishes for this project. Wishes are features that have a positive impact on the end result but are not essential for the project to succeed.

3.3.1. IMPROVE ECOLOGICAL STATE OF THE BAY

Like stated in the requirements section the ecological state of the Jamaica Bay area is of great importance. Requirement 3 states that the measures should have no negative influence on the ecological state of the area. The wish for this project is that the ecological state of the bay is improved by the proposed measures.

1. **The proposed should measures improve the ecological state of the area**

3.3.2. MORE RECREATION

Currently there is some recreation in the bay and at it's banks. The possibilities are described in the location analysis (section **??**). A wish is to improve this recreation and with that make the area more attractive to visit.

2. **With the proposed measures the possibilities for recreation should be improved**

3.4. LIST OF REQUIREMENTS, BOUNDARY CONDITIONS AND WISHES

In this section only the boundary conditions will be given. For the explanation see the above sections.

3.4.1. REQUIREMENTS

1. The projected lifetime of the measures is 50 years
2. The measures should protect the hinterland from inundations during a 1/100 year storm
3. Whenever possible, improvements in infrastructure, nature and society should be integrated within the measures designed for mitigating flood risk

3.4.2. BOUNDARY CONDITIONS

1. Mean sea level is +0.07 m NAVD88
2. For the tidal ranges and amplitudes within the area, the figures given by table 3.2 will be used
3. For the surge heights within the area, the heights given by table **??** will be used
4. For the wave conditions within the area, the conditions given by table **??** will be used
5. The governing sea level rise during this study can be calculated by adding up the local rise plus the global rise, which leads to a total sea level rise of 0.65 m
6. For this study the wind speeds will be based on the wind speeds during Hurricane Sandy. The governing (eastern) wind speed is 25 m/s
7. The soil types for the Jamaica Bay area are shown below (for soil parameters see table 3.4)
   - Rockaway Peninsula: tidal sediments an upper glacial sands, approximated as *clean sand with a moderate consistency*
   - Jamaica Bay perimeter: dark gray clayey silt to silty clay sediments, approximated as *greatly sandy clay*
   - Underlying glacial sand, approximated as *clean sand with a solid consistency*
8. The measures cannot create bird habitat within a 1 mile radius from JFK International Airport
9. The measures must meet NPS regulations
10. The measures will be designed for the locations given by figure 2.25

3.4.3. WISHES

1. The proposed should measures improve the ecological state of the area
2. With the proposed measures the possibilities for recreation should be improved

4

Sea Side of Rockaways

This chapter will elaborate on possible measures for the Atlantic side of Rockaway Peninsula. This will only be a preliminary discussion.

4.1. Area Analysis

In chapter **??**, Location Analysis, and section **??** on page **??** some general information about the Atlantic side of the Rockaways has already been given. This section will shortly summarize that information and add some more detailed information as introduction for the proposed measures. The proposed measures should protect the Rockaways and hinterland from water comming from the Atlantic Ocean and the South side of Rockaway Inlet (see figure 2.25). It must be noted that for this study only nourishment like measures will be discussed for this area, there are more possibilities but because of time limitations these are not considered.

Figure 4.1: In yellow the considered area

The considered area starts at the Marine Parkway Bridge, goes around Breezy Point, follows the Atlantic side of the Rockaways ending at the inlet of the Reynolds Channel (see the yellow shaded coastline in figure 4.1). The reason to stop at the Marine Parkway bridge is that the embankments from that point on changes significantly, making it impossible to have the same measure. The other edge at Reynolds Channel's inlet is chosen because this is a logical end of the scope of the Jamaica Bay region. As you can see from figure 4.2 the banks look pretty similar at all four locations, with sandy, gently sloped beaches. One of the main focus points for this region is the erosion that takes place along the banks according to The City of New York (2009) [8]. Flood risk mitigating measures could possibly be combined with erosion reduction measures if possible. The bottom right photo in figure 4.2 shows the remainders of the boardwalk that used to be there but was destroyed during Hurricane Sandy. It is preferable to design a measure that can be integrated in the surroundings to keep the beach a recreational and attractive area for residents and visitors. At some points houses are built directly next to the beach (top right photo in figure 4.2) and at other places there are dunes or some sort of heightened beach in place to protect buildings and people (other three photos in figure 4.2). However the measures that are in place at the moment have proven to be insufficient during a Sandy-like hurricane. It is striven for to design one measure that can be applied for the whole area.

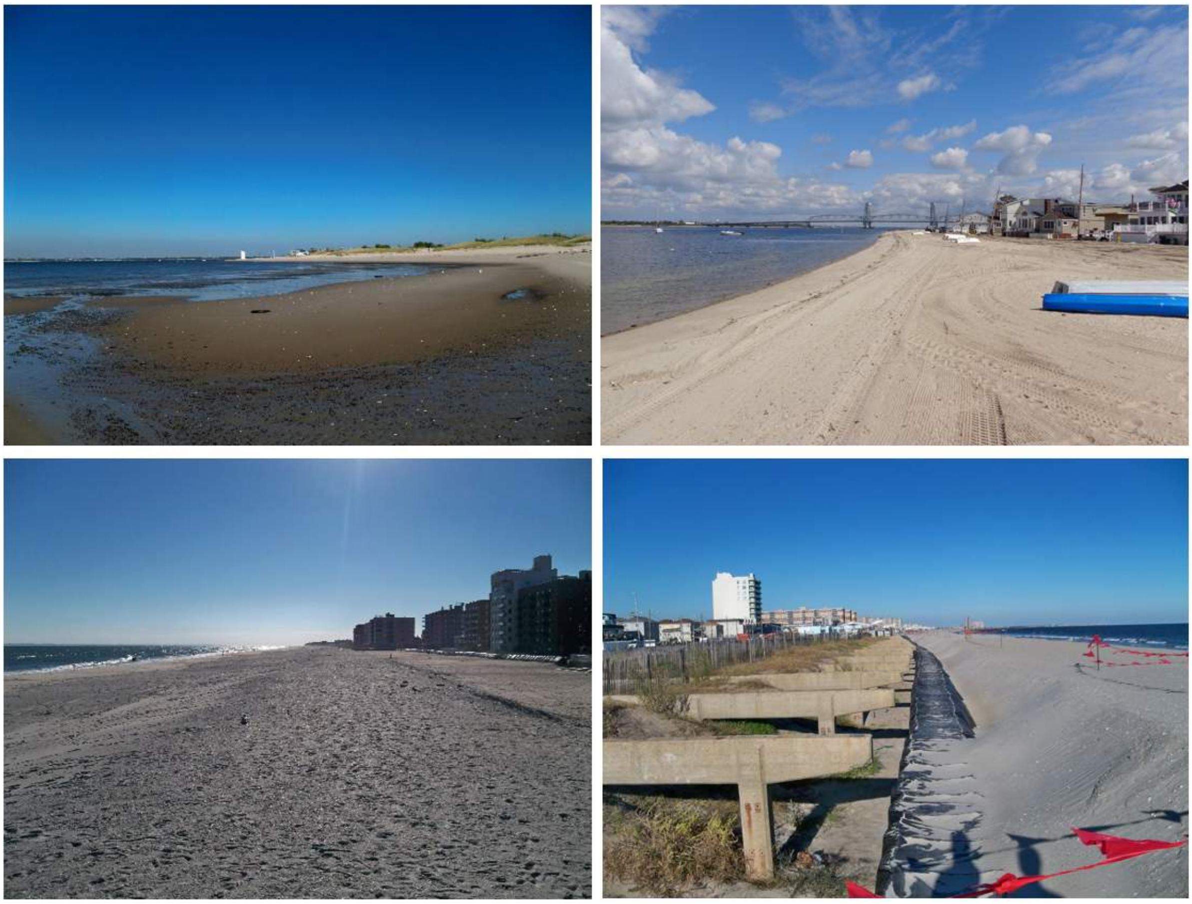


Figure 4.2: Photos taken within the considered region. Clockwise starting at the top left photo these are taken at: 1)Just West of Marine Parkway Bridge, 2)North bank Breezy Point, 3)Rockaway Beach 101 (B101ST) and 4)Rockaway Beach 116 (B116ST).

Locations 16 - 22 in figure 3.5 on page 38 are within the considered area for this measure. The water conditions for these points are given by table 4.1. These will be the governing water levels for this preliminary design of the measure.

N.	Name	Location	Latitude	Longitude	2013 BAFH 100yr Elevation (feet)	2013 BAFH 100yr Elevation (meter)	2013 BAFH Flood Zone	2013 BAFH 100yr Wave Height (feet)	2013 BAFH 100yr Wave Height (meter)	2013 BAFH 100yr Wave Period (seconds)
16	Bay side Rock. Peninsula	Flatbush Ave.	40.56872	-73.8814	14	4.27	VE	2.5	0.76	2.8
17	Bay side Rock. Peninsula	Beach 201st St.	40.57516	-73.9116	15	4.57	VE	3.9	1.19	3.1
18	Breezy Point	Tip	40.54296	-73.9406	17	5.18	VE	10.2	3.11	7.8
19	Ocean side Rock. Peninsula	Beach 193rd St.	40.55705	-73.9055	17	5.18	AE	10.4	3.17	9.3
20	Ocean side Rock. Peninsula	Beach 142nd St.	40.56926	-73.857	17	5.18	VE	11	3.35	9.8
21	Ocean side Rock. Peninsula	Beach 90th St.	40.5837	-73.8107	17	5.18	VE	10.3	3.14	10.1
22	Ocean side Rock. Peninsula	Marvin St.	40.59166	-73.7604	17	5.18	VE	8.2	2.50	9.3

Table 4.1: Water conditions during a 1/100 year storm for locations within the considered area for this measure (Data extracted from FEMA Preliminary Work Maps)

Three different things can happen when a storm hits a peninsula like Rockaway Peninsula: *collision*, *overwash* and *inundation*. Figure 4.3 shows the difference between these three events. During *collision* the waves reach the dune construction and the front of the dune erodes. The sand is transported offshore, recovery of the beach will take weeks and recovery of the dune will take years. When the wave and surge levels exceed the dune height *overwash* takes place. Sand from dunes and beach is transported landwards, this makes it impossible for the area to recover itself. In the situation of mean water levels during a storm exceeding the dune height, very extreme coastal changes can occur. The beach system is completely submerged and sediment is expected to be transported landwards. For narrow barrier islands this can result in breaches due to strong currents, this is called *inundation* (Doran et al. (2013) [29]). During Sandy Rockaway Peninsula suffered mostly overwash (AON Benfield (2013) [30]).

Figure 4.3: Examples of post-storm conditions after collision (Nags Head, North Carolina; Isabel, 2003), overwash (Santa Rosa Island, Florida; Ivan, 2004), and inundation (Dauphin Island, Alabama; Katrina, 2005) (Doran et al. (2013))

4.2. GENERAL NOURISHMENT

For this study there has been made a distinction between beach nourishing and constructing dunes. Beach nourishing is treated as "adding large volumes of beach-quality sand, called beach fill, from outside sources to restore an eroding beach. Or, a beach is constructed where only a small beach, or beach, existed" (Shore Protection Assesment (2007) [31]). The goal is to increase the height and width of the berm without having negative impacts on adjacent areas (Waterway et al. (2011) [32]). A typical beach nourishment can bee seen in figure 4.4. The use of nourishment is not only to prevent the beach from eroding, it can also have a function in reducing the inundation risk due to hurricanes and storms. Furthermore, it can provide environmental, recreational and aesthetic benefits (Shore Protection Assesment (2007) [31]).

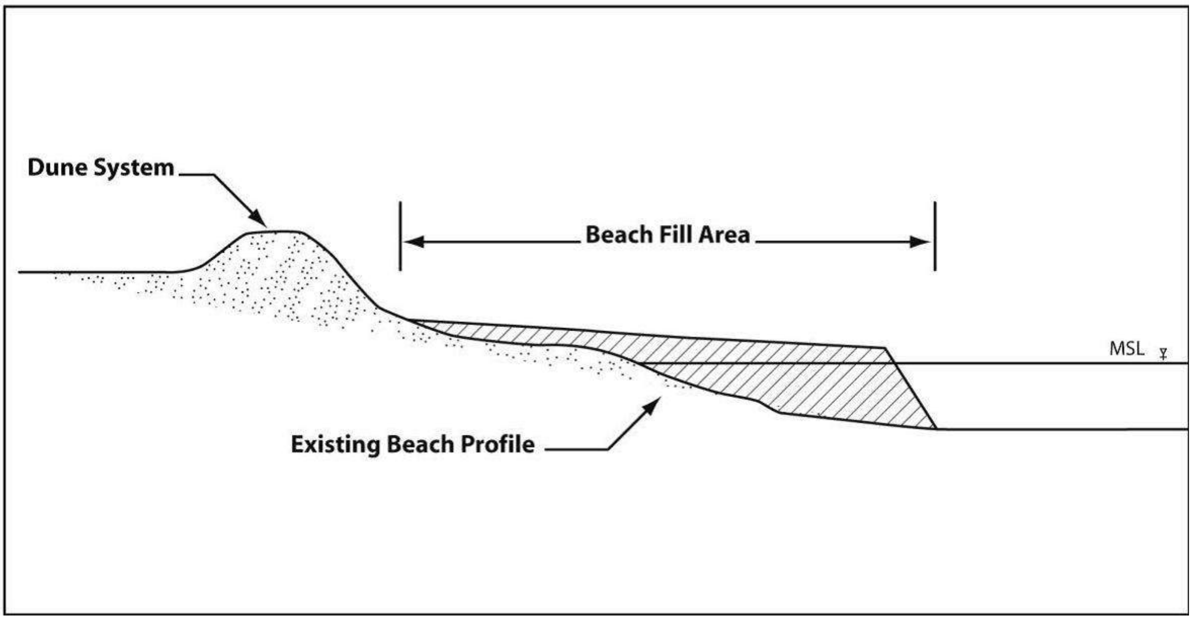


Figure 4.4: Impression of a cross section of a beach with a nourishment (Waterway et al. (2011))

A nourishment usually changes overtime to a more natural condition. When constructed, a nourishment usually has steep slopes, it is expected that modest waves move and spread the sand in the first few months (see figure 4.5). The sand will be moved offshore and alongshore by the wave. Although this results in a reduction of beach width, it is not seen as erosion and may even be seen as indicator that the nourishment worked as designed (Shore Protection Assesment (2007) [31]).

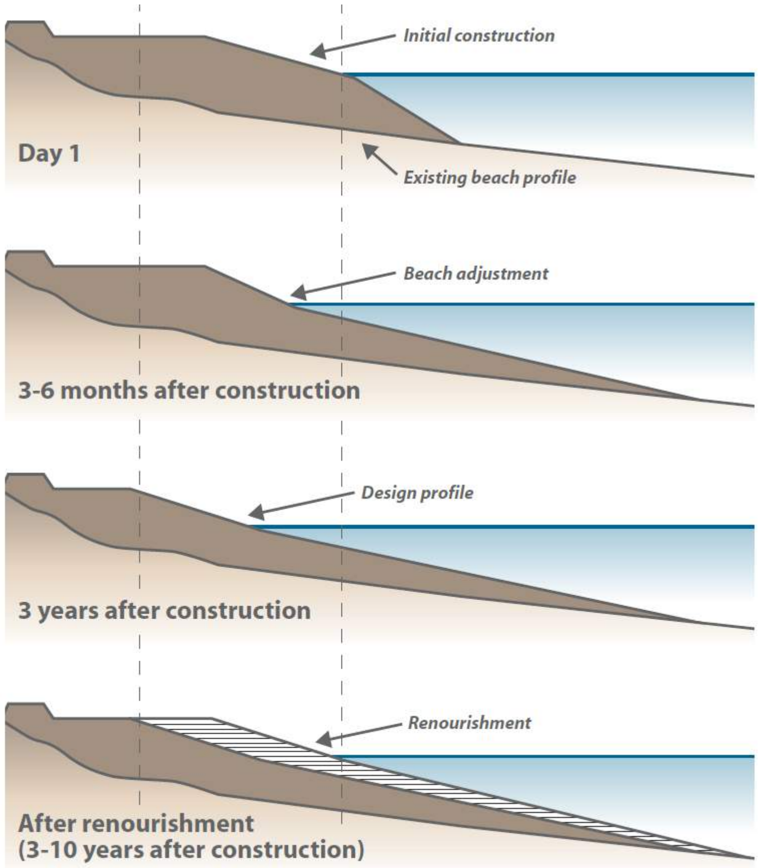


Figure 4.5: Impression of the changes in time for a nourished beach (Shore Protection Assesment (2007))

During a storm or hurricane sand is expected to be transported offshore and because of this, waves tend to break further offshore (because of reduced depth further offshore). With this further offshore breaking, waves lose more energy on their way to the shore, this reduces the wave impact at shore and with that helps protecting assets near shore. A nourished beach with enough volume absorbs part of the storm energy (Shore Protection Assesment (2007) [31]). However, a nourished beach is not able to defend the hinterland from inundation due to storm surges higher than the nourished beach.

GROYNES

In addition to beach nourishment, structures like groynes, can help stabilize the beach and prevent the beach from eroding. A typical disadvantage of groynes is that they directly impact sediment flows and with that have a big influence on the downstream situation. Usually there is erosion due to lack of sediment just behind the last groyne. A groyne like structure stops the longshore sediment transport, this means that accretion will take place at the updrift side of a groyne because of additional sediment. At the downdrift side of a groyne there will be less sediment and erosion will take place. Groynes are only useful if there is enough longshore sediment transport, if there is nog longshore sediment transport the groynes will not capture sand (Bosboom & Stive (2013) [33]). *Note: this information is copied from the literature study.*

4.3. DUNE CREATION

For this study dune creation is seen separately from beach nourishment. Dune creation is the creation of one or multiple dune in a dune system to protect properties behind it from storm surges and wave attack. Figure 4.6 shows the different parts of a beach with a dune next to it. As can be seen a dune is some sort of hill of sand, usually this is built by water or wind. Because a dune has a certain height it can be effective as storm surge barrier during high waters. Dunes usually have some sort of summer- and winter profile. During the summer, the milder waves move sediment onshore creating a wider berm and during the winter the heavier waves transport sand offshore where it settles. This profile change can also occur when a storm period interrupts a calmer period. This can be seen in figure 4.7. Normally a beach returns to its summer profile after the storm (Bosboom & Stive (2013) [33]).

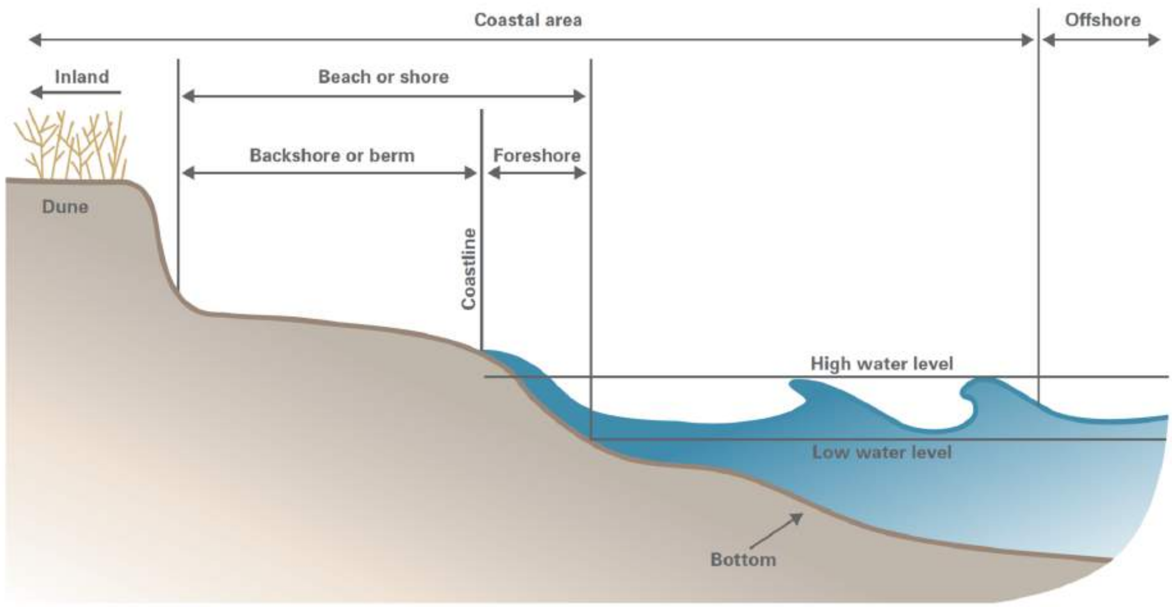


Figure 4.6: Impression of a beach with different parts and functions named (Shore Protection Assesment (2007))

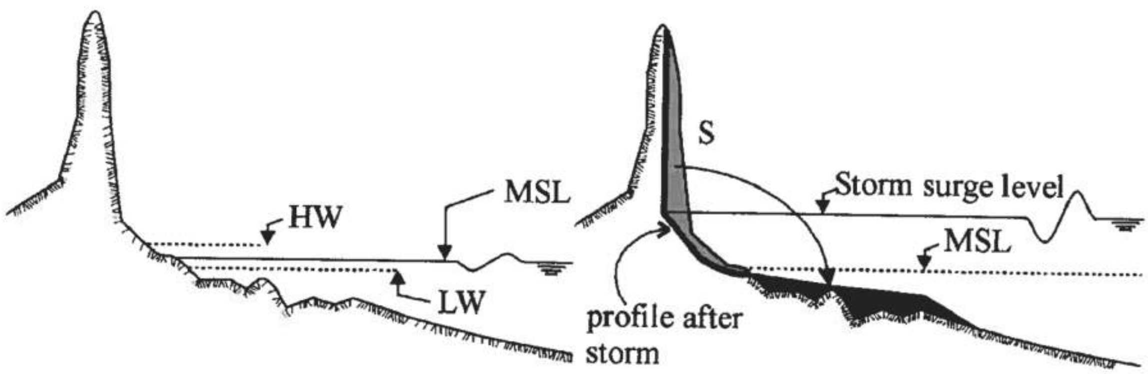


Figure 4.7: Impression of a dune before and after a storm, the summer profile turns into the winter profile due to a storm (Bosboom & Stive (2013))

Dune erosion takes place when waves can reach the dune face, impacting it. This sand is transported offshore by a strong undertow and settles offshore when sediment transport capacity decreases. The new profile fits storm conditions better than the old one because it is far more effective in dissipating energy and with that the dune erosion rate decreases later in the storm. Using Bruun's rule, see equation 4.1, a first-order magnitude estimate of the dune retreat can be made. According to this rule the volume of eroded sediment and the deposited sediment are equal (Bosboom & Stive (2013) [33]).

$$\text{Dune retreat} = SSL\left(\frac{L}{d}\right) \tag{4.1}$$

SSL is the storm surge level above MSL, L is the length of the profile over which erosion and sedimentation takes place (so the distance between the top of the dune and MSL) and (h+d) is the corresponding (closure) depth (see figure 4.8 for an impression). This rule can be used to calculate the expected dune retreat for specific storm conditions, this can by calculated with a rewritten form of Bruun's rule shown in equation 4.2 (Bosboom & Stive (2013) [33]).

$$\text{Retreat} = \frac{L * SSL}{h+d} \tag{4.2}$$

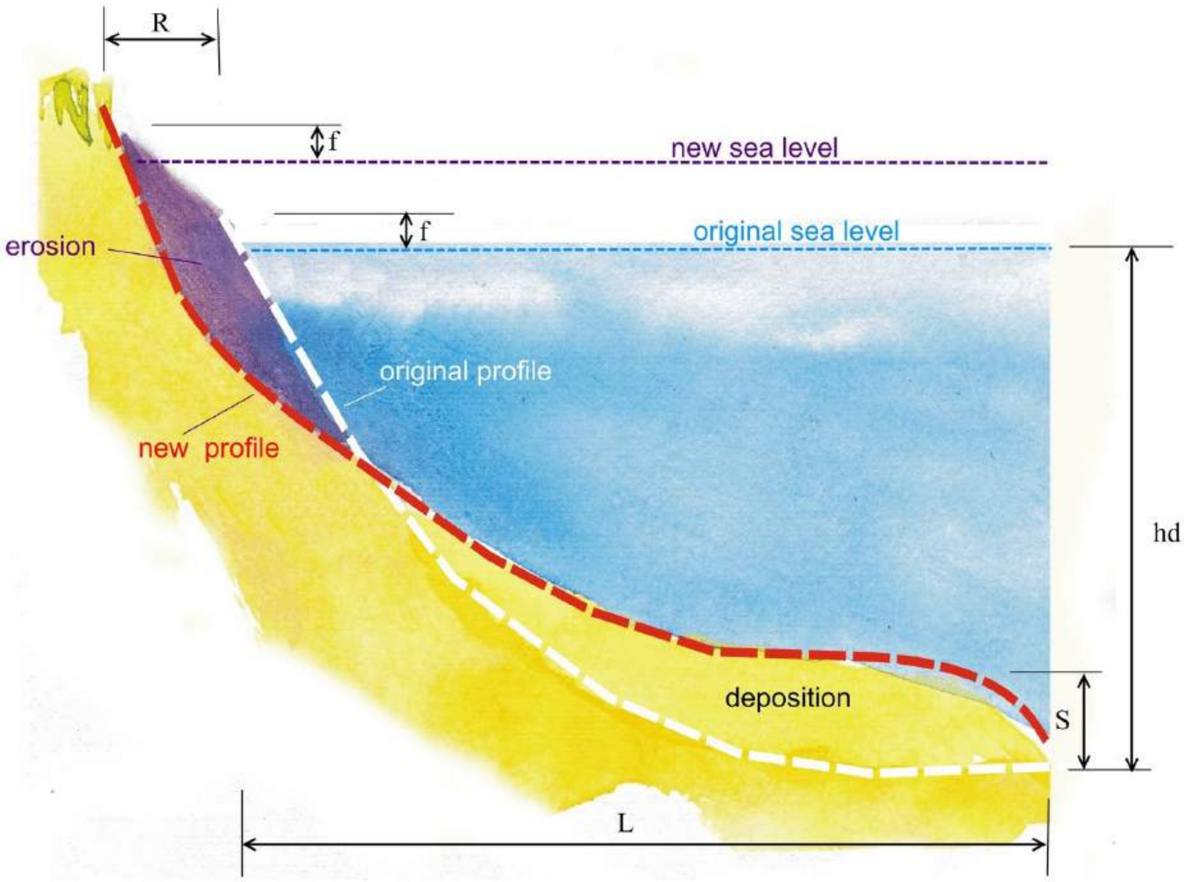


Figure 4.8: Illustration of Bruun's Rule, note: S=SSL and hd=(h+d) in equation 4.2 (Venus Bay Observation Project (2008) [34])

Here $h+d$ is the dune height above MSL. With this, one can calculate the predicted dune retreat and with that design a dune for particular storm conditions. The relationship between dune retreat and dune height for the current situation is given by figure 4.9. For this situation the width of the beach is assumed to be 80 meters everywhere and this whole width will be used to create a dune. The governing SSL is 5.18 m (see table 4.1). At the end of the dune retreat the dune should be as high as the SSL to prevent the hinterland from flooding. This means that for x (see figure 4.10) should hold: $x \geq 0$ to be safe. It can be calculated that a dune with a height of about 7.8 meters would just be enough. Off course a dune height below SSL makes no sense.

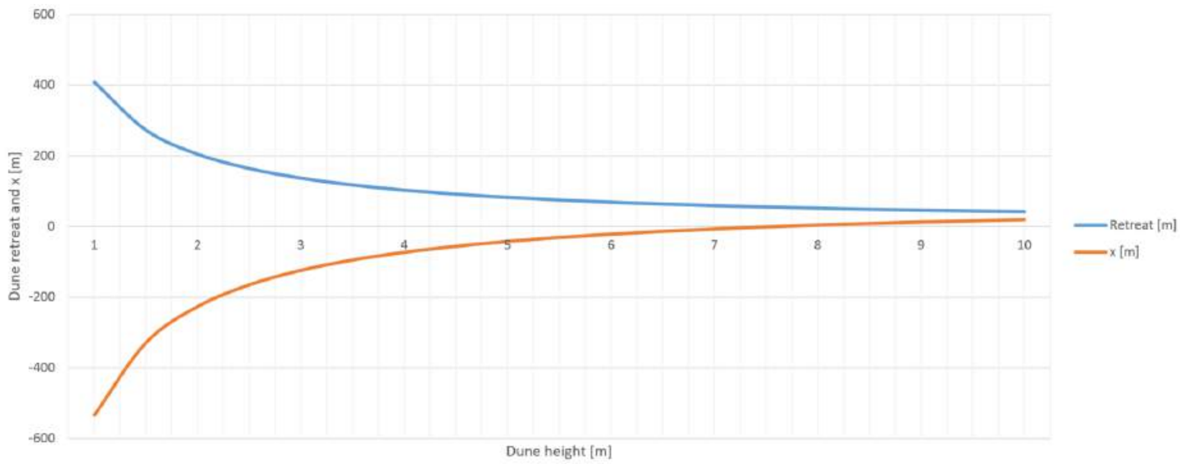


Figure 4.9: Relation between dune retreat and dune height (blue) and x and dune height (orange) for current situation

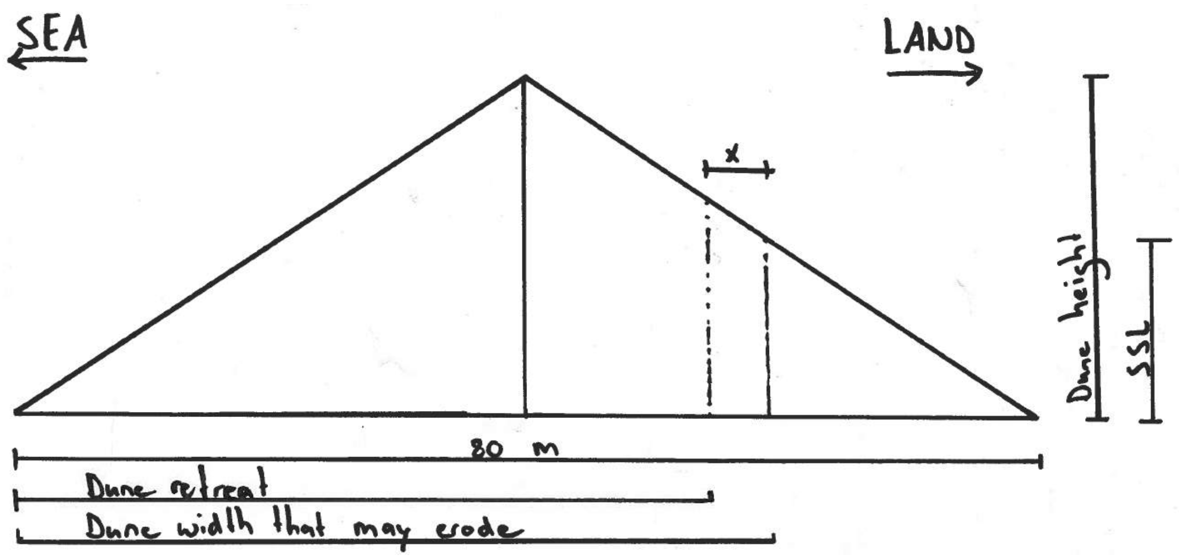


Figure 4.10: Explanation for the meaning of "x" for a dune creation

It must be noted that the above dune structure is under the assumption of a dynamic equilibrium of the shoreline. The profile adapts itself to the hydraulic conditions, a distinction can be made between erosion in winter and accretion in summer, or erosion in high energetic events like a hurricane and accretion in calmer periods when wind and waves carry sand upwards to restore a steeper profile. This equilibrium only holds when solely lateral sediment transport is accounted for. When there is a high amount of longitudinal sediment transport is to be expected (alongshore current), the profile can change overtime. In such a case the following combination of measures can be a solution.

4.4. NOURISHMENT AND DUNE CREATION COMBINATION

The third possibility is to combine nourishment with dune creation. With this the dune height may be decreased and a wider beach may exist. For this calculation the same equation (4.2) is used. The dune width is held on 80 meters and there is only variation in the amount of nourishment (see figure 4.11).

The dune retreat (figure 4.12) and x (figure 4.13) are both plot for different nourishment distances. It can be seen from figure 4.12 that with increasing the nourishment, the dune retreat also increases. However, for, for instance, the 10 meter high dune, an increase of nourishment length of 20 meter leads to an extra dune retreat of about 10 meter. It can be calculated for every dune height what the gain is per meter nourishment, for a 10 meter dune this is 0.5 meter per extra meter nourishment. From figure 4.13 can be seen that the more

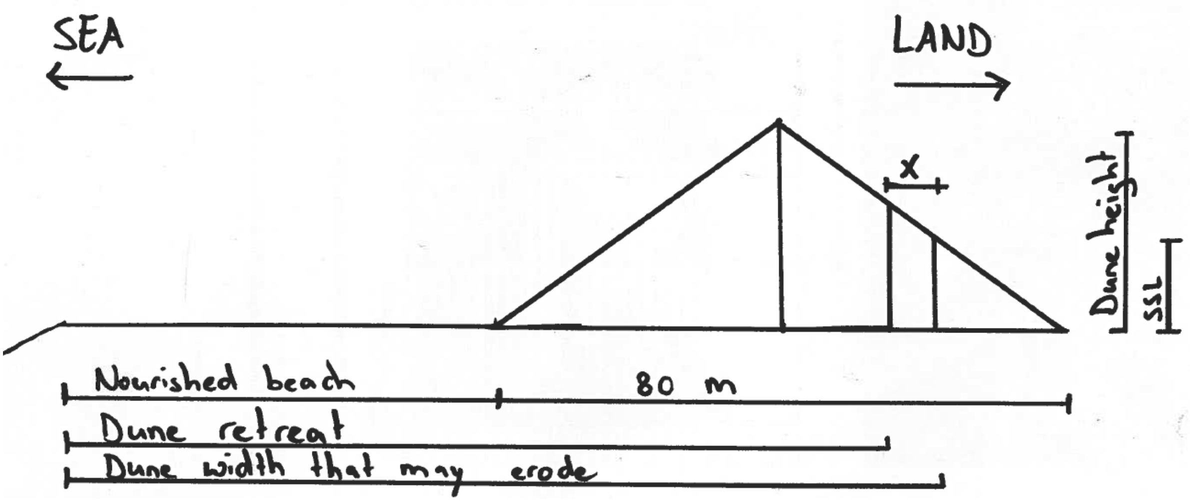


Figure 4.11: Explanation for the meaning of "x" for a combination of dune creation and nourishment

nourishment is being done, the less dune height is needed. For 100 meter nourishment a dune height of approximately 6.25 meter is needed. This is a reduction of about 1.5 meter with regard to the no nourishment situation. So, it can be concluded from this very simple first calculation that a nourishment combined with a dune can decrease the required dune height. This nourishment can also be combined with groynes (see section 4.2).

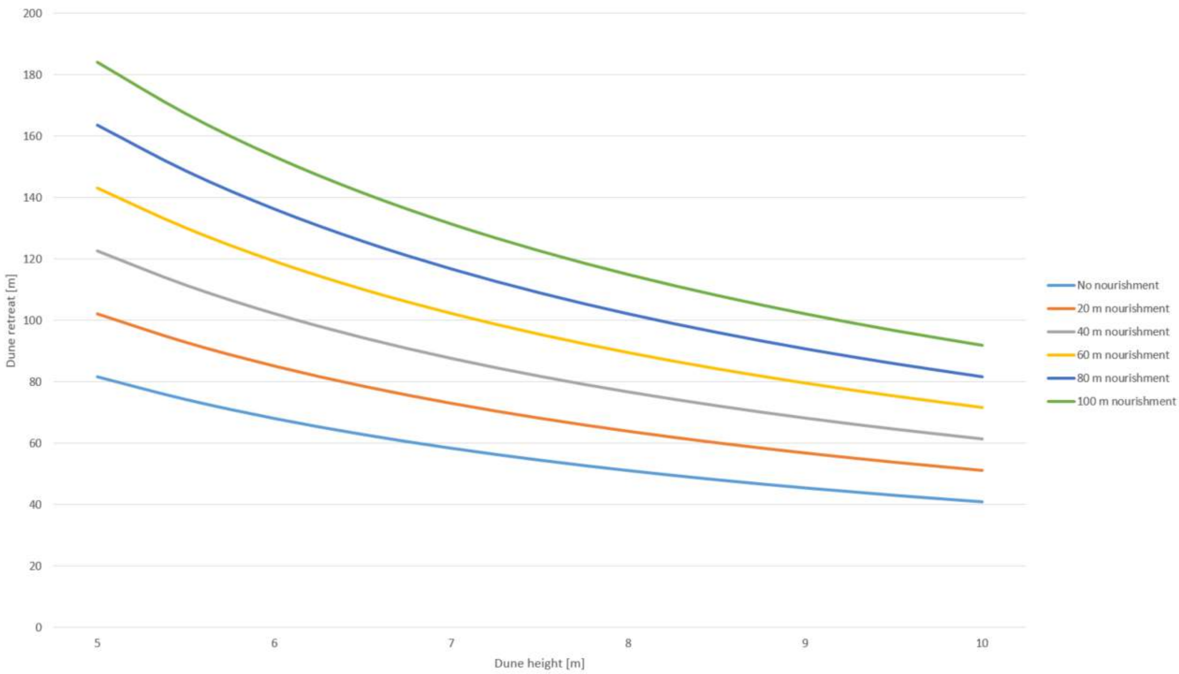


Figure 4.12: Relation between dune retreat and dune height for different nourishment situations

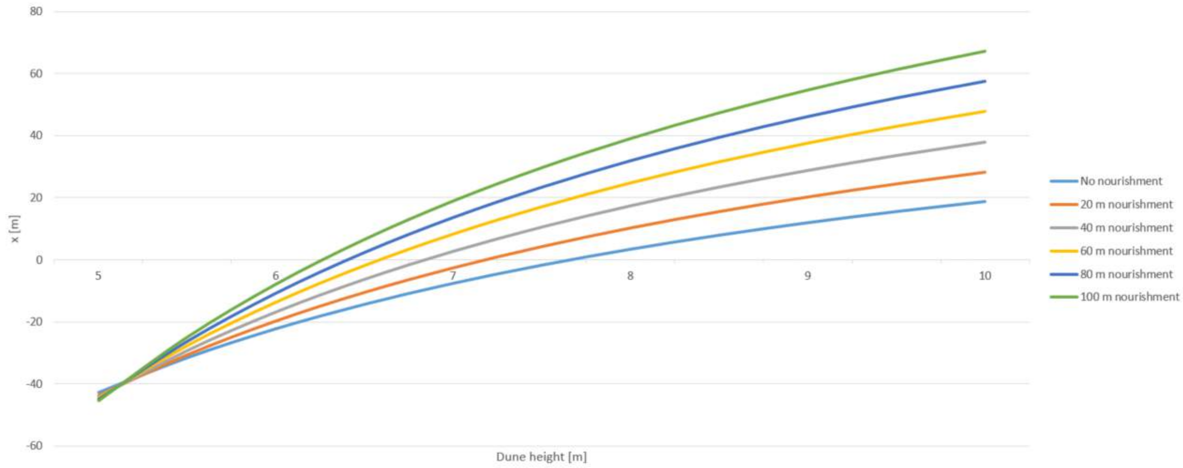


Figure 4.13: Relation between x and dune height for different nourishment situations

4.5. HARDENED CORE STRUCTURES

To secure stability and safety, structures with a hardened core should be considered. These structures are fixed in a way that they can be relied on if designed addicately. Hardened core like structures generally take less amount of space then soft like measures, dunes for example. Therefore they do not require landward activities in many cases. Hard measures are rarely favored in an ecologic and aesthetic point of view. However, current developments have tried to combine the features from hard and soft measures, trying to exploit the advantages they have and providing opportunists for other activities. Two systems are elaborated below, which fit well in our area of interest.

4.5.1. DIKE IN DUNE

The first option is to use a dike in dune construction like the one built in Noordwijk in the Netherlands. This means that a dike will be constructed and after that be covered by sand and vegetation to maintain the look of dunes (see figure 4.14). An advantage of this measure is that dune retreat during storms stops when it hits the dike inside the dune. This means that the dune can be less wide and the dike can be less high.

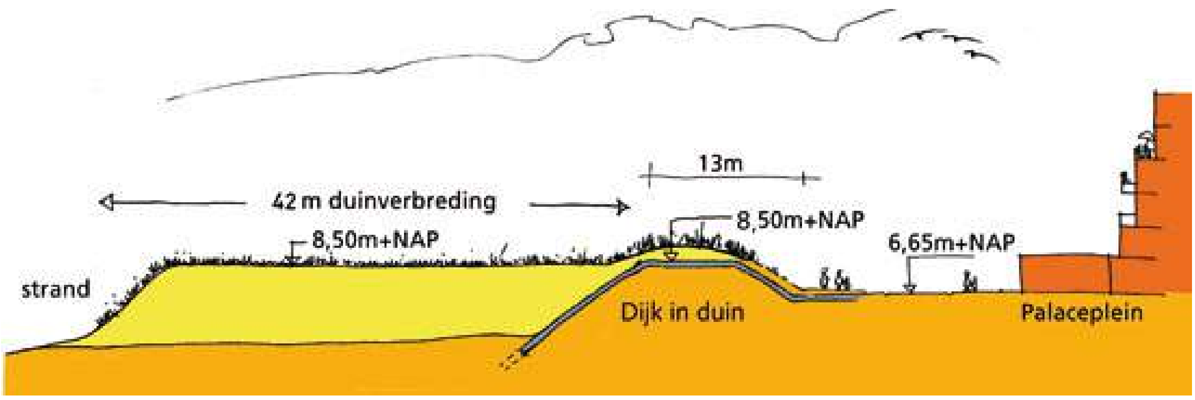


Figure 4.14: Impression of a section of a dike in dune construction (CAD Magazine (2008) [35])

One could approach this design as two separate systems combined. First you have the sand dune in front of the dike which is subject to erosion. A hurricane type event will introduce erosion for about 24 hours. In this period, the sand will be redistributed, resulting in a different cross-shore profile (see Bruune Rule, equation 4.1). During high surge levels the initial dune is transformed into a protective berm. Because the berm reduces the water depth when approaching the shore, wave height is reduced subsequently. As can be seen from the shallow water equation expressed by Miche (1944), equation 4.3. Where γ is the breaker index, H_b is the breaking wave height and h_b is the water depth at the breaking point. The sand in front of the dike, will provide a wide berm which has a great beneficial effect on wave height reduction.

$$\gamma = \left[\frac{H}{h}\right]_{max} = \frac{H_b}{h_b} \approx 0.88 \tag{4.3}$$

The sand in front of the dike, will provide a wide berm, this profile is the input for the second system, the dike behind it. The dike system has to be able to withstand the storm for a relatively short amount of time. In the dike-in-dune solution, the wave height is reduced, and a smaller crest level can suffice. So the biggest advantage is that you would need less dunes width and less dike height. To show this, the situations with just a dike or just a dune will be compared to the dike in dune situation.

ONLY A DUNE WITHOUT A DIKE

This solution has been elaborated on in section 4.3.

ONLY A DIKE

The crest level of a dike is estimated as the summation of the design high water level + wind induced surge level + wave height + predicted subsidence (+ a preferred freeboard), see figure 4.15. Also climate change has to be taken into account to ensure a sufficient crest level in the future.

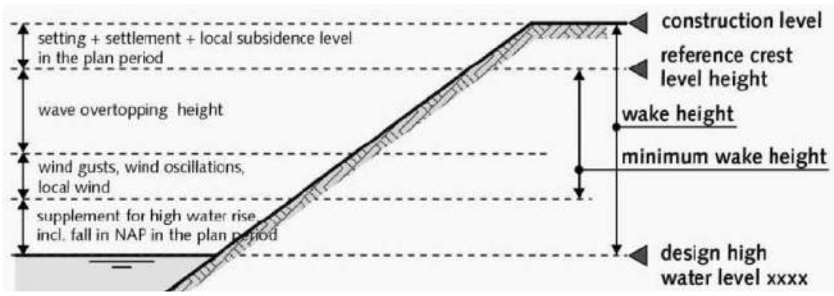


Figure 4.15: Crest height approximation (Weijers & Tonneijck (2009)) [36])

From all the monotoring points, three stand out with the highest values concerning elevation and wave height, namely the tip of Breezy Point, Beach 142th Street and Beach 90th Street. On these three levels a crest height will be elaborated. The design water level and wave height follow from table 4.1.There an elevation of 5.31 [m]. This value needs to be converted to NAVD88, therefore, 5.31 + 0.07 NAVD88 = 5.38 [m] NAVD88. On top of this value you will get a certain wave height, $H_s = \frac{3.11+3.17+3.14}{3} = 3.14[m]$. Now we have to take wave run-up into account. We can use the old delft formula for a first estimation. For this example a slope of the dike is considered of $\frac{1}{4}$.

$$H_{2\%} = 8 \cdot H_s \cdot \tan\alpha = 8 \cdot 3.14 \cdot 0.25 = 6.42[m] \tag{4.4}$$

We could also approach this issue using the CUR-TAW calculation method. This method also incorporates the wave period T_p, the roughness γ_f, berm influence γ_b and angle of incidence γ_β. The wave period follows from table 4.1. In this example we will be using gabions as revetment. No berm is present. Waves approach the shore usually from the Northeast, however in case of a super storm, the wind can force the wind in the most unfavorable angle. Therefore perpendicular waves are chosen.

$$T_{m-1.0} = 0.9 \cdot T_p = 0.9 \cdot 9.23 = 8.31[s] \tag{4.5}$$

$$\xi = \frac{\tan\alpha}{\sqrt{H/L}} = \frac{0.25}{\sqrt{3.14/(1.56 \cdot 8.31^2)}} = 1.46 \tag{4.6}$$

$$R_{2\%} = 1.74\gamma_b\gamma_f\gamma_\beta\xi H_{m0} = 1.75 \cdot 0.70 \cdot 1.46 \cdot 3.14 = 5.62[m] \tag{4.7}$$

This more comprehensive estimation for wave run-up from CUR-TAW saves us about 80 [cm] compared to the Old Delft Formula. However, it does show that the fairly simple Old Delft Formula gives a good estimation in a preliminary stage of a design.
To make good estimation for expected settlement in the next 50 years, a soil research has to be done to determine which layers of soil are present in the subsoil. For now, an additional 20[cm] will be taken into account. Lastly, sea lever rise (SLR) is expected to by 55 [cm], see section 3.2.3. This gives a total crest height of;

$$\text{Total crest height} = 5.38 + 3.14 + 5.62 + 0.20 + 0.55 = 14.89[m]NAVD88 \tag{4.8}$$

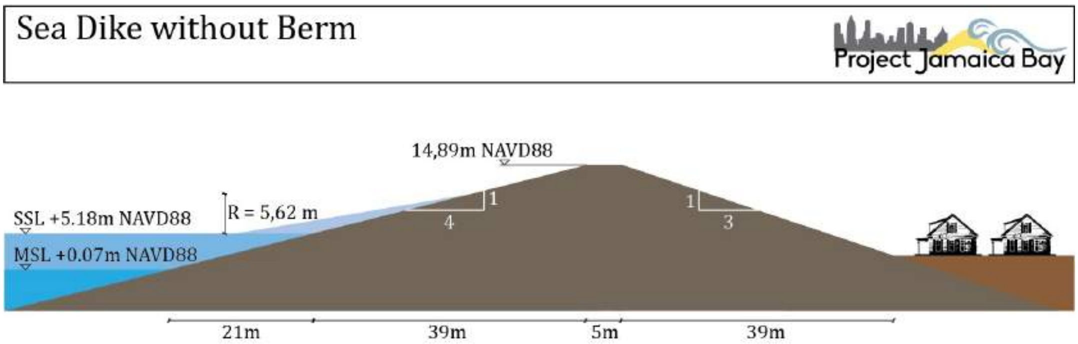


Figure 4.16: Sea dike without berm

Please do realize, that this crest height of 14.89 [m] is for a dike without a berm. This is hardly a commonly used design since lot of reduction in height can be won in the berm area. Therefore that will be elaborated in the next example, combining the dike and the dune system. In a further stage of the design, special care has to be takin into account to design the dike in such a way that is not subject to any of the failure modes described by Weijers & Tonneijck (2009) [36], see figure 4.17.

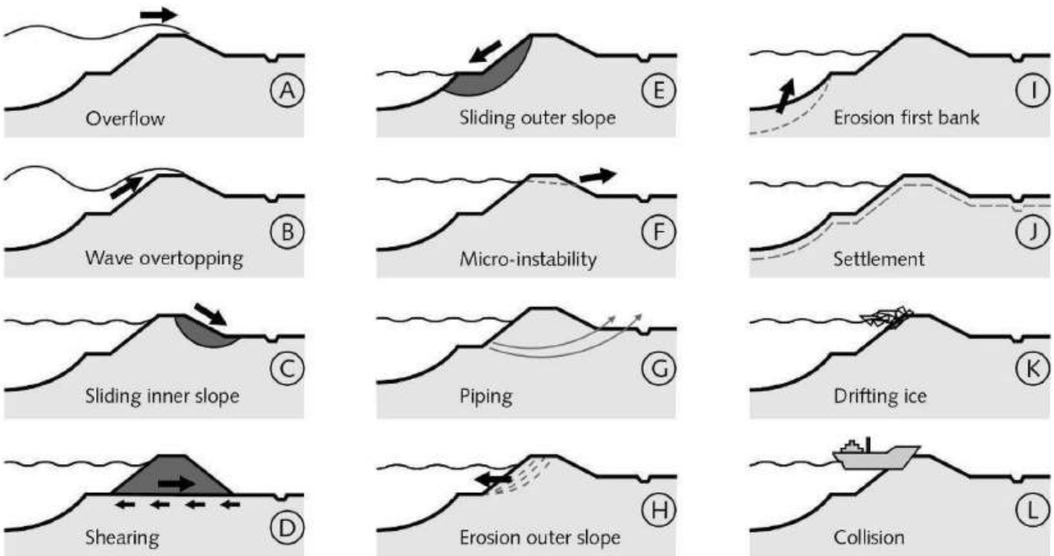


Figure 4.17: Failure modes defined by Weijers & Tonneijck (2009) [36]

DIKE IN DUNE

In this case, we assume the dune profile will be redistributed as a berm during a super storm. The deposited sand will result in a large berm in front of the dike of approximately 1000 [m] in this example. An simplification in the redistributed profile is made in such a way we can make a calculation using the CUR-TAW calculation method. Now we can introduce the factor γ_b for berm influence for the run-up equation 4.10. See figure 4.18 for

$$\begin{aligned}
\gamma_b &= 1 - \frac{B_b}{L_b}\left[0.5 + 0.5\cos\pi\frac{h_a}{2H_s}\right] \\
\gamma_b &= 1 - \frac{1000}{1200}\left[0.5 + 0.5\cos\pi\frac{1}{6.28}\right] \\
\gamma_b &= 0.17
\end{aligned} \tag{4.9}$$

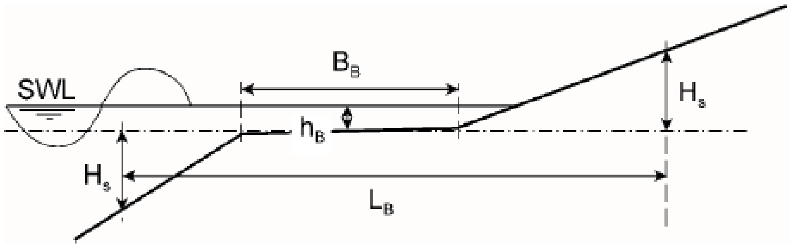


Figure 4.18: Berm definitions [25]

$$R_{2\%} = 1.74\gamma_b\gamma_f\gamma_\beta\xi H_{m0} = 1.75 \cdot 0.17 \cdot 0.70 \cdot 1.46 \cdot 3.14 = 0.96[m] \tag{4.10}$$

Also, the berm introduces a limitation for the wave height in a way described by Miche (1944), see equation 4.3. With $h_a = 1[m]$ being our water depth above the berm, the new wave height will be;

$$H_b = 0.88h_b = 0.88h_a = 0.88 \cdot 1 = 0.88[m] \tag{4.11}$$

Therefore the total crest height can be reduced. In figure 4.19 a visual impression can be found.

$$\text{total crest height} = 5.38 + 0.88 + 0.96 + 0.20 + 0.55 = 7.97[m]NAVD88 \tag{4.12}$$

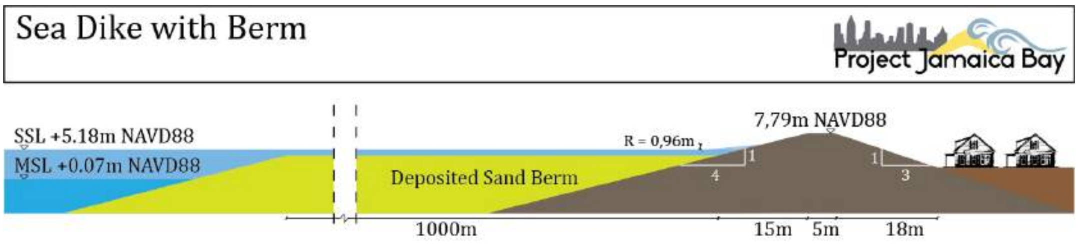


Figure 4.19: Dike in dune during storm surge, the dune has been transformed to a berm in front of the dike

What can be concluded is that a berm in front of a structure can reduce the impact of waves significantly. If this option is to be considered in a later stage, the method used above has to be checked throughly, since this is a rough estimation as mentioned before.

4.5.2. GEOTEXTILE TUBE CORE

Another option can be a construction with a core made out of a geotextile tube. Sand is relatively less expensive then stone, and recent projects have shown that these measures can cope with storm like conditions if maintained properly. A large tube made out of geotextile is filled with sand. This tube on its own is more stable and not vulnerable to erosion. The tube is buried under a sand dune, see figure 4.20. When a storm occurs, sand of the dune can erode, however the sand enclosed by the tube can not, and can therefore offer protections against high surge levels. Preventing further erosion and damage of the hinterland. After the storm, the tube should be covered again, such that it cannot be damaged by other external loads.
As an example, a first indication of feasibility is given. For this indication the design rules have been followed from Bezuijen & Vastenburg (2013)[38]. The structure will consist three tubes. One on top of the other two. The geotextile tube material is made of woven polypropylene/ The maximum tensile strength of the geotextile is 200 kN/m. The task is to test the stability of the structure.

The needed crest height follows from table 4.1, this is surge level + wave amplitude = 5.18 $[m]$ + $\frac{3.11}{2}$ $[m]$ = 6.74 $[m]$. As a rule of thumb, for a first estimation the base of the tube has to be 2 times the height of the tube. Therefore, the needed height of about 3.50 meters gives a width of 7.00 meters. Now the circumference is estimated using the Ramanjan formula ('a' being half the major axis, and 'b' being half the minor axis). For the lower tube elements theoretical maximum radius can be determined from the this circumference:

$$S = \pi\left[3(a+b) - \sqrt{(3a+b)(a+3b)}\right] = 16.95m \tag{4.13}$$

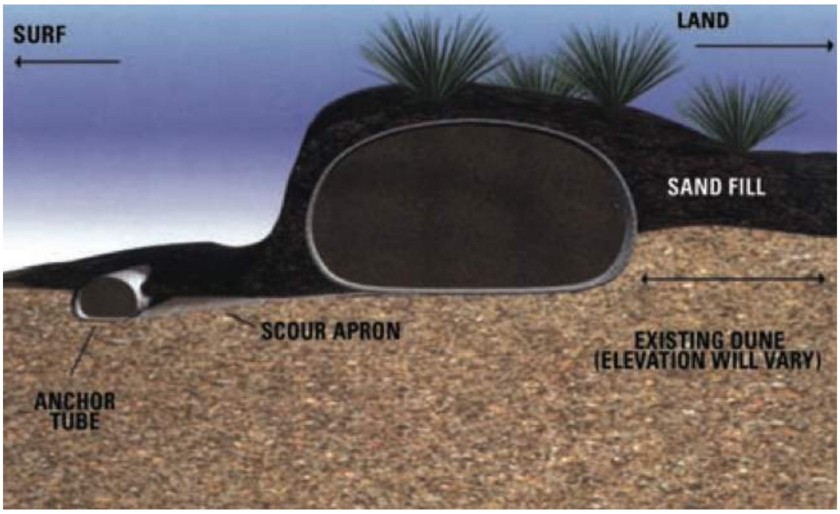


Figure 4.20: Geotube® sand dune cross section. (Tencate (2012)) [37])

$$R = \frac{S}{2\pi} = 2.70m \tag{4.14}$$

A degree of filling 80% is chosen for this example. In practice the theoretical filling of 100% is never met. Extreme degree of fillings could potential harm the geotextile, and harm the integrity of the structure. A reasonable filling is between 70% and 80%. From the theoretical maxium radius, the dimensions of the tube can be determined, following from Bezuijen & Vastenburg (2013) Appendix D [38]. For a more exact dimensions the Timonshenko method can be applied, however, for now this simple approximation suffices.

$$\begin{aligned} r_{80\%} &= 0.43R = 1.16m \\ b_{80\%} &= 2.56R = 6.91m \\ h_{80\%} &= 1.17R = 3.16m \end{aligned} \tag{4.15}$$

The required tensile strength has to be checked. Tensile strength of material chosen is 200 kN/m. Tensile force needed is taken from the graph shown in figure 4.21 which has been acquired using numerical modeling based on the Timoshenko method, which needs to be extrapolated to some extent. From figure 4.21 it follows that the needed strength is about 47 kN/m. Due to strength reduction material factors the required tensile strength will be raised by a factor of 3.5 to arrive at a design strength. Therefore, the required tensile strength is;

$$\begin{aligned} \text{Design strength} &= \gamma \cdot 47 = 3.5 \cdot 47 = 164.5kN/m \\ \text{Safety factor} &= \frac{200}{164.5} = 1.22 \end{aligned} \tag{4.16}$$

The following check is for the ensure the stability in waves. It has been noted that, based on the available results of research into the stability of geotextile tubes under wave loading it can be concluded that the critical wave height is about the same as the theoretical diameter of the geotextile tube [38]. This applies to those geotextile tubes most exposed. If the waves are perpendicular to the tube, then $D_k = b$. Also, Δ_t is the relative density of the geotextile tube. The following formula applies to the element on top;

$$\begin{aligned} \frac{H_s}{\Delta_t \cdot D_k} &\leq 1.0 \\ 0.459 &\leq 1.0 \end{aligned} \tag{4.17}$$

The design complies with the required tensile strength and stability under wave attack. This is the preliminary stability check provided by Bezuijen & Vastenburg (2013) [38]. An visual impression can be seen in figure 4.22.

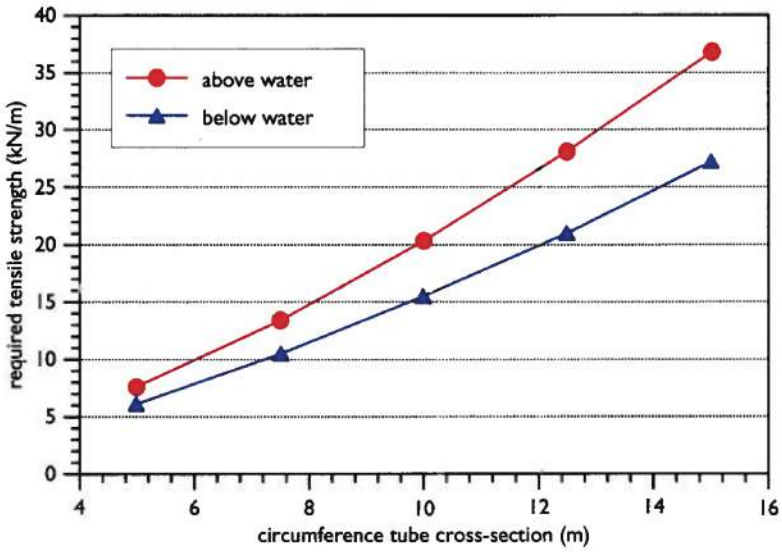


Figure 4.21: Theoretical required tensile strength of geotextile as a function of the circumference of the geotextile tube [38]

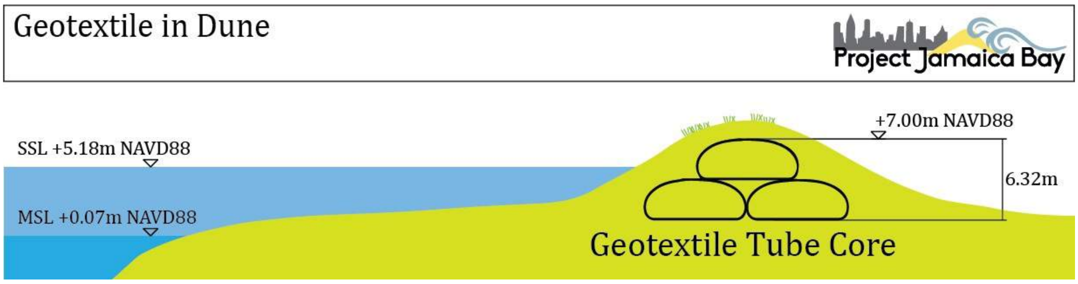


Figure 4.22: Preliminary geotextile tube core for dune design

4.6. EVALUATION

As has been said in section 4.1, only nourishment-like measures have been considered. In the previous sections measures with and without a hardened core have been discussed and estimates of possible designs have been given. It is striven for to use measures that help solve the erosion issues and mitigate flood risks during a 1/100 year storm.

Because the designed measure should be able to prevent the hinterland from inundations during a 1/100 year storm, just beach nourishing is not a good solution. A nourished beach can help reducing the wave height by creating a berm. However, it is unable to protect the hinterland from high water level, for example because of storm surges. This means that the solution with just beach nourishment will not be advised.

It can be concluded that, in order to mitigate flood risks due to a 1/100 year storm, a designed measure should be high enough to prevent the storm surge from reaching the properties and infrastructure. The discussed possibilities are:

1. Dune creation
2. Dune creation combined with beach nourishment
3. Dike in dune
4. Geotextile in dune

All four of these strategies are able to prevent the water from inundating Rockaway Peninsula and they show that a height of 6 to 8 m is minimally required to do so. They also show that it is possible to combine aesthetics, ecology and safety in one measure. For all four measures it has been calculated (using short calculations) that they are able to protect properties behind it during 1/100 year storms, but they look like they could be formed naturally. In this way people living next to the beach can still have their natural view.

The associated costs are probably one of the most important aspects in determining which measure will be built. Costs are not taken into account in this study. This means that, in order to make a justified decision, the costs of the strategies should also be taken into account during further studies. //

5

Improved Banks

This chapter elaborates on the northern/bay side of the Rockaways. The area is highlighted in black on figure 2.25. In general the possible measures are discussed, followed by explanations of those different measures based on the boundary conditions.

5.1. Area Analysis

5.1.1. Introduction

This area spans from Marine Parkway Bridge to Rockaway Community Park, then followed by the banks to Barbados Basin. This area faces some spatial fitting issues. One of these issues is the limited available amount of space where a measure can be situated. Aside from the Beach Channel Drive which is built near the banks of the Peninsula, one has to integrate the rapidly increasing water depth perpendicular to the banks, partly a result of dredges navigation channels. The navigation channel "Beach Channel", illustrated in figure 2.14, does not allow for a lot of landfill extension into the bay. A solution should be incorporate the navigational demand in both on land and water means. Furthermore, the Beach Channel Drive is far from attractive, and could even be considered for pedestrians or cyclists because of the speeding of cars and the narrow roads. However, this area calls for improvement. This section provides an introduction into the range of factors that could be considered when building a more coastal resilient Rockaways.

5.1.2. Current situation

The following coastal descriptions represent a range of the different land use conditions and coastal measures which are current present at the northern part of the Peninsula.

Marine Parkway Bridge

Like stated in the introduction, this area starts at the Marine Parkway Bridge. The banks adjacent to the bridge are strengthened with a riprap revetment. There is an huge elevation difference between the eastern side of the bridge and the western side. In the adjacent eastern part there is a riprap revetment present situated on a levee structure, on the eastern part the function of the riprap structure is limited to reduce the erosion and does not contribute to retain high storm surges. This significant difference is shown in figure 5.1.

Beach Channel Drive

If the Beach Channel Drive is followed to the East, the banks adjacent to this road are protected by hard structures. The banks near Beach 149th street are bulkheaded, see figure 5.2. The two different parts are also shown in figure 5.3

Like shown in the next figure (5.4), besides the road there is enough space available to build an hydraulic structure to protect the hinterland.

Beach 123rd and 116th Street

Further down Beach Channel Drive, heading East and between Beach 123rd and 116th street, the banks are still bulkheaded. Besides this bulkheading, there is also constructed an additional concrete flood wall, see figure 5.5. However, there is much less space available to build new hydraulic structures (see figure 5.6).

Figure 5.1: Elevation difference between the eastern and western part of the bridge; on the other site of the cycling lane the elevation is much higher

BEACH 108TH STREET

If again the Beach Channel Drive is followed to the East, at Beach 108th Street, the banks are protected by using sheetpiles. These sheetpiles prevents erosion and stabilizes the ground. In figure 5.7 it can be seen that

Figure 5.2: Bulkheads near Beach 149th street and a view of the Marine Parkway Bridge afar

Figure 5.3: Left: western part of the Marine Parkway Bridge; Right: eastern part adjacent to the bridge

Figure 5.4: Available space besides Beach Channel Drive near Beach 149th Street and the Marine Parkway Bridge

the distance between the road and the water is also limited, furthermore the sheetpile construction is shown. Next to the Cross Bay Bridge the sheetpiled banks changes again into a bulkhead structure, protected with a stone revetment (figure 5.8).

Figure 5.5: Bulkheading and height impression flood wall

Figure 5.6: Limited space besides Beach Channel Drive near Beach 123rd and 116th street

Figure 5.7: Sheetpiled bank and available space adjacent to Beach Channel Drive

Figure 5.8: Bulkhead construction next to the Cross Bay Bridge

5.2. IDENTIFYING BARRIER STRATEGIES

This part will elaborate on possible flood reduction measures for this area. The coastal strategies can be site-specific or can be employed at a neighborhood or regional scale. During this project local/individual measures are not considered therefore only regional measures will be elaborated. The regional or reach strategies are coastal measures that require either the geographic space or the resources of multiple neighborhoods. The tools influences many sites and require cooperation between the different jurisdictions. Furthermore also combinations of the following measures could be an eligible flood risk reduction strategy.

LEVEES

One of the flood reduction measures could be constructing a levee adjacent to the Jamaica Bay banks. Two impressions are shown in figure 5.9. In dense waterfront cities, traditional levees can impose unwanted negative consequences for urban life by cutting off public access and disturbing views [39]. Mitigating these consequences could be done by raising Beach Channel Drive and obtain a multi-purpose levee. If the new Beach Channel Drive will be built on the levee, the water retaining function is combined with a transporta-

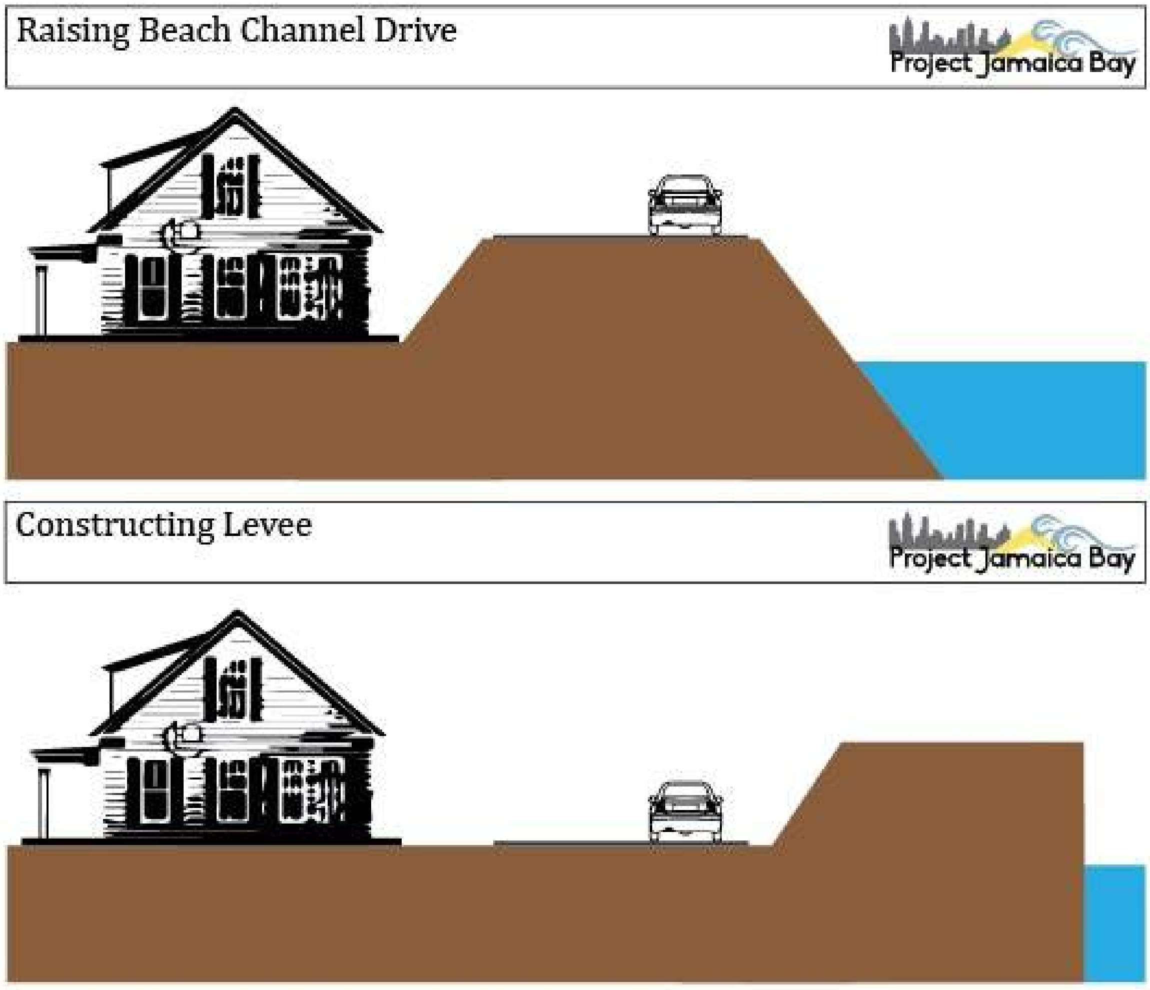


Figure 5.9: Levee impressions

tion function. Multi-purpose levees can become more attractive by combining those other uses with flood protection.
While designing such a levee, different stability and failure mechanisms have to be considered. These mechanisms are briefly discussed in the following text. The different stability mechanisms are:

- Macro Stability of slopes: The stability of an entire slope is usually referred to macro-stability. This stability analysis is usually approached with at slip-circle analysis, for which the Bishop-method is widely used. The load and the strength of the construction have to be considered. The load is the weight of the soil mass within the circle and the strength the shear along the circle, hence Schiereck (2012) [40]. If the strength divided by the load is larger than 1, the slope is stable. The method is illustrated in figure 5.10. If one defines F as the load-strength ratio:

$$F = \frac{\Sigma[(c + \sigma'_n)/\cos(\alpha)]}{\Sigma \rho_s g h \sin(\alpha)} \tag{5.1}$$

- Stability of the applied revetment: The stability analysis depends on the applied revetment and the wave load. Several stable protections against waves are possible. In Schiereck's book [40] they are divided into three categories, i.e. loose grains, coherent and an impervious revetment. The different calculations are based on the load transfer between the external and the internal load. When considering a loose grain revetment (e.g. riprap) the stability of loose material under waves have to be considered. A good formula to determine the stone size for these kind of revetments, is the Van Der Meer formula. The other two groups are not as open and permeable as the loose grain revetment. These layers have to withstand occuring water pressures. Due to the head difference between the phreatic level in the levee and the water level outside, the top layer can fail because of the uplifting (resulting) force. This excess pressure needs to be compensated by constructing a heavier layer, a more permeable layer or increasing the friction between the revetment and the subsoil.

- Toe stability: Toes are a special kind of transition within the revetment construction [40], i.e. from a slope to a horizontal plane. The slope of the levee causes a horizontal force at the toe. In soft soil this toe needs extra protection.

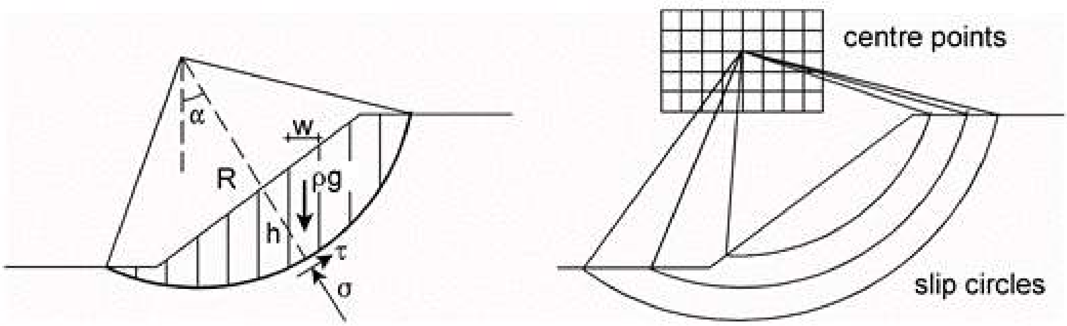


Figure 5.10: Slip circle approach of marcro-stability (Schiereck)

To determine the minimum space which is necessary to raise the Beach Channel Drive, the following calculation is made. The design life of the dike is 50 years. The current sea level projection 3.2.3 is 65 cm. The different design water levels are stated in chapter 3.2.3. The water level in point 11 is governing for this area. The design water level and the wave height in this point are respectively +4.27m NAVD88 (North American Vertical Datum 88) and 0.76m. The wave run-up can be calculated with the "New Delft" run-up formula. Run-up is defined as the maximum water level on a slope during a wave period, hence Schiereck (2012) [40]. The calculation is illustrated in figure 5.11.

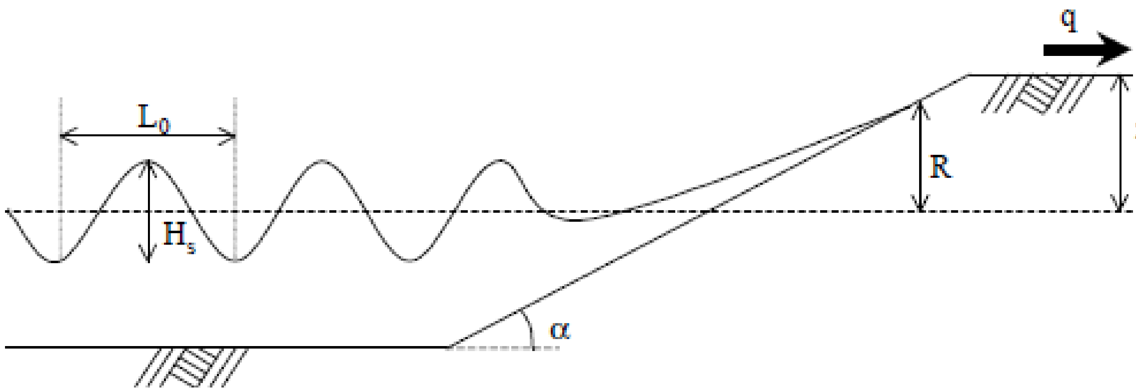


Figure 5.11: Wave run-up (Vrijling et al. (2011))

$$R_v = 8H\tan(\alpha) = 8 \cdot 0.76 \cdot \frac{1}{3} = 2m \tag{5.2}$$

The calculation results are:
The design crest level can be found from: design crest level = design water level + sea level rise + wave height + wave run-up = 7.68m The banks of this side are situated at approximately +1.85m NAVD88 2.8. Therefore the levee height can be reduced to 7.68-1.85 = 5.83 m If a general slope of 1:3 is applied and a crest width of 20 meter (the width of the current Beach Channel Drive is approximately 16m), the total width of the levee becomes:

$$W_{levee} = (2 \cdot 3 \cdot 5.83) + 20 = 55m \tag{5.3}$$

Design water level	+4.27m NAVD88
Sea level rise	0.65m
Wave height	0.76m
Wave run-up	2.0m

Table 5.1: Levels

This also includes an additional 4 meter for bicycle and pedestrian paths.

FLOOD WALLS

Already the majority of the current protection varies from concrete bulkheads to steel sheet piles, like stated in the area analysis. Sometimes these measures are strengthened with additional protective infrastructure, such as flood walls. These walls are massive stone or concrete structures built parallel to the shoreline to withstand the forces of heavy waves and prevent flooding from the hinterland. Raising of these flood walls could be one of the solution. However, raising of the current walls could have negative consequences for urban life by for example cutting of views to the waterfront. To make such constructions more attractive, they can be integrated with other urban uses, such as waterfront parks, transportation network and other development. An example of such an integration is Hudson River Park, Manhattan (see figure 5.12). Hudson

Figure 5.12: Hudson River Park Greenwich Village

River Park is a waterside park on the Hudson River that stretches from 59th Street south to Battery Park in NYC. Bicycle and pedestrian paths span the park north to south, opening the waterfront for recreational uses. Recreational facilities of many kinds are located throughout the Hudson River Park, i.e. tennis and soccer fields, children's playground, dog run, recreational piers and many other facilities.
The current flood wall is about 1.30m high, see figure 5.5. Based on the following levels (see previous chapter): The mimimum required additional height is:

Design water level	+4.27m NAVD88
Sea level rise	0.65m
Wave height	0.76m
Bank Height	+1.85m NAVD88

Table 5.2: Levels

$$h_{add} = 4.27 + 0.65 + 0.76 - 1.85 - 1.30 = 2.53mam \tag{5.4}$$

This implies that the total wall height becomes:

$$h_{wall} = 2.53 + 1.30 = 3.83m \tag{5.5}$$

An impression is shown in figure 5.13.

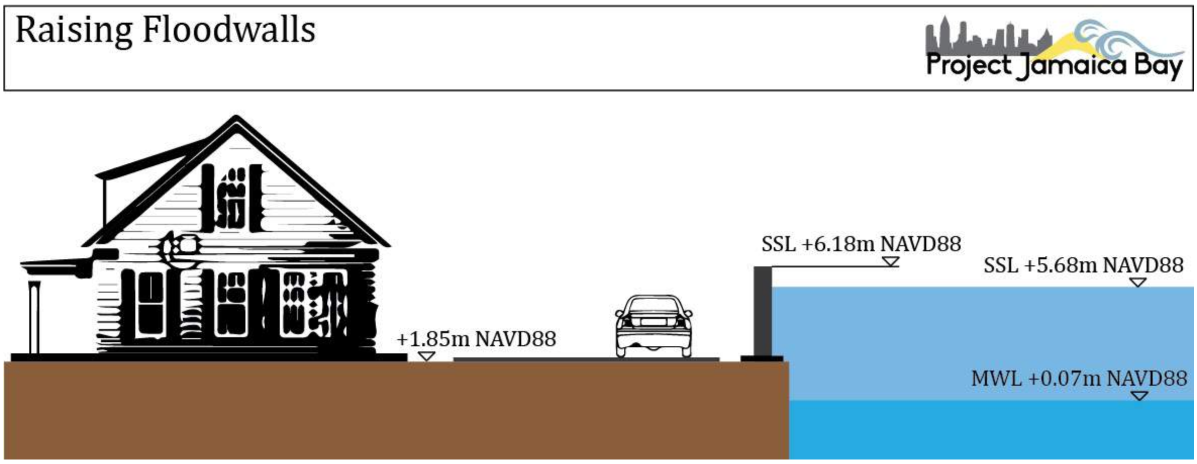


Figure 5.13: Flood Wall impression

ELEVATED BULKHEAD

Approximately 25 percent of the NYC shoreline has a bulkhead [39]. One solution could be an elevation of the current bulkhead along the banks. This measure takes up a fair amount of space, but should be feasible along most parts of the banks considered above. More functions can be integrated into the design then solely a bulkhead to withstand extreme surge levels. For instance, the busy Beach Channel Drive cannot be neglected in the design. As the situation is now, the Beach Channel Drive is already a 'barrier' with respect to the banks and the inner side of the peninsula. To elevate this road should make sense from a conventional area management point of view. Also, on the bay side, aside from the elevation in vertical direction, not a lot of alterations have to be made into the bay, because this measure does not extent into the bay. Therefore, there is no interference with morphodynamics and navigation channels. For the inner side a (gentle) slope can be considered of about 1:3 or 1:4. To add aesthetic value, several materials can be considered for constructions. Both wood or stone structures can be applied, although steel or concrete structures give a better cost benefit ratio, also considering maintenance. By using the same levels as in table 5.2, the design in figure 5.14 is obtained. With this solution the total width becomes:

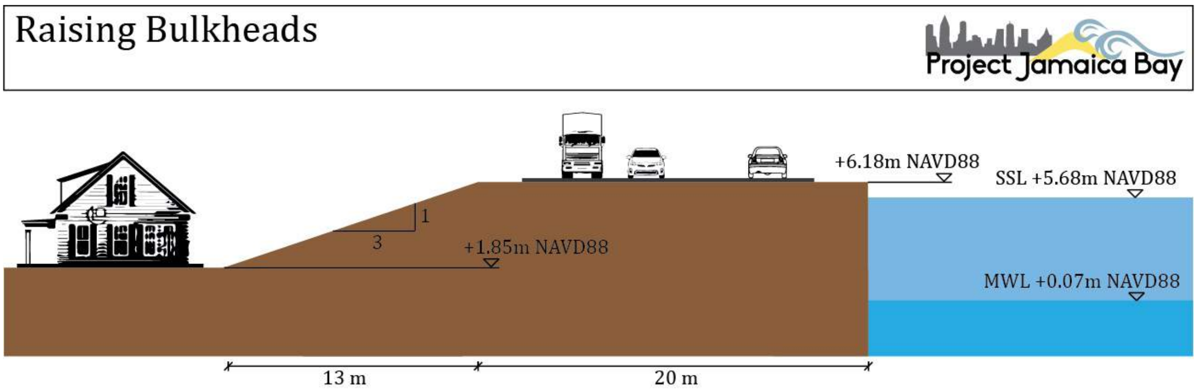


Figure 5.14: Impression elevated bulkhead

$$W_{road} = 25m \tag{5.6a}$$

$$\text{Inner slope} = 1:3 \tag{5.6b}$$

$$\text{Elevation difference} = 6.18 - 1.85 = 4.33m \tag{5.6c}$$

$$W_{new} = 20 + (4.33 \cdot 3) = 33m \tag{5.6d}$$

5.2.1. FINAL MEASURE

From the above calculations, it can be concluded that the new levee requires a sufficient amount of space (60m). Like stated in the chapters and shown in the figures there is sufficient space available between the Marina Parkway Bridge and Bach 144th Street to construct such a levee. The situation more to the East becomes difficult because the neighborhoods are living much closer to the shoreline. In many of those areas the levee would require fill into the water, which can create environmental impacts and consequences. Such construction works would require an environmental analysis to what extent the impacts on hydrology, water quality and ecosystems in the Jamaica Bay are. Because the levee requires this amount of space, its construction is considered not to be feasible.

Applying flood walls is a relatively easy solution. However, because it is highly disturbing for the beautiful view of the bay, it will not be advised to apply such a solution. An eligible strategy could be raising the current bulkheads and the Beach Channel Drive with 4.30-4.40 meter. In contrast with constructing a multi-purpose levee, now only one slope is needed to construct. By applying this barrier, you can 'save' 55-33=22 meter in comparison with the multi-purpose levee. To make the elevated road more attractive, the road could be executed with for example bicycle and pedestrian paths. If the current flood wall is applied, the elevation could also be reduced with 1.30m.

6

JFK

This chapter elaborates on the JFK area. First the possible measures are discussed, followed by an explanation and recommendation of those different measures based on the boundary conditions.

6.1. Area Analysis

At the northeastern part of the Jamaica Bay area the John F. Kennedy International Airport is situated, which is owned by the city of NY and operated by the Port Authority of New York and New Jersey. This airport was created in April 1942 when NYC began placing hydraulic fill over the marshy tidelands of Idlewild Golf Course. Today, JFK is the national's leading international gateway, with more than 80 airlines operating from its gates.

Currently there is not any substantial structure present at the JFK banks, only a riprap revetment to reduce the erosion, hence the Port Authority of New York & New Jersey. In figure 6.1 it can be seen that there is not a dike like structure present and that the runway is built adjacent to the banks of the bay. This current revet-

Figure 6.1: Southern part/bay side of JFK Aiport

ment is built around 1947-1949. Because JFK is a little build up, the height of the flooding was 'only' 3 feet high (92 cm). Besides this flooding, the interaction between the salt water and the electrical equipment was

causing the majority of the damage. Although JFK is not surrounded by levees, there has been built an extensive drainage system which takes care of the high discharges during high tides and storms to protect JFK from flooding. Moreover, it is not allowed to build any structure that affect the runway due to FAA (Federal Aviation Administration) laws. This aviation authority regulates the aviation in the United States and makes the regulations regarding safety around runways. The higher one wants to build, the difficult it will be to get permission from the FAA. Therefore building high levees besides runways is also unacceptable; pilots must have a clear sight over the runway, i.e. they need to see the lamps that are situated next to the runway.
Furthermore the available space to built any permanent structure is very limited; the current southern runway has been built very close to the bank of the bay. A possible solution for this problem could be to reclaim more land southwards from the water. However, one needs permits issued by the DEC to start with such kind of works. Because JFK is surrounded by wetlands, it is very tough to get such permits (see boundary conditions 3.2.6). Moreover, next to the wetland restriction, a levee would require fill into the water, which is not possible because of the very low-lying bed adjacent to the JFK banks caused by the construction (landfilling) of JFK in 1942.
Due to the above mentioned restrictions and requirements we have chosen for designing a non-permanent measure.

6.2. Non-permanent measures

In general, non-permanent measures can be divided into two groups, i.e. temporary measures and semi-permanent measures. These two groups will be elaborated during this chapter. Non-permanent flood protection systems have been available for decades in the form of filled containers such like bags, partly pre-installed demountable barriers such as stop logs and fully pre-installed demountable barriers such as flood gates. There can be seen a significant increase of innovative non-permanent flood protection products across the US and Europe in the last few decades. These temporary and demountable flood protection systems provide the opportunity to reduce flood risk where permanent measures are not technically feasible, environmentally acceptable, economically viable or financially affordable. Non-permanent solutions are sometimes the only feasible structural solutions to reduce flood risk. The ones applicable to this situation, i.e. technically feasible and environmentally viable, are the main reasons to choose for such s measure. One can distinct four different types of non-permanent flood protection systems:

1. **Temporary barriers**
   This type of barriers are completely deployed before the flooding will occur, afterwards it will be completely removed.
2. **Demountable barriers**
   Demountable systems are partly or fully pre-installed, but require some operation when flood is forecast.
3. **Building skirt barriers**
   These systems are local measure and are built to surround individual infrastructure and buildings.
4. **Building aperture barriers**
   This system is about sealing the gaps of for instance doorways and air bricks.

An integral design for the entire Jamaica Bay area will be elaborated, this implies that local measures will not be designed. Therefore only the first two systems, temporary barriers and demountable barriers, will be considered for the JFK area.

6.2.1. Boundary Conditions and requirements JFK Area

The different design water levels are stated in chapter 3.2.3. The water levels 6 and 7 are governing for this area. The design water level in those points are respectively, +4.27 m and +3.0 m NAVD88 (North American Vertical Datum 88). Furthermore the wave heights are respectively 1.19 and 0.95 meter, the corresponding wave periods are 2.8 and 2.4 seconds. The governing data for our design will be, including a sea level rise 3.2.3 of 65 cm, a design water level of + 4.92 m NAVD88, a wave height of 1.19 m and a corresponding wave period of 2.8 s. Another requirement, compared to permanent barriers, is an additional operational risk of non-closure before flood water reaches the lowest level of the natural defense. For those barriers which requires a manual installation, there is a need to receive flood alert in time to enable erection or closure. This in turn requires a reliable forecast.

6.2.2. TEMPORARY BARRIERS

Where permanent flood protections systems are not an option for an area, flood protection systems which require full installation prior to the flooding and complete removal after the event might be an option. Reasons why one can choose for a temporary barrier are:

- Demountable systems are not economically viable
- Dual use of function such as the need for access through a flood protection system
- Unacceptable environmental impact of permanent or semi-permanent solutions.

The solutions range from straight forward sandbags to complex inflatable structures. The barriers are often held in place by the weight of the water and therefore require no fixing. Two examples of temporary barriers are shown in figure 6.2 and figure 6.3. An advantage of these kind of barriers is the speed and flexibility with

Figure 6.2: The Watergate system protecting the National Archives in Washington DC

which they can be deployed. Due to this advantage these structures are often lightweight and also ideally compact for storage. Although these temporary barriers have multiple advantages, these measures are not eligible for coastal protection purposes, due to the heavy impact caused by waves and currents. Therefore these kind of measures will not be selected to protect the JFK hinterland from flooding.

6.2.3. DEMOUNTABLE BARRIERS

As an alternative to permanent flood barriers, one can make use of protection systems which remain open during normal conditions and require part installation during high water levels. Different reasons can be mentioned why one should choose for a temporary barrier:

- Dual use of function such as the need for access through a flood protection system

Figure 6.3: An example of a BoxBarrier application; box elements are filled by water and connected by joint elements

- Unacceptable environmental impact of a permanent flood barrier
- Management of flood risk above permanent standard of protection

Demountable barriers are partly or fully pre-installed, but require some operation when flood is forecast. The big advantage is that there is a permanent and fixed solution present when implemented but during non-storm conditions the structure does not limit the access as usual. The demountable flood protection systems therefore include temporary and permanent elements, i.e. the foundationss, the seals and joints within the structure and the connections between the structure and the surface. In the following chapters, different demountable barriers are elaborated.

Self Closing Flood Barrier

In operational globally use since 1998, the Self Closing Flood Barrier (SCFB) is acclaimed as the world's most effective flood protection system [41]. Some applications of this system are: protecting building apertures, coastal defenses, protecting underground public transport systems and entrances to underground car parks. This system operates furthermore completely automatically. The force caused by the rising water level starts the mechanism during floods. The principle is as follows:

- After installation and during normal condition the barrier is situated in a buried basin and therefore completely invisible (see step 1 in figure 6.4).
- When floodwater rises, the enclosed basin, which houses the floating wall, starts to fill up through an inlet pipe from the adjacent flood pit. Subsequently the flood wall floats and rises. When the basin is totally filled, the support blcok will 'lock' the barrier into position making it watertight (see step 2 in figure 6.4).
- The flood water is now retained by the flood wall. As the water level decreases to normal level, the flood water in the basis is drained by a pump located in the flood pit, through drain pipes which are fitted with one way check valves. Due to the decreasing water level, the flood wall returns to its original position within the (invisible) basin (see step 3 in figure 6.4).

An impression of the SCFB barrier is shown in figure 6.5.

Vlotterkering®

The Vlotterkering is an innovative design for a temporary water defense in the Woudse Polder of the municipal of Midden Delfland in Holland. The Vlotterkering is a temporary barrier, integrated in a dike or embankment. This system is the winning design of a European competition, organized by the Water Board of Delfland, for temporary flood barriers in December 2006. A Dutch engineering company, Witteveen & Bos,

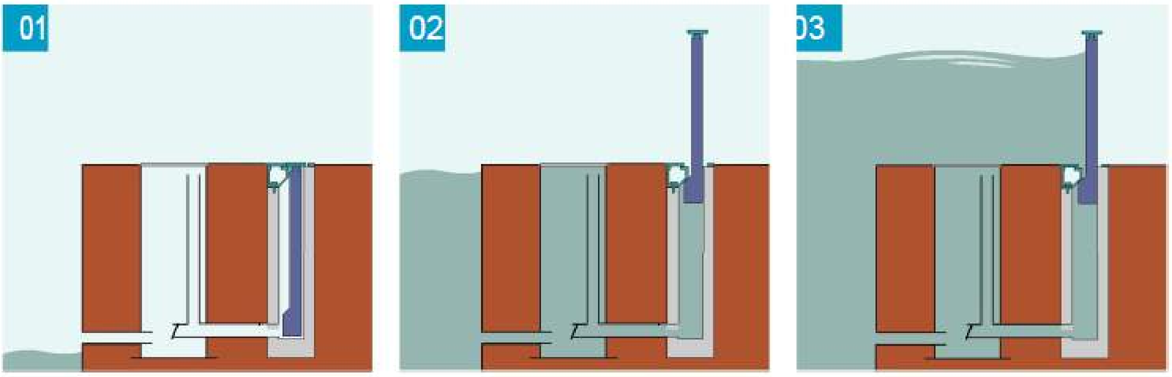


Figure 6.4: Principle of Operation SCFB system

Figure 6.5: SCFB barrier in position, Schelle Belle Belgium

provides consultancy and engineering services for this project. The defense system consists of a concrete tank and a floating element (the floater) fixed to a steel pan as cover, that works as a water defense. If the barrier is not in use, the floater is in the concrete tank that is part of the quay (invisible). When water is let in the tank, the water pushes the floater with the panel up, which creates the barrier function. Advantages of this barrier are: minimal impact on the environment, no manpower or equipment needed, permanent presence and any time ready to set. Research is currently conducted to investigate the system's resistance against wave impact and floating objects. Impressions of the Vlotterkering is shown in figure 6.6.

WATERWALL

The WaterWall System has been developed as a quick and convenient method of building a water tight flood barrier that can be easily erected in the event of a flood and also dismantled and stored away when danger has passed. Suitable for installation for commercial property, WaterWall makes use of two permanently-fixed vertical channels fitted either side of the opening to be protected, along with pre-installed unobtrusive ground fixtures to allow a patented system to be put in place. Aluminum panels are then dropped into position so that, when deployed, a barrier up to 1200 mm high for any required span to protect the JFK property, see figure 6.7.

6.2.4. CONCLUSION AND FINAL MEASURE

Floodwalls are permanent or deployable walls used at the shoreline or upland to prevent flooding. Deployable floodwalls are best suited for areas -like the JFK area- where space is in high demand. These hydraulic structures are vertical structures anchored into the ground to withstand inundations and prevent the hinter-

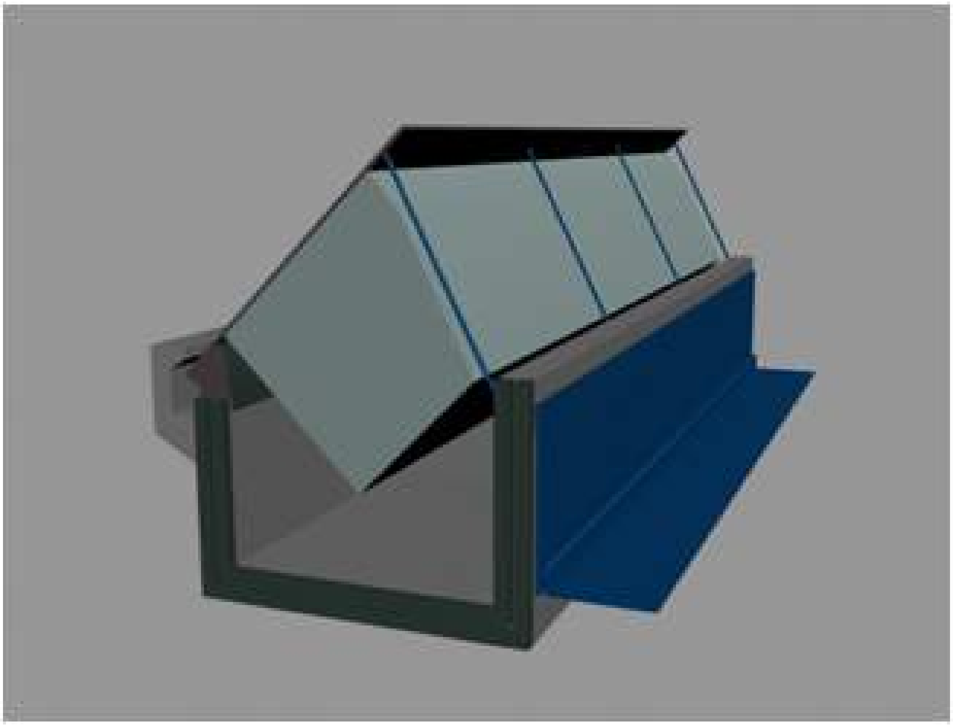


Figure 6.6: Vlotterkering in defense position

Figure 6.7: An example of a WaterWall System application

land from flooding. There are different types of floodwalls, like explained in the previous chapters. One of those types is the deployable floodwall, which requires wall slats to be installed in preparation of a forecasted flood. Some deployable walls do not require human intervention and function completely automatically. The benefits of having a clear visual and no height restrictions according the FAA regulations, have led to the decision of a non-permanent floodwall. Such a barrier is desired in the JFK area because a permanent barrier would conflict with the use of the airport along the bank. Furthermore engineering companies have already gained a lot of experience with this type of hydraulic structure. Deployable floodwalls are found throughout the Midwest to protect critical infrastructure sites, such as airports, from flooding as well as in urban waterfront areas, such as along the Potomac in the Georgetown neighborhood of Washington, DC [39]. The SCFB will be elaborated to prevent the JFK banks from flooding. Firstly, the global use of this product proves the capability of this barrier. Current projects vary from protecting banks in Belgium to local parking lots. The flood wall of this system is designed to withstand more than 10 times the hydrostatic pressure exerted by floodwater at its maximum height [41]. This system (SCFB) is buried in the ground when not in use, therefore it also does not interrupt with the aesthetic appeal of the location where the system is installed and does not affect the height restriction based on the FAA regulations. Furthermore the barrier can retain a water height up to 2.5 m and is lined with Kevlar for a huge impact strength. As the floodwater subsides, the barrier gradually returns to its resting positing. Moreover, this system is tested by ARCADIS NL to function as a primary flood barrier. The results were positive; this system is eligible according the Dutch legislation and can therefore be used, in Holland, as a primary flood barrier. With a lifetime expectancy in excess of fifty years, and requiring minimal maintenance, the SCFB is on only an extremely effective flood defence systems, but it makes a strong economic case too.

6.2.5. DESIGN AND SKETCH

In figure 6.8 the cross-sectional profile at JFK can be seen. A lot of landfilling has been done during the construction of JFK, which also can be concluded of the low-lying bed adjacent (approximately minus 40 feet NAVD88) to the JFK banks. In figure 6.9 the spot (red line) where the cross-sectional profile is taken, is illustrated.

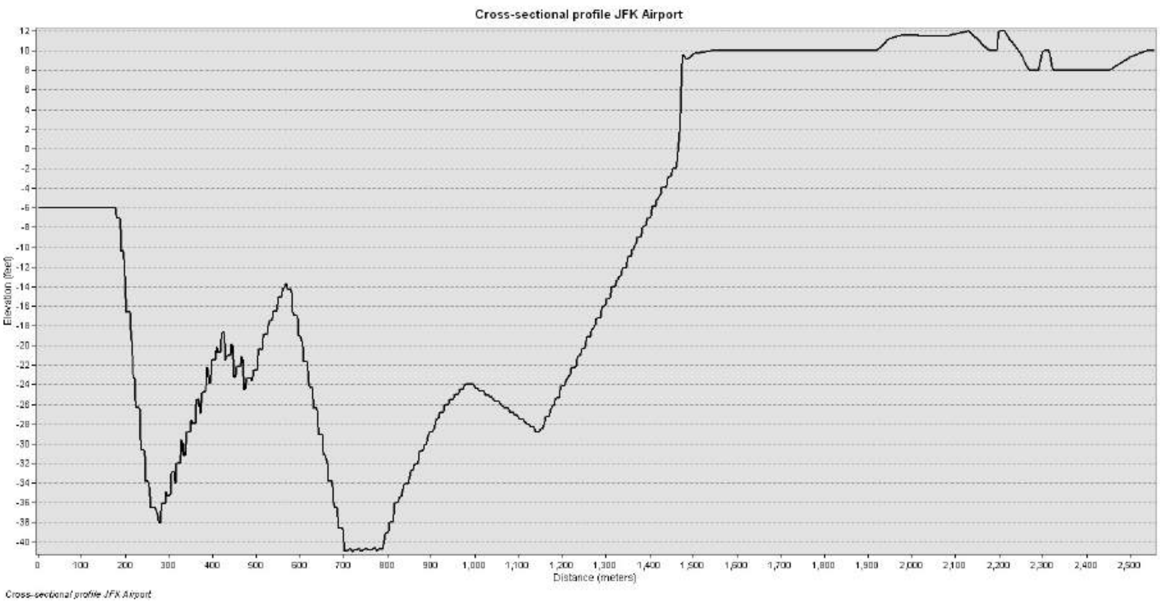


Figure 6.8: Cross-sectional profile at JFK (ArcGIS)

From the boundary conditions chapter 6.2.1, the following (governing) values were determined.
The design water level is based on the flood modeling data plus the projected sea level rise.

$$h = +4.92m \text{ NAVD88} \tag{6.1a}$$

The wave height and the wave period are also based on the modeling work.

$$H = 1.19m \tag{6.1b}$$

$$T = 2.8s \tag{6.1c}$$

However, because a limited amount of overtopping is allowed, also due to the extensive JFK drainage system, the wave height will not be taken into account. With an additional freeboard of 1.0 meter, the final design height of the wall becomes:

$$H_{wall} = 4.92 + 1.0 = +5.92m \text{ NAVD88} \tag{6.2}$$

To check whether the drainage system can cope with the extra discharge, the overtopping has to be calculated. Wave overtopping is usually given as an average discharge per meter of width. Various overtopping formulas

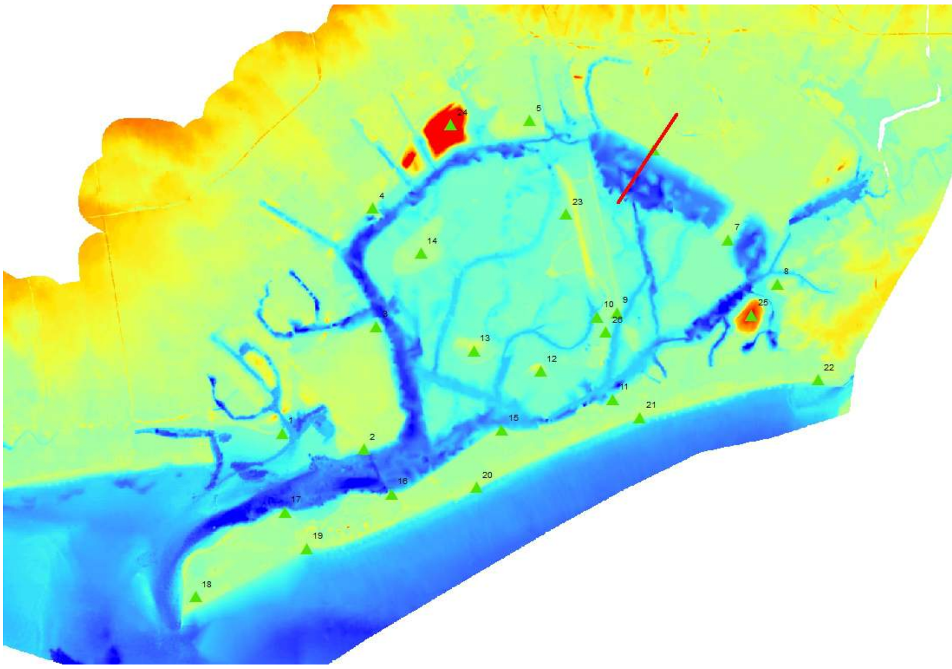


Figure 6.9: The spot where the cross-sectional profile of figure is taken (ArcGIS)

for vertical structures are published. The formula used in the Dutch guideline is:

$$q = 0.13\sqrt{gH_s^3}\,e^{-3\frac{R_c}{H_s\gamma_b\gamma_m}} \qquad (6.3)$$

Wherein:
q = mean overtopping discharge [m^3 per m width]
H_s = significant wave height [m]
R_c = relative crest height with respect to still water level [m]
γ_β = reduction factor for angle of wave attack [-]
γ_n = reduction factor for a wave return wall [-]
For this case: R_c = 1 m, H_s = 1.19 m The reduction factor for oblique wave attack can be described by:
$\gamma_\beta = 1$ for $\beta < 20°$
$\gamma_n = 1.3 - 0.6\,\frac{R_c}{H_s}$ for $0.5 < R_c/H_s < 1.0$
Using formula 6.3 the overtopping discharge is 26 l/s per m width. The extensive drainage system can drain this discharge. However, additional bed protection behind the walls have to be built to withstand erosion caused by the water. From figure 6.9 it can be seen that the banks around JFK are situated at:

$$h_{JFK} = +10ft = +3.05m \text{ NAVD88} \qquad (6.4)$$

The necessary height of the flood wall is:

$$h_{wall} = 5.42 - 3.05 = 2.37m \qquad (6.5)$$

Therefore a wall of 3 m will be chosen. The overtopping discharge will be reduced to 10 l/s/m with this flood wall height.
An impression sketch of the final measure is shown in figure 6.10.

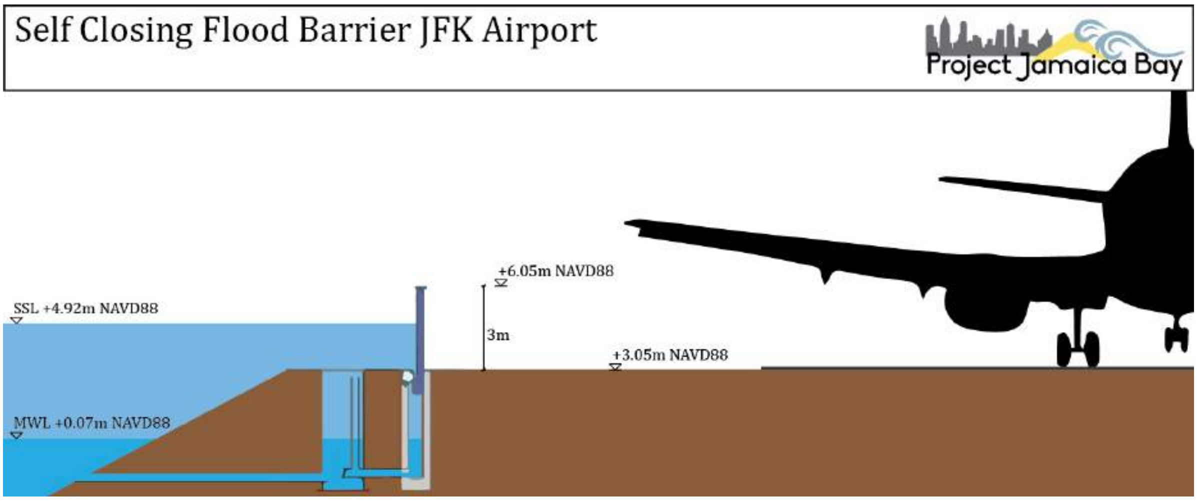


Figure 6.10: Impression sketch SCFB system at JFK

7 Exceptions

When looking at the Jamaica Bay characteristics, besides integrating measures like living shorelines, improved banks and temporary solutions, there are a couple of exceptions that need to be taken into account. These exceptions need to be designed by the same boundary conditions that are used for the different measures stated earlier in this report. Also the design level needs to be the same to be able to ensure flood protection for the whole region.

This chapter encompasses a brief overview of the options that could be taken to maintain the level of safety. It should be noted that before designing a system that is able to mitigate food risk for the whole Jamaica Bay region, it is important that these exceptions are researched and designed extensively.
[42]

7.1. CREEKS/BASINS (CAPTION 1.)

The first exception is indicated by caption 1. on the overview map, see figure 2.25. The exceptions comprise the creeks that are located largely at the northern side of the Jamaica Bay area (see figure 7.1). These creeks are mostly located in highly urbanized areas where inundation could have a large impact on the safety of the people. Because some inhabitants of the surrounding neighborhoods live closely to the perimeter of the bay, there is not a lot of room to integrate a living shoreline (see figure 7.2). Without a living shorelines different measures need to be taken to make sure that these areas are protected against flooding.

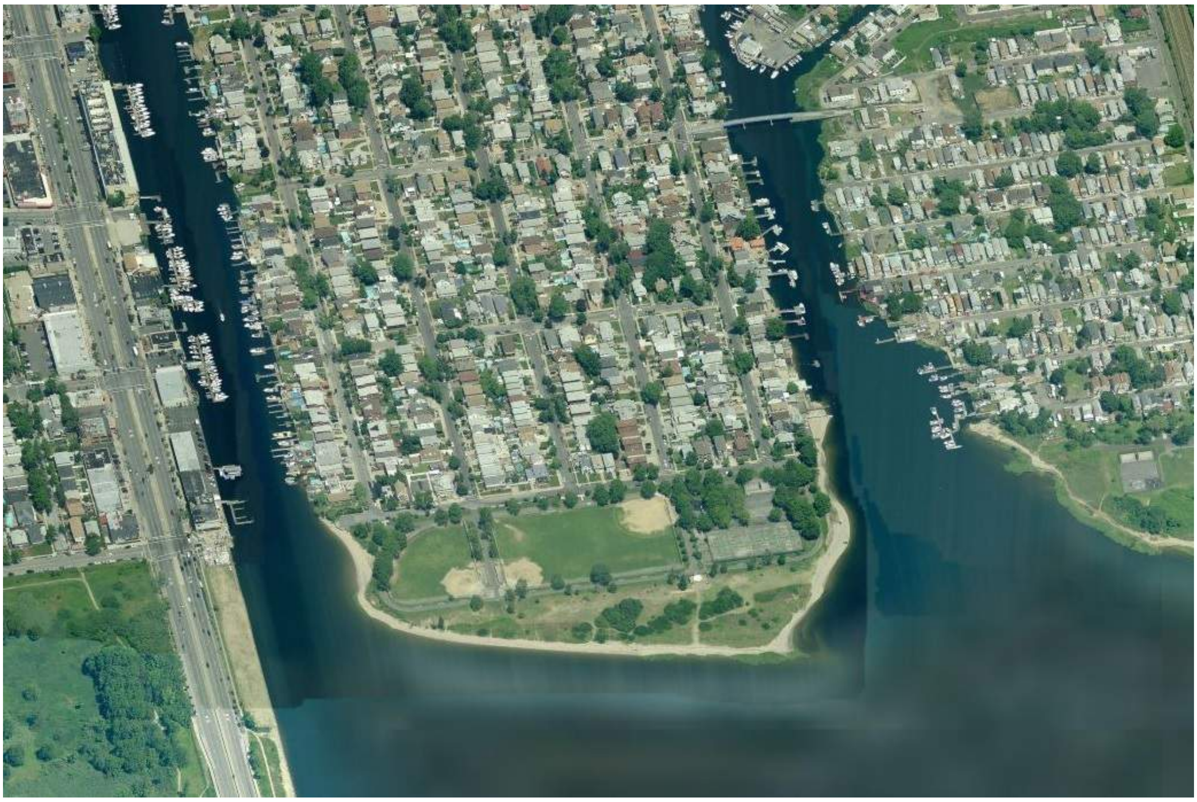


Figure 7.1: Howard Beach Creek Inlets (Bing Maps)

Figures 7.3, 7.4 and 7.5 compare elevation heights of Paerdegat Basin and Norton Basin. It should be noticed that the maximum dept of Paerdegat Basin is around 15 feet below mean sea level. In Norton Basin, the lowest point of the elevation for this particular section ranges upto 32 feet below mean sea level. The figures show the different kind of conditions that need to be kept in mind when comparing different measures.

PARTICULAR DESIGNS

Although there are twelve different cases where the creek needs to be secured, this section of the report only gives general options. When making a detailed flood protection design for the Jamaica Bay area, these options should be further fitted to each individual creek to be able to decide which option would be best for that particular creek. The individual designs of those hydraulic structures is not in the scope of this project.

Paerdegat is an example of a creek that needs to be secured. The creek is located between Canarsie and Bergen Beach and came to its present conditions around 1930, because of filling as a precursor to plans to create a great world harbor in Jamaica Bay. For the flood risk mitigation of these creeks, two distinctions are made (see figure 7.6):

- Measures along the perimeter of the creek
- Measures at the inlet of the creek

Both types of measures have their own beneficial attributes, which are discusses in this section.

Figure 7.2: Howard Beach Creek Shore

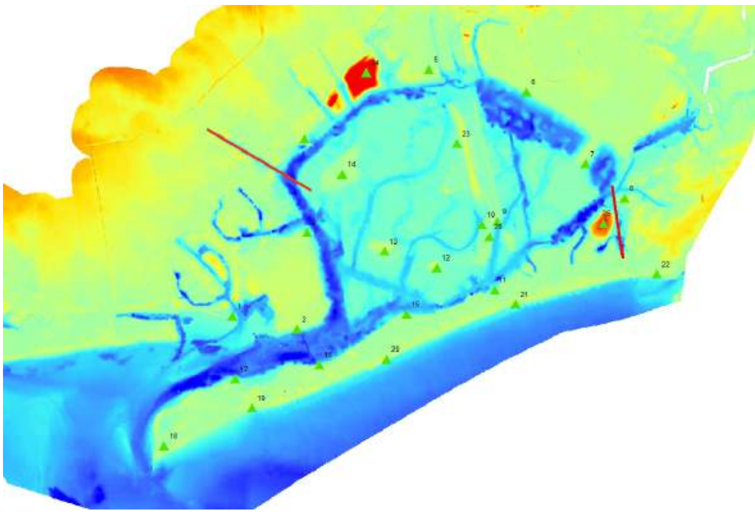


Figure 7.3: Paerdegat Basin (Left Section)/Norton Basin (Right Section) Location Overview, created by ArcGIS (DEM, [6])

7.1.1. CREEK PERIMETER MEASURES

When looking at measures for the perimeter of the creek, several pros and cons can be stated. First of all, the accessibility of the creeks would be well attained when looking at a solution for the perimeter. Also, keeping the creeks open would maintain the refreshment rate of the water which will preserve the water quality. However, it needs to be noted that the length of the structures is much longer than it would be when constructing a structure at the inlet. The long shoreline could question the robustness of the system and

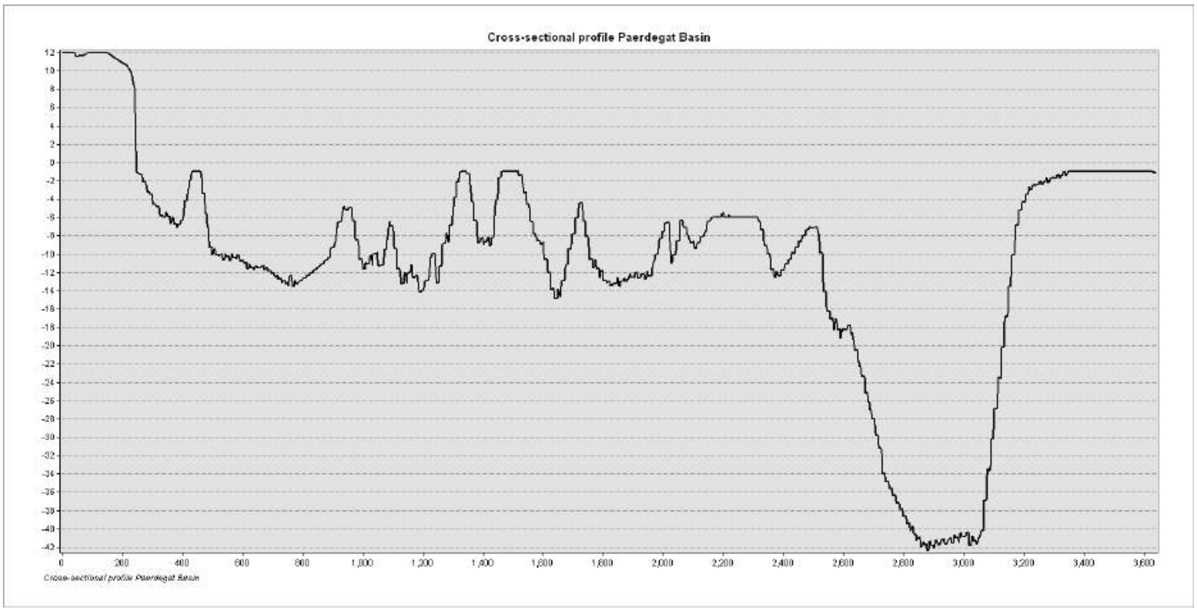


Figure 7.4: Paerdegat Basin Section Showing Elevation: Lowest Recorded Depth 15 Feet, created by ArcGIS (DEM, [6])

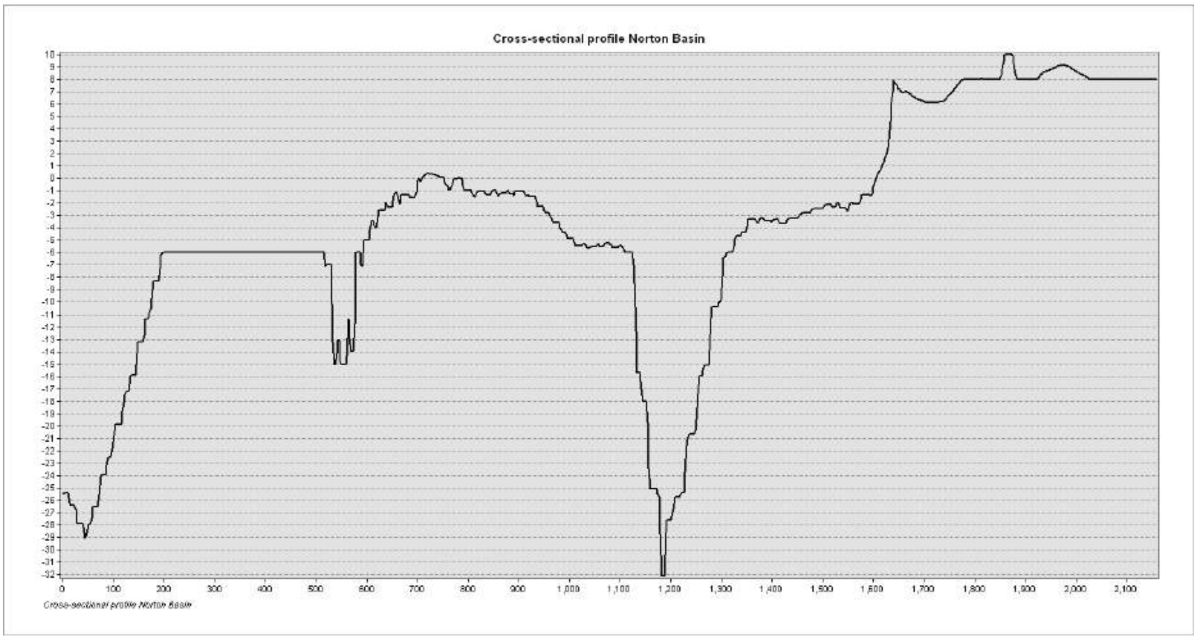


Figure 7.5: Norton Basin Section Showing Elevation: Lowest Recorded Depth 32 Feet, created by ArcGIS (DEM, [6])

therefore also the level of safety.

REMOVABLE FLOOD WALLS

One of the options could be to implement removable flood walls at the shorelines within the creek (see figure 7.7). These walls will make sure that the perimeter will be secured without obtaining a lot of space. For more information about removable flood walls see chapter 6.2.

ELEVATE ON LEVEE

Another options along the shorelines of the creeks could be to elevated the buildings on a levee like structure (see figure 7.8).This would mean that the buildings themselves would also be elevated, raising the costs but also extending the view. Also the elevation of the whole development site could be considered (NYC DCP, 2013)[39].

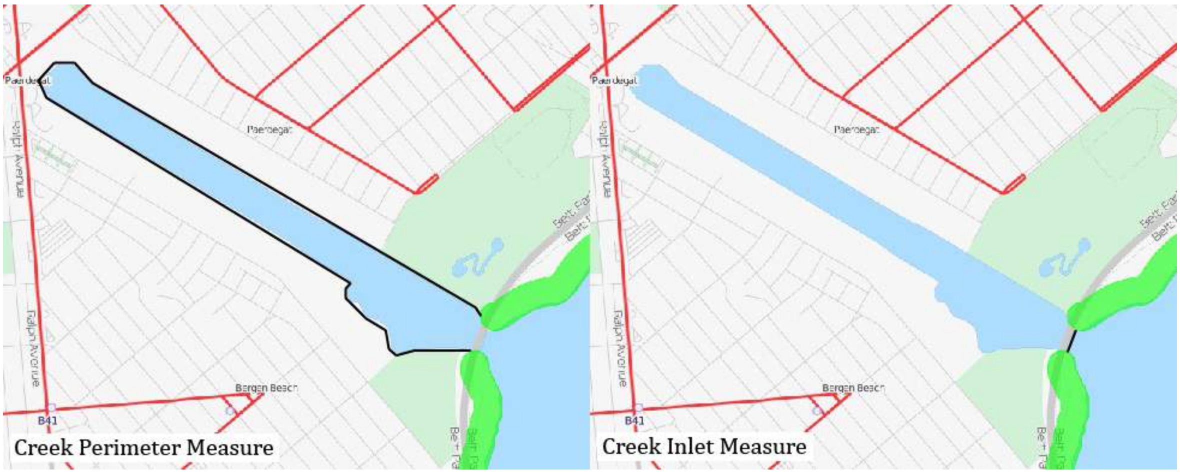


Figure 7.6: Paerdegat: Base Options for Creeks

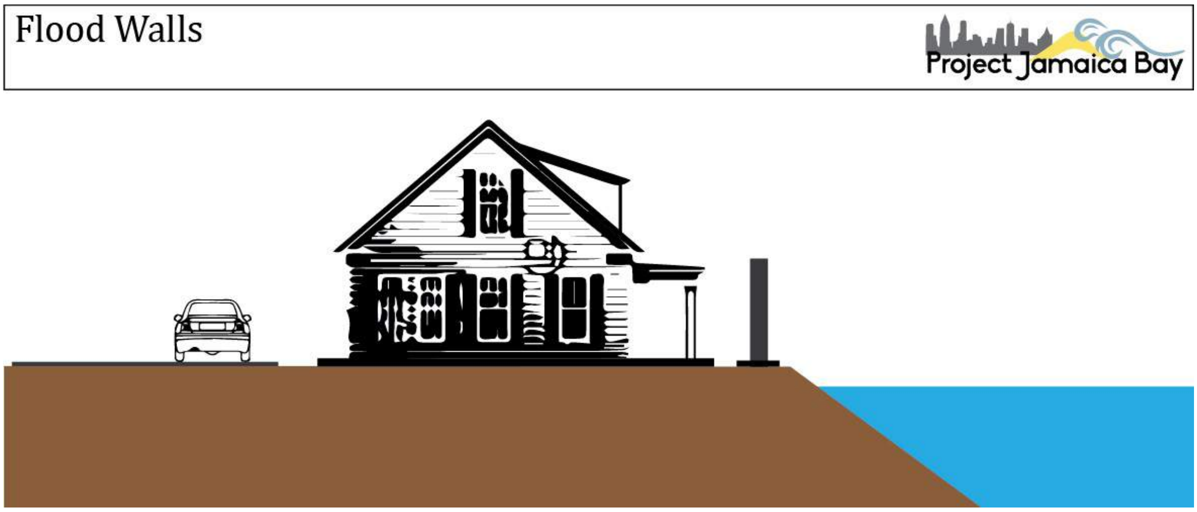


Figure 7.7: Removable Flood Wall

7.1.2. CREEK INLET MEASURES

To shorten the length at which flood protection measures need to be taken, instead of protecting the whole perimeter of the creek, the inlet of the creeks can be protected. This protection could involve several different kinds of hydraulic structures, but also shutting the creek of and including a lock.

CLOSING THE CREEK

The easiest option to protect the creek against inundation would be to fill the inlet up to a the same design level as the living shorelines right next to it. However, any filling in the national park is not desirable because of the history of filling. Also filling the inlet would lead to navigation channels being cut off and could also lead to a degrading water quality within the creeks. A way to eliminate the navigation channel being cut off could be to integrate a sluice.

Sluices An eligible option could be to build a sluice-structure which remains open during non-storm conditions and can be closed when a storm surge occurs. Sluice structures are widely used, for different purposes. The main functions of a sluice, as defined by the Dutch TAW are:

- Water retention
- Water locking
- Water discharge

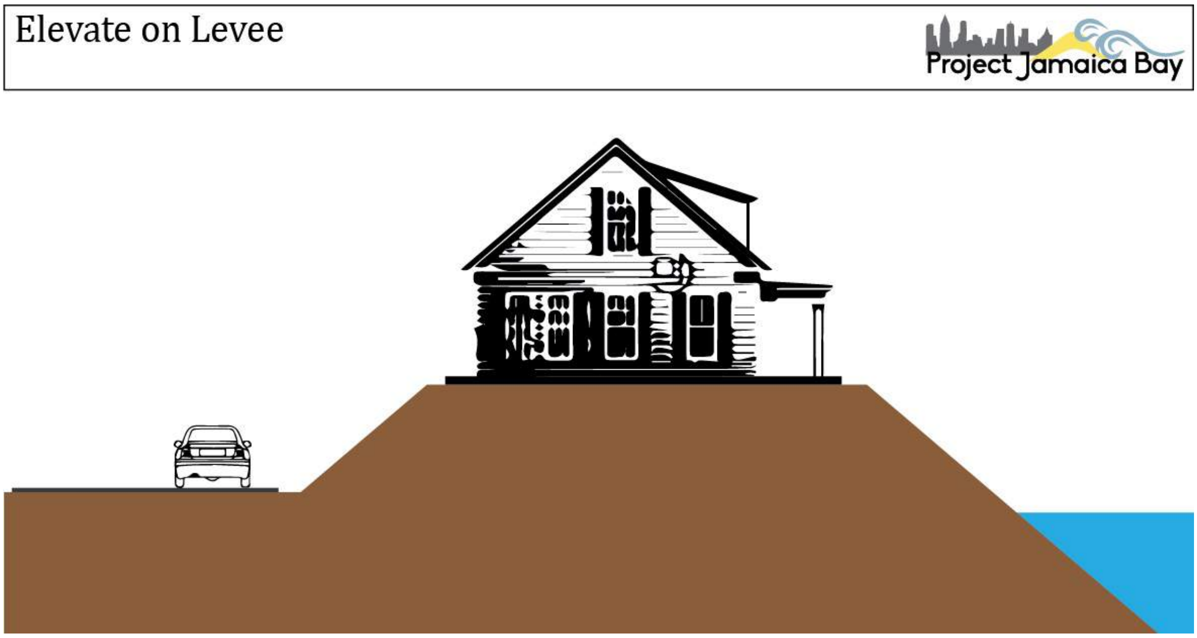


Figure 7.8: Elevate on Fill

- Shore connection

A lock is part of the sluice family. Because there are harbors situated in some of the creeks, also navigation locks will be considered. Before focusing on navigation locks, some other locks will be briefly discussed. The word sluice is used to indicate that the lock belongs to a larger family of structures (Van Baars et al., 2013) [43].

Guard Lock Guard locks and storm surge barriers have two conflicting primary functions, i.e. passage of vessels and retention of water. During normal conditions the gate remains open to allow ship passage. If the water level in the Bay would be too high, the barrier can be closed and therefore it prevents further navigation. One can distinct two kind of guard locks: one-way retaining or both-ways retaining (Van Baars et al., 2013) [43].
one-way retaining
The one-way retaining lock retains water in one direction only in extreme conditions. The doors are closed when the outside water level reaches a certain predefined level. The lock is part of a flood system, e.g dikes or other structures. However, the design height of the doors may be less than the design height of the dikes and therefore allowing an amount of overtopping. This type of lock is commonly found in areas with a small tidal range.
both-ways retaining
In areas with large tidal ranges, harbor entrances are usually equipped with guard locks retaining in both ways. A minimum water level is required, within the harbor basin, to enable a vessel to maneuver safely without running aground. During low tide the water must be kept within the basin, during high tide the water must be kept out. This implies that the locks are only open between high and low tide. Different gates can be used for this lock, i.e. mitre, rolling, sliding or vertical lift gates. These types are able to retain the water in both directions. However, lifting gates have a limitation regarding the air draught of ships.

Lock Navigation locks enable the transfer of a ship from one section to the other section of the waterway and act as a link between two section with different water levels. The water levels between both sides of the lock and the tidal range are one of the main parameters to be considered when designing a lock (Van Baars et al., 2013) [43].

GATES

In order to keep the current water refreshment rate in tact for the most part and still considering a measure at the inlet of the creek, several gates can be considered. These hydraulic structures only conflict with navigation during a storm or exceptionally high tide event, depending on the programming of the gate. When

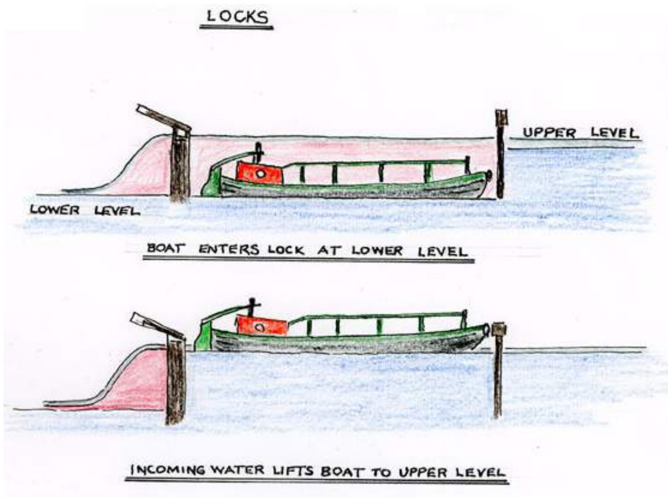


Figure 7.9: Locks (narrowboats.biz)[?]

designing a gate, for each inlet several requirements need to be met. The requirements include looking at the risk of failure, the amount of storm water overtopping allowed, flow- and wave induced vibrations, siltation impacts and winds loads. Also ecological conditions like the passing of fish and tidal flow in combinations with water quality should be taken into account. Because each inlet is different regarding these conditions, there is no single best gate. Each gate has its own benefits and for every inlet the best measure should be tailor made (Dircke et al., 2011)[44].

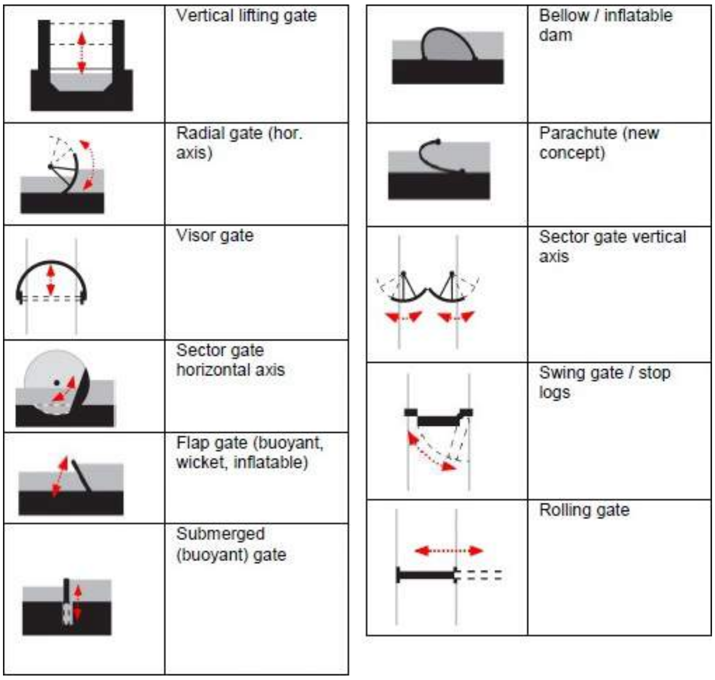


Figure 7.10: Different Barrier Types (Van Ledden et al., 2012)[45]

In this section different kind of gates are elaborated (see figure 7.10). Also a brief overview of their advantages and disadvantages is given.

Vertical Lifting Gate/ Visor Gate A vertical lifting gate is a gate that has been used for a long time. It typically does not require a lot of space, its maintenance is relatively easy and it is a proven concept. However, it has limited clearance for boats, in a raised position it is subject to wind load and it is sensitive to vibrations from a hydraulic point of view (Dircke et al., 2011)[44]. A visor gate is similar to a vertical lifting gate. However, at a visor gate there is an axis which needs to be maintained.

Flap Gate A flap gate is a gate that is lies underwater when the barrier is not in use. The advantage is that it does not pollute the view. Also, it has no limitation of the span and no clearance height for boats. There is little space required and is not subjected to wind loads. On the other hand, it has a small stiffness and a great mass. Also, it is subjected to corrosion, the maintenance is difficult and the hinges may wear out in sand (Dircke et al., 2011)[44].

Submerged Gate A submerged gate is an underwater gate. Because of this, there is no navigable clearance height. Also the gate is not visible and has limited influence on the ecology. However, maintenance is difficult under water and it is not easy the construct in deep water.

Inflatable Dam An inflatable dam is a relatively new type of barrier. They are widely used in the world mainly at river engineering projects. The inflatable dam has neither a limitation of span nor clearance height limitations. It is not subjected to wind and little space is required. However, the structure has a small stiffness and a great mass. The storage of the rubber sheet could lead to complexities and it is vulnerable to vandalism and collision with ships (Dircke et al., 2011)[44].

Parachute Dam The parachute dam is a new concept that has not proved itself yet. It is supposed to be similar to the inflatable dam. It has no clearance height for navigation. The maintenance and storage of the rubber dam could lead to complexities and it is vulnerable to vandalism.

Sector Gate with Vertical Axis/Rolling Gate/Swing Gate These gates can be described as horizontally moving gates and are characterized by the housing chambers in which the structures are stored. These structures are not subjected to wind, and have not clearance height for boats. Also when the doors are stored in dry docks, they demand a low level of maintenance. However, a large excavation is required for the door chambers. Also, silting on the slide ways of the doors could hamper operation. When using a sector gate, it is sensitive to ship collisions (Dircke et al., 2011)[44].

Sector Gate with Horizontal Axis/Radial Gate A vertically rotating sector/radial gate can be used with a large gate span. It is immediately ready for operation and there is little space required. Also, it is relatively easy maintainable. However, the gates are vulnerable to silting. A segment gate is less easy maintainable and a radial gate has limited clearance height (Dircke et al., 2011)[44].

7.1.3. CONCLUSION

Depending on the importance of different outcomes regarding the measures that can be taken in the creek areas, both measures at the inlet as measures along the perimeter of the creeks could be considered. In the following, the benefits for each of the distinctions are summarized.

Creek Perimeter Measure Benefits

- Maintaining water quality
- Maintaining accessibility navigation
- No major interventions in ecology

Creek Inlet Measure Benefits

- Shorter line of flood defense
- Easier to achieve the same level of safety
- Chances to integrate beneficial infrastructure (cycling path)
- Probably more financially attractive

7.2. FLOYD BENNETT FIELD (CAPTION 2.)

When looking at the area which includes the Jamaica Bay inlet, Floyd Bennett Field (FBF) can be noticed as an exception. This exception is indicated by caption 2. on the overview map (see figure 2.25) and includes an area of former marshes which were filled throughout the twentieth century. FBF distinguishes itself by encompassing several municipal institutes. Also, the field does not inhabit a large amount of people and during Sandy, only a small percentage of the area was subjected to inundation.

Figure 7.11: Floyd Bennett Field (Bing Maps)

BASE OPTIONS

Together with the marshes, parts of FBF are also eroding (National Park Service, 2009)[17]. This is an important characteristic of FBF to be taken into account when looking at future purposes. If no measures are taken some functions of the field could be at stake. Because of the differences from the rest of the area, there are several different options for integrating FBF into the protection system. These options depend on the envisioned future for area. Because of the FBF area mostly being fill material that has been put there during the twentieth century, the current state of the area is not as it would have been without any human interference. The municipal institutes could be at risk when not covering the area in the protection proposal. However, from an ecological point of view it might be best to give the area back to nature and just protecting Flatbush Avenue as a main access route to the Rockaways.

The two base options are (see figure 7.12):

- Measures along the perimeter of FBF
- Traverse measures for FBF

A benefit-cost analysis could help in weighing the possible future damage when the institutes currently situated at FBF will flood. Also, the cost of possibly having to move these institutes can be compared to the costs of protecting the area. By these means, a decision can be made whether or not to protect FBF.

Figure 7.12: Base Options for Floyd Bennett Field

7.2.1. MEASURES ALONG THE PERIMETER OF FBF

If the current functions of FBF are assigned to be of significant importance, one of the possibilities is to protect the FBF area. Within the protecting of FBF lie a couple of distinctions. The perimeter of the field could be protected against erosion and/or the whole area could be protecting against inundation. Figures 7.13 and 7.14 show a cross section and its location. The section shows the ground elevation and a small elevations at the perimeter of the field area. When improved, this elevation could be used for flood protection.

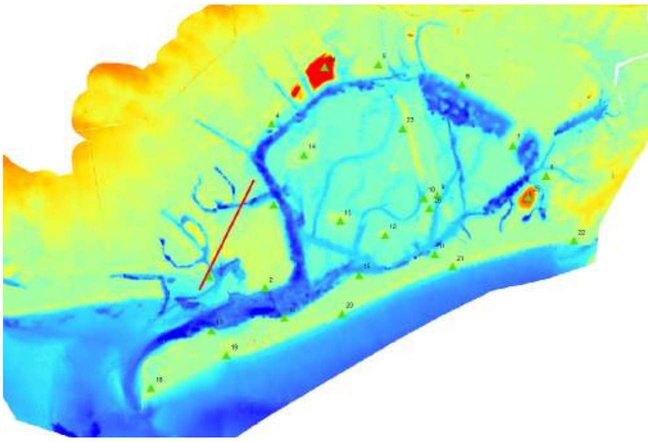


Figure 7.13: Altitude Overview for Floyd Bennett Field with Section 7.14 Location, created by ArcGIS (DEM, [6])

KEEPING FBF FROM EROSION

To be able to withhold the ongoing erosion, the shorelines of FBF should be protected. This protection could be ensured by implementing one of the following measures. To make sure erosion stops, the measures should be taken and maintained all along the shore of FBF.

Revetments At some locations, there are already revetments partly situated at the FBF shores (see figure 7.15). However, these revetments are mostly neglected and in bad shape. An options would be to repair and improve the revetments currently located at the FBF shorelines and to construct revetments where right now sandy beaches are situated. These revetments could be bulkheads or quay walls.

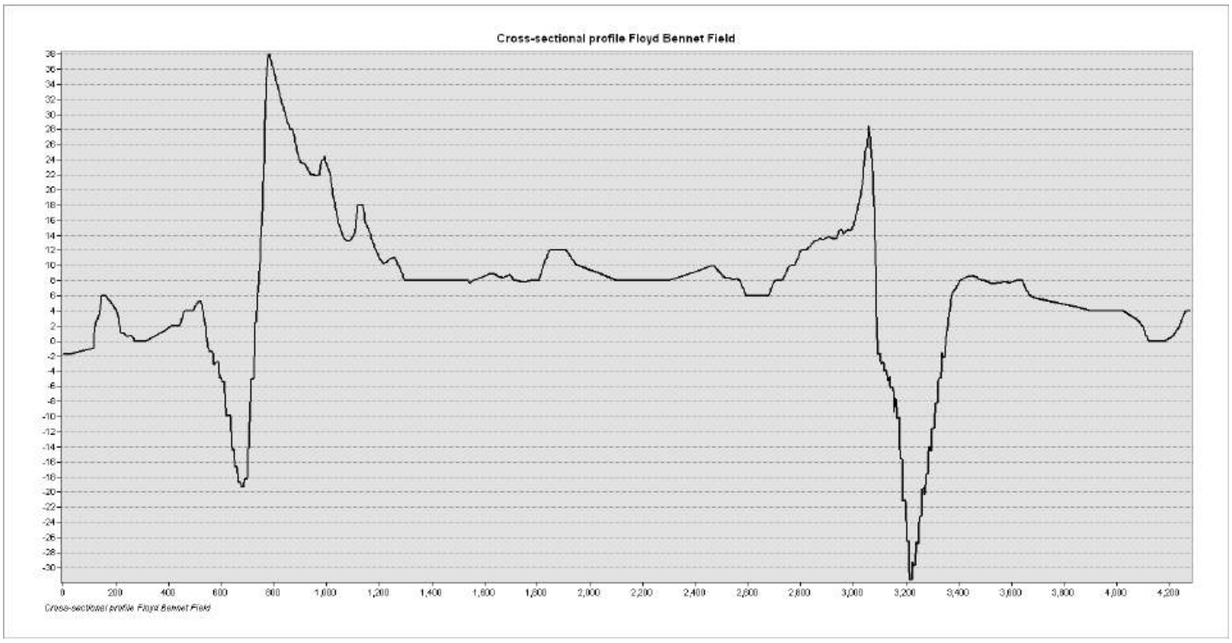


Figure 7.14: Section at Traverse Measure Showing Ground Elevation, created by ArcGIS (DEM, [6])

Figure 7.15: Revetments at Floyd Bennett Field

Groins Also groins would be an options to keep the FBF shorelines from eroding. Groins are hydraulic structures build vertically from the shoreline. Groins interrupt water flow and therefore local erosion.

PROTECTING FBF FROM INUNDATION

If it is important for the city of New York that the facilities currently situated at FBF can stay there for a long time, it is necessary to protect the area from inundation. Protecting the area from inundation means that no water can temporarily cover the land outside of its normal confines, and therefore the perimeter needs to withstand high water levels.

Levees To be able to keep water from inundating the FBF area, levees could be constructed that are designed with the same standards and boundary conditions as the other measures proposed in this report.

Living Shorelines Another protection against high water levels would be to implement the same living shorelines as mentioned earlier on in the report (see chapter 8 on page 113).

Filling, Heightening Ground Level Also heightening the overall ground level would be an option to protect the FBF area from inundation. When the area is high enough, it will not inundate during heavy weather events. Surplus sediment could be used as fill material.

Non-Permanent Measures Non-permanent measures like demountable flood walls can be used to protect the area from inundation. Temporary barriers and demountable barriers are elaborated in chapter JFK (see chapter 6.2).

7.2.2. TRAVERSE MEASURES

A different type of solution regarding integrating FBF into the Jamaica Bay flood projection system would be to ensure that the north western side of the field is protected against flooding. These measures should be connected to the creeks at both sides of FBF and should continually be implemented with the same height as the other measures stated earlier in the report. The section (see figure 7.14) shown earlier roughly follows the proposed traverse measure. To be able to protect the inland from flooding a levee like structure could be implemented.

LEVEE LIKE STRUCTURE FROM MILL BASIN TO GERRITSEN CREEK

To be able to maintain the same level of safety for the whole Jamaica Bay area, an option would be to implement a levee or levee like structure with the same height as the measures to which it connects at Mill Basin on the north side and Gerritsen Creek on the west side (see figure 7.12). To make sure that the important infrastructure would be protected as well, the levee should be located at the east side of Belt Parkway. The levee should be optimized in length, meaning that the shortest route should be determined while still meeting the above stated requirements.

When looking at the traverse measures, the following options for the field area are briefly elaborated:

- Not intervening in ecology
- Restoring historical conditions

FIELD AREA: NOT INTERVENING

The easiest and therefore the cheapest options while still maintaining the same level of safety for the whole region would be to let the FBF for what it is. This means that over time the area might be confiscated by nature meaning that the facilities currently located at FBF would have to move. When looking at the field area from an ecological point of view, the degradation of the shorelines could be seen as irreversible in the long term.

FIELD AREA: RESTORING HISTORICAL CONDITIONS

A more extreme measure when looking at the field area from an ecological point of view would be to help nature in reclaiming its land. Land that was filled in the twentieth century could be excavated and placed at sites that eroded because of human interference. By these means historical conditions could be restored (see figure 7.16). Filled creeks connecting the ocean with the bay can be restored. This could change the tidal movement within the bay and change the erosion process at different location within the whole bay. Although it is hard to determine the cause of erosion, before choosing a restoration measure, further research needs to be done regarding the consequences of such measures.

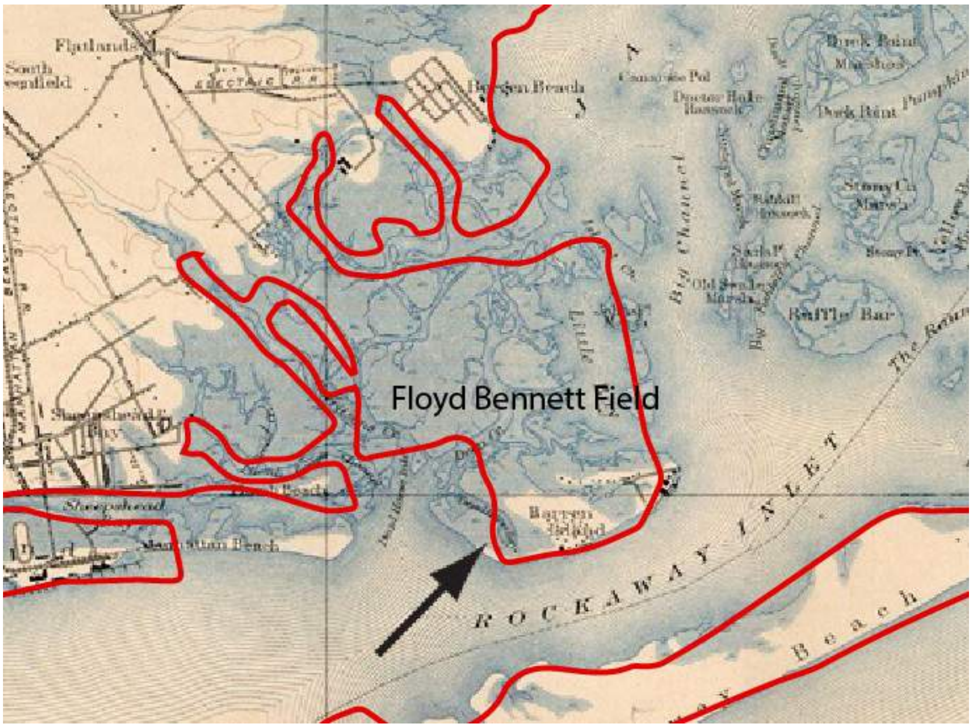


Figure 7.16: 2013 Shoreline overlay on top of a 1898 map

PROTECTION FLATBUSH AVENUE

Flatbush Avenue is an important access route for the Rockaway Peninsula. When looking at a traverse measure for the FBF issue, it is important to look at measures to protect Flatbush Avenue from flooding. Measures like elevating the avenue or surrounding it with a levee could be investigated.

7.2.3. CONCLUSION

Depending on the importance of different outcomes regarding the measures that can be taken the FBF area, both measures along the perimeter as traverse measures could be considered. In the following, the benefits for each of the distinctions are summarized.

FBF Perimeter Measure Benefits

- Maintaining facilities located at FBF
- Keeping FBF from further erosion

Traverse Measure Benefits

- Cheaper
- Improving ecology in the Jamaica Bay area
- Possibly improving tidal movement within the bay

7.3. CANARSIE PIER (CAPTION 3.)

Canarsie Pier is a pier on the North West side of Jamaica Bay in the neighborhood Canarsie. This pier is used as recreational area and fishing. The both sides of the pier will be protected with living shorelines, but something has to be designed for the pier. The living shorelines cannot be connected because of the pier, and connecting them behind the pier is difficult because of the roundabout. However, behind the roundabout lies the heightened Belt Parkway. Figure 7.18 shows the crossing of Belt Parkway and Rockaway Parkway which goes through the center of Canarsie and ends up at Canarsie Pier. This study will only shortly elaborate on this problem and give only one solution (where there is a whole range of solutions possible), the team thinks the discussed solution could be applied over here without that much changes.

Figure 7.17: Top view of Canarsie Pier and infrastructure (Bing Maps)

Figure 7.18: Two pictures of the viaduct near Canarsie Pier. Left: photo taken during a field visit, right: Google Street view, photo taken January 2013 (Left: own photo, right: Google street view)

As can be seen from figure 7.18, Belt Parkway is heightened with only an opening for Rockaway Parkway. The solution this study will suggest is to connect the living shorelines to the heightened Belt Parkway and close of the viaduct during a storm with a temporary structure (see figure 7.19). By doing this, Belt Parkway would act as a levee just like the living shorelines. For different temporary measures see section 6.2.

Figure 7.19: Canarsie Pier Option

7.4. SHELLBANK BASIN/CROSS BAY BOULEVARD (CAPTION 4.)

At the entrance of Shellbank Basin located at Howard Beach (see figure 7.20), Cross Bay Boulevard causes an exception. The boulevard is located close to the shoreline which does not allow enough space for a living shoreline (see figure 7.21).

Figure 7.20: Shellbank Basin Inlet/Cross Bay Boulevard (Bing Maps)

OPTIONS

To make sure the flood protection is also guaranteed at this intersection of infrastructure, a couple of options are briefly elaborated.

- Extending removable floodwalls alongside Cross Bay Boulevard
- Constructing removable floodwalls attached to inlet barrier
- Elevating Cross Bay Boulevard and connection it to inlet barrier

An optimized solution depends on the intended measure for Shellbank Basin. The measures that can be taken can be found in section Creeks/Basins (see chapter 7.1).

7.4.1. EXTENDING REMOVABLE FLOODWALLS ALONGSIDE CROSS BAY BOULEVARD

If it is decided to use removable floodwalls at the Shellbank Basin, a solution would be to extend the walls and connect them to the living shoreline at the western side of Cross Bay Boulevard (left picture in figure 7.22).

Figure 7.21: Shellbank Basin Inlet/Cross Bay Boulevard (Google Maps)

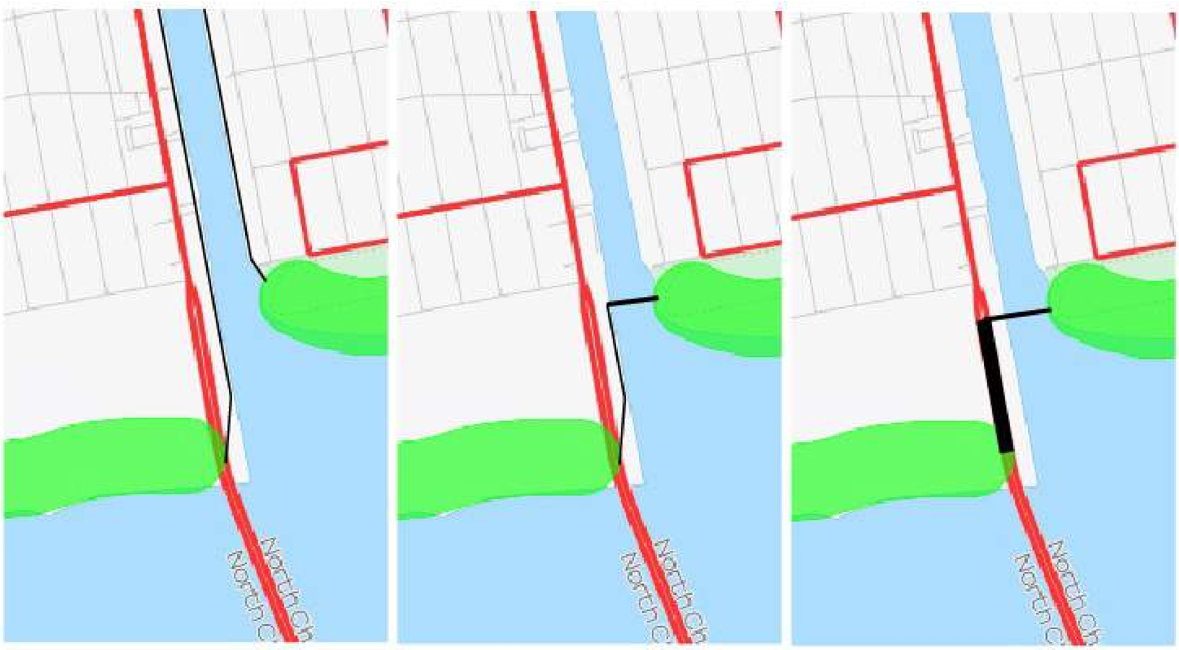


Figure 7.22: Different options for Shellbank Basin/ Cross Bay Boulevard

The entrance point where Cross Bay Boulevard first comes onto shore should be elevated as well to keep the same design level for the whole region.

7.4.2. CONSTRUCTING REMOVABLE FLOODWALLS ATTACHED TO INLET BARRIER

Also if in inlet measure is chosen for Shellbank Basin, removable floodwalls can be used for flood protection. These removable floodwalls would connect the inlet barrier to the living shoreline at the location where Cross Bay Boulevard comes onto shore (middle picture in figure 7.22). Also with this option, Cross Bay Boulevard should be elevated at the point where it comes onto shore, to maintain the right design level.

7.4.3. Elevating Cross Bay Boulevard and Connection it to Inlet Barrier

Instead of elevating Cross Bay Boulevard only at the shore entrance, to protect the inland from inundation, the Boulevard could be elevated up to the point where it can be connected to a barrier in the inlet (right picture in figure 7.22).

7.5. HEAD OF BAY (CAPTION 5.)

The fifth caption shown in figure 2.25 shows the Head of Bay basin as an exception. The Head of Bay basin provides a navigation channel for freight ships to go to the JFK Airport harbor. At the eastern side of Head of Bay the industrial activities are located (see figure 7.23). Also at the shorelines of the Head of Bay basin it is not allowed to create a bird habitat zone, due to regulations (see chapter 3.2.7). This means that the green area marking living shorelines should be implemented without any vegetation that inhabits birds. Another point of attention would be the refreshment rate of the water at this side of the bay (see chapter 2.7). Withing the Head of Bay basin, the refreshment rate extends up to 40 days (see figure 2.21), which means that any pollution stays in the bay a ling time. This could cause a lot of contamination/odors within the basin.

Figure 7.23: Head of Bay (Bing Maps)

OPTIONS

To be able to decide which measures need to be taken for the Head of Bay basin, further research is necessary. The research will help making a benefit cost analyses for each options, and should focus on the impacts of the different measures.

In the following section three of many different options are given to protect the Head of Bay area against inundation (see figure 7.24).

- Navigable surge barrier at inlet
- Extending JFK shoreline measures with separate protection for harbor and borough
- Navigable barrier within dam half way

7.5.1. NAVIGABLE SURGE BARRIER AT INLET

One of the options for the Head of Bay basin would be to implement a navigable barrier (see the upper left options in figure 7.24) at the inlet of the basin (for different types of navigable barriers see 7.1.2). Because of the navigation route tot the JFK harbor, the gate should be chosen by least navigation interference. Closing the inlet would be a relatively easy option, because of the complex conditions at the eastern side of the basin. Also it will shorten the length of the other measures to be implemented. However, because of the interference of a navigable barrier on the in and outflow of the basin, the refreshment rate of the basin could get worse.

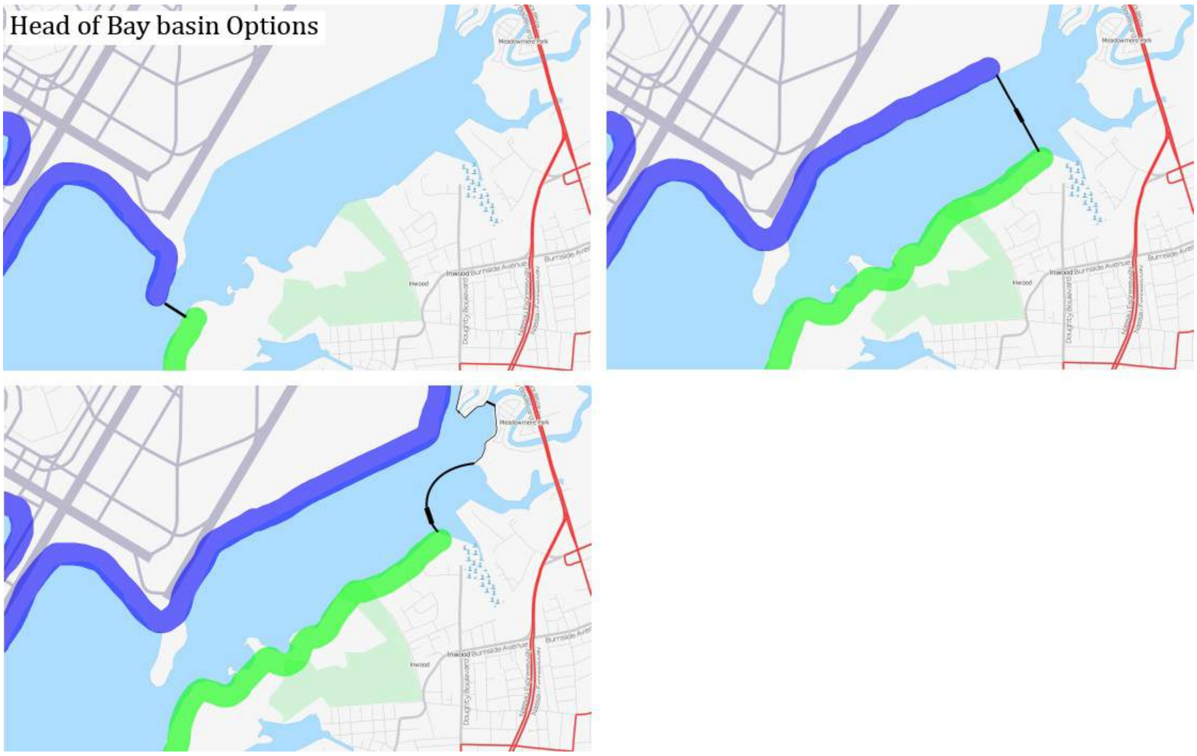


Figure 7.24: Head of Bay Options

Because the time of refreshment already being up to 40 days, further research would have to be done to analyze the impacts of such a barrier.

7.5.2. Extending JFK Shoreline Measures with Separate Protection for Harbor and Borough

Another option is to extend the shoreline protection as proposed for JFK airport and use different kinds op protection for the inhabited area and the JFK harbor (see the lower left options in figure 7.24). The inhabited areas could be protected by removable flood walls and the harbor area by a dam around it. Within this dam, a navigable barrier should be realized to allow ships to dock the harbor. Also at the inhabited areas, navigable barrier should allow recreational navigation to enter the creeks. This way, the refreshment rate of the basin will not get affected as much while still protecting the inland from storm surges. Also, this option allows for the JFK harbor to take protecting measures into its own hands. However, when implementing several different kinds op measures the transition between the measures can be problematic. Also instead of one, multiple navigable barriers need to be constructed, causing higher costs.

7.5.3. Navigable Barrier within Dam Half Way

To decrease the length of the measures a the shoreline of the Head of Bay basin and also decrease the influence on the refreshment rate, a navigable barrier half way the basin is given as an intermediate solution (see the upper right options in figure 7.24). Research could state the the option includes the best op both above stated options. However, it could also be that the option includes the worst of both worlds.

7.5.4. Conclusion

The above stated options are three among many. Below, the benefits of each of the options are stated.

Navigable Surge Barrier at Inlet

- Decreases length of total measures
- Least complex option

- Probably the cheapest option

Extending JFK Shoreline Measures with Separate Protection for Harbor and Borough

- Less interference with refreshment rate of water in basin
- Allows for different stakeholders to take protection in own hand

Navigable Barrier within Dam Half Way

- Has the potential of including the best of the above stated options

7.6. ROCKAWAY BRIDGES (CAPTION 6.)

At the bay side of Rockaway Peninsula are two bridges connecting the peninsula with Brooklyn and Queens. Marine Parkway Bridge goes over Rockaway Inlet and connects West Rockaways to Floyd Bennett Field and Brooklyn, this is also the location where measures change. West of Marine Parkway Bridge, nourishment-like measures are considered, east of the bridge innovative "improved banks" are considered. More to the West, Cross Bay Bridge is situated to connect this part of the peninsula with Broad Channel and Queens. On both sides of this second bridge improved banks will be considered. The difficulty is to connect the measures on both sides of the bridge. This problem has to be addressed for both bridges separately. Both locations are shown by the red dots with number 6 in figure 7.25.

Figure 7.25: Showing the location of both bridges

7.6.1. MARINE PARKWAY BRIDGE

Marine Parkway Bridge is shown in figure 7.26. The photo shows the banks just West from the bridge and the bridge itself. One can see that there is a small tunnel within the bridge foundation for pedestrians. The solution for this bridge can be pretty simple as it seems and can be almost similar to the Canarsie Pier solution. Both measures surrounding the bridge have to be connected to the bridge and the tunnel should be closed by a non permanent measure. More on these non permanent measure can be found in section 6.2. For the remainder of the study it will be assumed that a temporary measure will close the tunnel during storms.

7.6.2. CROSS BAY BRIDGE

Cross Bay Bridge is a more complex situation as can bee seen from figure7.28. The bridge has multiple branches connected to the shore. Figure 7.25 shows the boardwalk which goes under the bridge. Closing all openings off with temporary measures and connecting these to each other is difficult and probably not safe. Because it is desirable to keep this boardwalk open for pedestrians an potential cyclists, it is also not an option to heighten the whole boardwalk. A possibility is to design a floodwall or a temporary floodwall which can be activated if needed. A floodwall can easily be connected to the measures surrounding the bridge. More on non permanent floodwalls can be found in section 6.2. More on permanent floodwalls can be found in section **??**. It will be assumed a floodwall will connect the measure surrounding the bridge to each other.

Figure 7.26: Photo taken during a field visit. This photo is taken West of the Marine Parkway Bridge facing the bridge

7.7. Broad Channel (Caption 7.)

In the middle of Jamaica Bay one can find Broad Channel, a marsh island partially wildlife refuge (northern part) and partly inhabited (southern part). Furthermore there are two fresh water pond on either side of the island; the smaller West Pond and East Pond. Both ponds were breached by Sandy, West Pond is likely to stay open and become a salt water pond, the East Pond breach has been repaired to protect the environment within the pond. According to CBS New York [46] every house on Broad Channel had inundations and was damaged by Sandy. Figure 7.30 is an example of the damage that is still visible in Broad Channel.

Broad Channel is one of lowest lying areas within the bay and for that reason very vulnerable. The banks of the southern part of the island are about +4.0 feet (+1.22 meter) NAVD88 and the highest location is about +7 feet (+2.13 meter) NAVD88 (see figure 7.32).

Table 3.2 on page 37 shows the flood heights for the Jamaica Bay region. Because there is no flood height given for Broad Channel, the mean flood heights within the bay will be used as an approximation. The figures are again shown in table 7.1.
It can be seen that the mean tide level is about +0.07 m NAVD88 which is only 1.15 m lower than the banks of Broad Channel. Mean flood level is determined to be +0.86 m NAVD88 which is just 0.36 m lower than the banks. For spring flood, which is determined to be +1.03 m NAVD88, there is only 0.19 m between the water level and the banks. In figure 7.33 these water levels are added to the cross section of Broad Channel, it can be seen that during spring tide the water level is almost equal to the banks of Broad Channel. This spring flood level is without waves, so with adding that one can imagine that the water is in the low parts of the island of the island. An inhabitant mentioned that he had to move his car during spring flood because otherwise the water would damage it.

Figure 7.27: Photo taken during a field visit. This photo is taken West of the Cross Bay Bridge facing the bridge

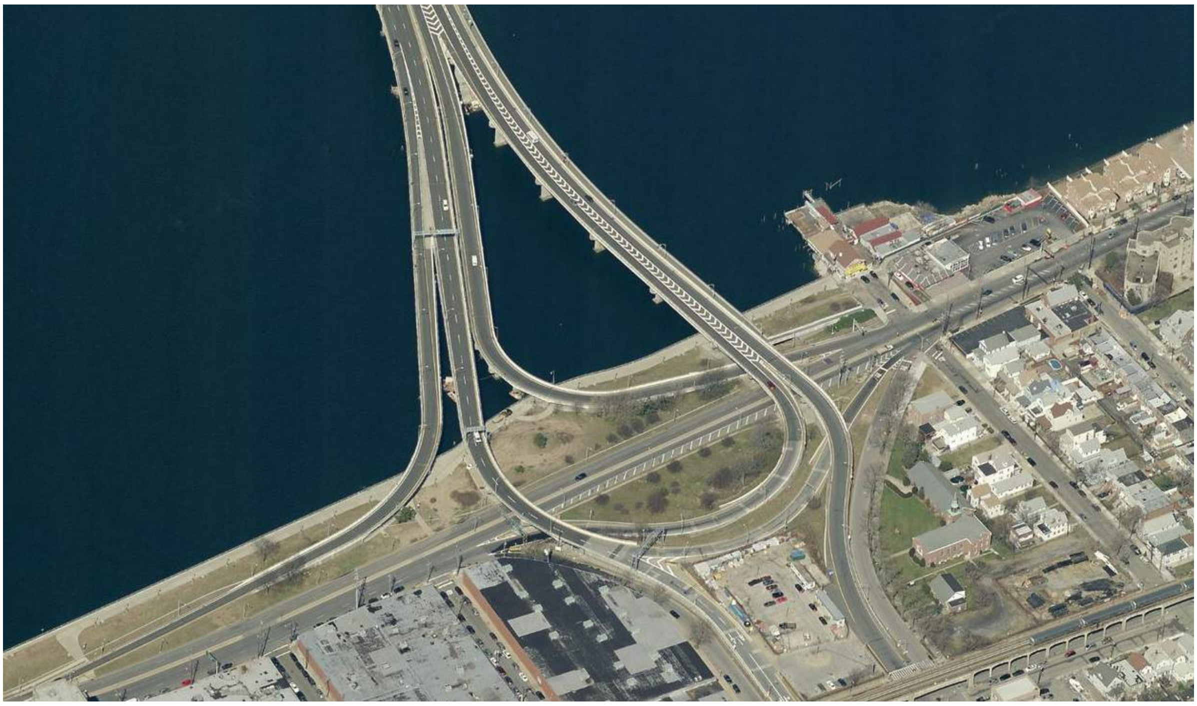


Figure 7.28: A topview of Cross Bay Bridge showing the different connections to shore (Bing Maps)

Figure 7.29: Board Channel Overview (Bing Maps)

Jamaica Bay	Mean tide level (m) relative to MLLW	Mean tide level (m) relative to NAVD88	Mean Flood Height relative to NAVD88	Spring Flood Height relative to NAVD88
Mean over all locations	**0.85**	**0.07**	**0.86**	**1.03**

Table 7.1: Tide level and flood ranges approximated for Broad Channel

Because of the above described situation,the location within Jamaica Bay and the choice to have an open Jamaica Bay (a barrier in the Jamaica Bay Inlet would protect Broad Channel), Broad Channel is not within the scope of this study. Only a few basic principles will be discussed shortly. There are three basic principles the team has determined for Broad Channel:

1. Strategic retreat
2. Improved building codes in combination with evacuation
3. Protect Broad Channel from flooding

Strategy 1 means that people living in Broad Channel have to abandon it and nothing will be done to protect the properties. This strategy will not be elaborated on because of the harsh effects for current inhabitants and political difficulties associated with this strategy.

Strategy 2 means that Broad Channel's buildings have to be improved so that they can withstand a 1/100 year storm. During a storm the inhabitants should be evacuated because of safety reasons. Aerts et al. (2013) [12] already discussed the possibilities of improved building codes and the associated benefits.

Strategy 3 implies that some sort of barrier or levee has to be built around Broad Channel to protect it from future storms. The measure should encircle at least encircle the Broad Channel buildings.

The team thinks strategy 2 is probably easiest applicable and most cost effective. It will be assumed that one of these measures will be designed for the remainder of this study.

Figure 7.30: Damaged house in Broad Channel, photo taken during a field visit October 2013

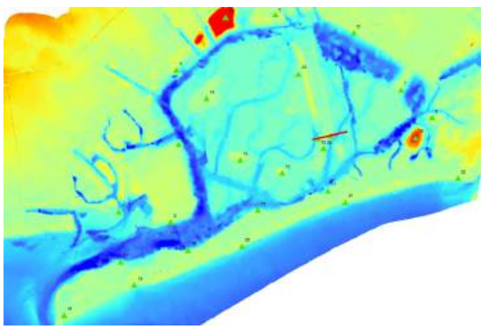


Figure 7.31: Location of the section in figure 7.32 in a DEM

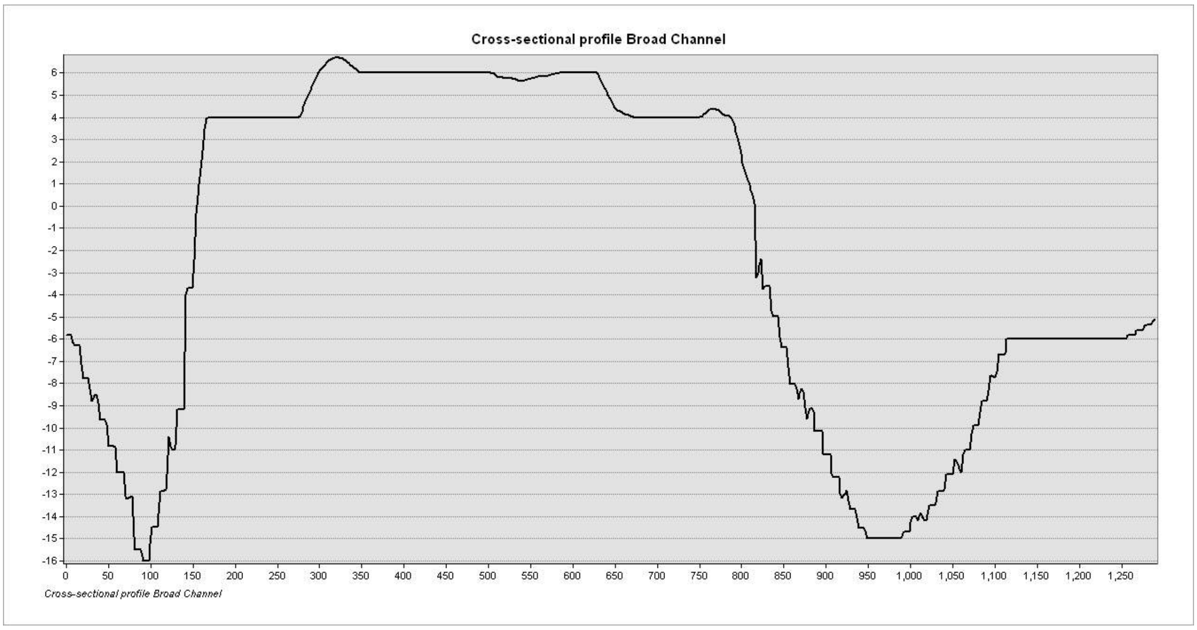


Figure 7.32: Cross section Broad Channel at the location shown in figure 7.31. Horizontal axis shows distance in meters and the vertical axis shows the elevation in feet

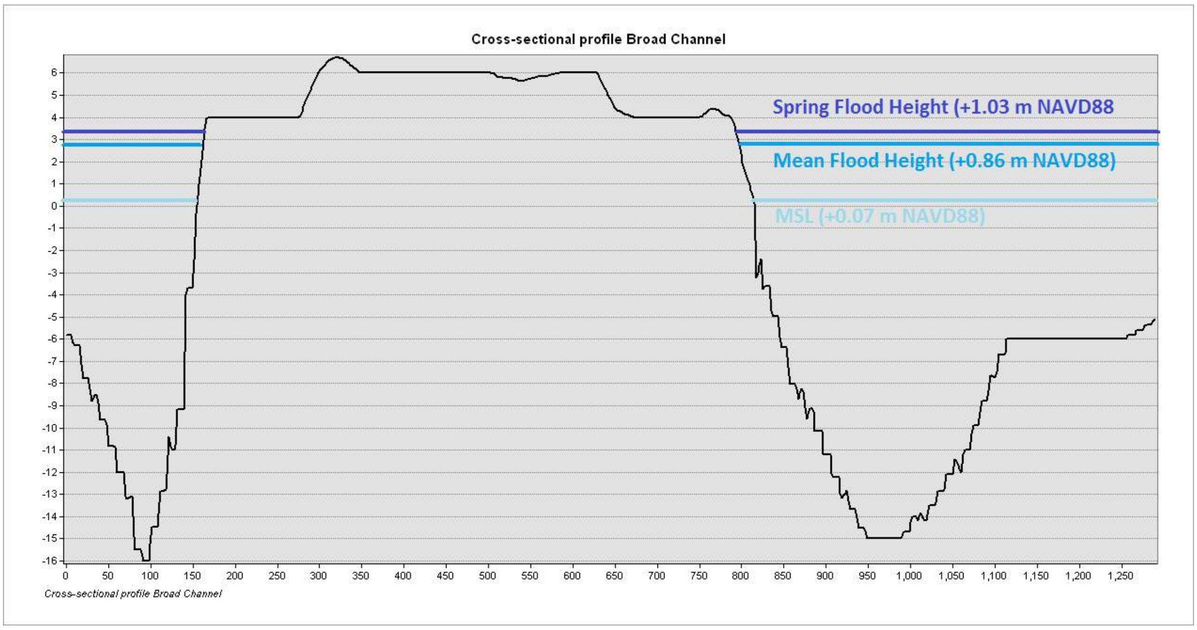


Figure 7.33: Cross section Broad Channel at the location shown in figure 7.31. Horizontal axis shows distance in meters and the vertical axis shows the elevation in feet. Mean water levels from table 3.2 are added

8

Living Shorelines

8.1. Introduction

The Jamaica Bay shorelines used to be inter tidal wetlands. Because of the filling throughout the 20th century, the surface at the perimeter of the bay has been raised and the bay it self has been dredged at multiple channel locations (see chapter **??**). This interference with nature caused that the natural way of protecting the inland from the ocean has been compromised.

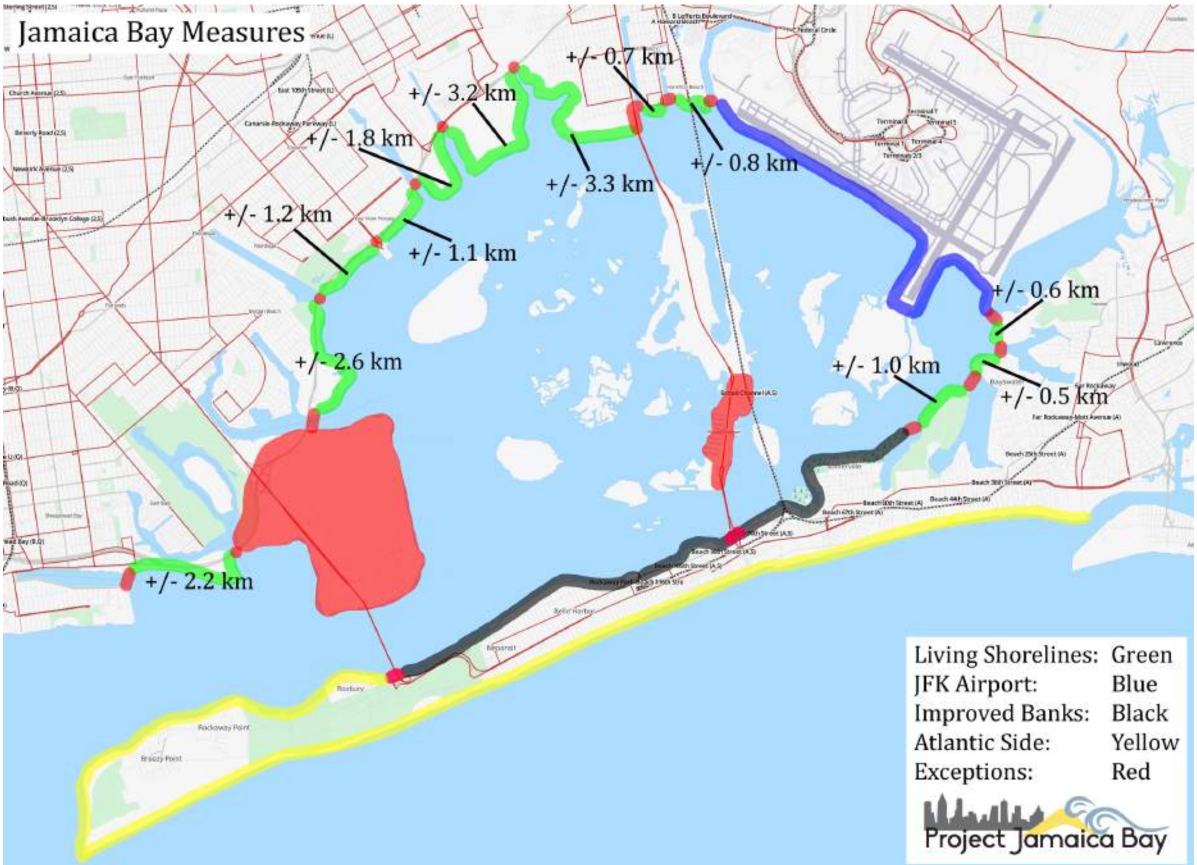


Figure 8.1: Jamaica Bay Living Shoreline Lengths

8.1.1. Ecology

The Jamaica Bay area inhabits around at least 335 species of birds and because it is the largest intact estuarine ecosystem in New York City (see chapter **??**), it accounts for the largest part of the NYC wildlife. This is why when proposing measures for the area, the ecology needs to be taken into account.

HUMAN INTERFERENCE

The Jamaica Bay is an important wildlife habitat which has been affected by human interference. Because of the past filling resulted in the degradation of the wildlife habitat, severe altering of the region is not allowed present day. Anything that affects the regions ecology needs to be researched and will be difficult to pass regulations. Also, nature can be use to cover parts of the functions that need to be integrated into a flood defense structure. For instance, instead of a hardened revetment, vegetation can function as a erosion control mechanism. This is why in this study, living shorelines are proposed as a way to mitigate flood risk and also help the ecology develop.

8.1.2. TECHNICAL SPECIFICATIONS

Instead of leaving the wetlands as a barrier for ocean protection, throughout time people started inhabiting the Jamaica Bay shore area. The flood protection balance has been affected and this caused inundation problems along the Jamaica Bay shorelines. To be able to protect the inland from inundation the proposed measures for the Jamaica Bay shorelines need to be design by certain boundary conditions (see chapter 3.2). At the location of the proposed living shorelines, the average 100 year design elevation is around 4.2 meter with respect to NAVD88. The 100 year wave height averages around 0.95 meter.

LOCATION

The locations where the living shorelines are proposed to be implemented are shown in figure 8.1. The proposed locations total approximately 19 kilometers of shoreline. The amount of space that is available for a measure depends on the different locations. With fewer space, the design needs to differ from a location with more space. At the end of this chapter a design will be given regarding two of the different areas.

Figure 8.2: Bird Habitat Zone Radius

When looking at regulations (see chapter 3), it is not allowed to create a bird habitat within 1 mile of JFK airport (see figure 8.2). Around 3 km of the green marked shorelines in figure 8.1 lie within the 1 mile radius of JFK airport. It should be noted that further research is needed regarding the proposed living shoreline and whether it creates a bird habitat. If so, chapter 7 gives examples of how other measures can be used to protect these areas from flooding.

8.2. REFERENCE PROJECTS

The ability to integrate green solutions into flood protection systems has been gaining attention for the last couple of years. The knowledge about vegetation benefits are still developing. This section will elaborate on a couple of project that integrates ecology and flood protection.

Figure 8.3: Fort Steurgat Location, green marks the area that is planned to be given back to nature (de Vries & Dekker, 2009)[1]

8.2.1. FORT STEURGAT WEKENDAM (DE VRIES & DEKKER, 2009)[1]

At the Noordwaard, located near Werkendam, the Netherlands, plans regarding reverse land reclamation and redevelopment arose questions for flood protection in the area (see figure 8.3). At Fort Steurgat, levees would not pass flood risk regulation anymore. Fort Steurgat was used in the former Dutch Water Defense line and is a monument. This is why it needs to be protected for flooding.

Instead of conventional methods to raise a levee, research was done to use vegetation for flood protection. The proposition is to create a levee with a small slope. De Vries & Dekker (2009)[1] state that because of the mild slope, the structure will look like raised ground level, instead of looking like a levee. The design chosen involved a wave reducing vegetated zone in front of the levee (see figure 8.4). Because of the boundary conditions, the vegetation chosen were willow trees. The report states that the 100 meters of willow vegetation reduce the wave height by 70 tot 90 percent. In this particular case this would mean that the height of the structure could be reduced by about 65 centimeters.

8.2.2. WADDEN SEA DIKE

In 1932, Dutch construction companies finished the Wadden Sea Dike (or Afsluitdijk), creating a giant lake, the IJsselmeer, and protecting the Netherlands form storm surges. In 2008, DHV together with Imares and Alle Hosper formed a consortium that recommended the Dutch Government to create inter tidal marshes in front of the Wadden Sea Dike to increase flood protection combined with creating a nature area with recreation opportunities (IWA Publishing, 2008 [48]). The reinforcement of the dike would must be finished in 2015 and would include tidal marshes on the Wadden sea side of the dike. The plant growth and introduction of sediment would allow the tidal marshes to grow on their own.

Figure 8.4: Fort Steurgat Concept Design (de Vries & Dekker, 2009)[1]

Figure 8.5: Wadden Sea Dike Impression (de Vries, 2013)[47]

According to the Wadden Sea project, the building with nature solution has a number of advantages opposed to the conventional way of reinforcing a dike. It is a quick way of reinforcing. It can be implemented within budget. The shoreline forms a buffer, increasing safety. Also with the establishment of thirty kilometers of tidal marshes it will establish 1500 hectares of new natural area boosting recreation[49].

8.3. BUILDING WITH NATURE

All around the world, deltas and coastal zones are urbanizing rapidly. By 2050, predictions are that half the world population will be living in cities in coastal zones (Ecoshape, 2012)[50] There are a lot of benefits of living near water, but also down sides. The ecology of these zones is important for several reasons, while within these zones chances of flooding are present. Because of climate change these questions become more challenging. An opportunity of combining the sustainable functions of the ecosystem and protecting developed areas from flooding could be building with nature. Instead of using conventional measures that are designed with a specific hydraulic level and failure mechanisms, building with nature looks at stabilizing soil, slowing down flows and reducing wave height.

Figure 8.6: Wadden Sea Dike Sketch (de Vries, 2013 [47])

For the last couple of years, Deltares has been doing research regarding biogeomorphology. Biogeomorphology encompasses researching the interaction between marsh vegetation, waves, water flows and sediment transport. Because conventional measures are neither resilient nor sustainable and mostly sub optimal for other uses (Van Slobbe et al., 2012[51]), using nature in mitigating flood risk can be beneficial in several ways.

8.3.1. ADVANTAGES AND DISADVANTAGES

When looking at nature, it has benefits over the conventional way of hydraulic engineering. But there are also down sides.

REDUCING WAVE HEIGHT

Instead of using hard revetments to protect a levee from erosion and several forms of fail mechanisms, living shorelines can be designed to reduce the wave height. The reduction in wave height can undermine the need for revetments on a levee like structure.

Wave attack is dangerous for a levee because waves contain high levels of energy. The energy is stopped by the levee which results in forces that can cause the levee to fail. A living shoreline could be used as a buffer zone to dissipate the wave energy meaning that the levee does not get exposed to large forces.

Depending on factors like the density, the roughness and the height of vegetation, wave height reduction can be estimated. Not only emerged vegetation can be used to dissipate wave energy, also submerged vegetation has a significant influence.

MAINTENANCE

An ecosystem is a constantly changing system, while conventional measures are designed to stay the same for a long period of time. Maintenance is an important factor for these measures to stay the same, and it is usually costly. Benefits of living shorelines are that they are in constant motion and therefore could be more easily maintainable[47]. Also, because of the root-like structure of vegetation, a living shoreline can be well resistant against erosion. This increases the durability of the shorelines and also enhances the storage of sand (Augustin et al., 2008)[52].

The costs of maintenance are mainly caused by the vegetation that is planted on the shorelines. The vegetation needs to be pruned. Also infrastructure needs to be available to remove the vegetation waste. The pruning of the vegetation also has an influence on the wave energy reduction of the shoreline. This means that the party that will be pruning the vegetation should be well informed.

Living shorelines are usually more heterogeneous than conventional measures. The downside is that calculations regarding the safety of ecological systems are more often rough estimations and therefore safety margins need to be larger.

Figure 8.7: 1780, 1840 and 1898 Map of Jamaica Bay

ADJUSTABILITY

Because vegetation has the ability to change relatively quickly, it can easily cope with challenges like sea level rise (Ecoshape, 2012)[50]. Throughout time, inter tidal wetlands have been able to cope with changing conditions. Figure 8.7 shows the changes the Jamaica Bay went through from 1780 to 1989. However, this meant changing and giving up land at some locations but also reclaiming land at other locations. The fact that developed areas can not easily be altered brings complications. When looking at building with nature, the positive sides of the changing ecology need to be exploited while still being able to maintain the developed areas. An advantage of building with nature is also that it is easily adjustable when the shorelines need to satisfy different requirements (de Vries & Dekker, 2009)[1]. For instance, when the living shorelines would be heightened, nature has its way of adapting. This means that on the new surface level, new plants will arise.

CONSTRUCTION TIME

When looking at construction time, the difference between conventional measures and building with nature is that the vegetation needs time to grow. It has been estimated that in about two years time the vegetation on the living shorelines will be of intended density (de Vries & Dekker 2009)[1]. Before the vegetation is fully developed, protective measures like coir logs could be implemented to keep the shoreline from eroding. Also possible storm surges need to be monitored. In the case that a surge is predicted to hit shore within these two years, temporary protective measures need to be stand on stand by. For instance geo synthetic tubes can be used as temporary measure. For instance, during Sandy, the US Army Corps of Engineers used geo synthetic tubes to keep Plumb Beach from eroding.

MULTI PURPOSE

At most points, the living shorelines leave enough space to implement other purposes. For instance, a cycling path could be interesting for the development of the area. Also different forms of recreation or pilots regarding the production of bio fuel could be implemented.

FINANCIAL FEASIBILITY

The construction costs of living shorelines is estimated to be similar to conventional levees (de Vries & Dekker. 2009)[1]. However, when looking at the benefits, living shorelines could be more economically feasible. Also future adaptation would probably be less costly.

ECOSYSTEM AND AESTHETICS

Opposed to a conventional levee, living shorelines can boost the ecosystem of the Jamaica Bay area. Strips of nature along the Jamaica Bay shore can serve as breeding ground for all sort of species. In the last couple of years, ecology has become a much larger item.

Also the aesthetics are beneficial to living shorelines. Instead of a massive levee, when implemented correctly, the living shorelines will look like a gradual raising of the surface. It will look more naturally which means that from first site human interference can not be noticed.

8.4. VEGETATION

To be able to reduce wave height during a storm, vegetation is needed. Before designing the living shoreline, it is important to get to know the vegetation in the Jamaica Bay area and analyze the characteristics of the different kinds of vegetation. Because of the Jamaica Bay originally being a divers ecological area, there are several types of vegetation that could be used to estimate the wave dissipation. In the next section, out of the vegetation available in the area a selection is made to be used in the estimations.

8.4.1. KINDS OF VEGETATION IN THE JAMAICA BAY AREA

The Jamaica Bay inhabits hundreds of species of vegetation (see chapter 2). Because of this being a preliminary design, for designing the living shorelines, only few of the species are used. Table 8.1 shows several types of vegetation that are common in the Jamaica Bay area.

Name Plant	Height (up to)	Diameter Stern (up to)	Type	Photo Identified
Ulva Latuca	-	-	Sea Grass	-
Schizachyrium Scoparium	-	-	Grass	-
Panicam Virgatum	-	-	Grass	-
Spartina Patens	-	-	Grass	-
Spartina Alterniflora	-	-	Grass	-
Ammophilia Breviligulata	0.9 m	-	Grass	-
Toxidendron Radicans	1.2 m	-	Shrub	-
Berberis Thunbergii	1.5 m	-	Shrub	-
Solidago Sempvirens	1.2 - 1.8 m	-	Shrub	-
Elaeagnus Umbellate	3.5 m	-	Shrub	Yes
Polygonum Cuspidatum	3 - 4 m	-	Shrub	-
Prumus Maritima	4 m	-	Shrub	-
Myrica Pensylvanica	4.5 m	-	Shrub	-
Phragmites Australis	2 - 6 m	-	Shrub	-
Betula Populifolia	6 - 9 m	0.4 m	Tree	-
Rhus spp.	10 m	-	Tree	-
Ilex Opaca	10 - 20 m	0.5 - 1 m	Tree	Yes
Salix spp.	14 - 21 m	-	Tree	-
Populus Grandidentata	18 - 24 m	2.4 - 3 m	Tree	Yes
Ailanthus Altisima	17 - 27 m	1 m	Tree	Yes
Prunus Serotina	15 - 30 m	0.7 - 1.2 m	Tree	-
Celtis Occidentals	30 m	-	Tree	Yes
Populus Deltoids	20 - 40 m	1.8 m	Tree	-
Pinus Thunbergii	40 m	-	Tree	-

Table 8.1: Vegetation in the Jamaica Bay area (Rhoads et al., 2001) [27]

Figure 8.8: Photo's of Vegetation from Field Visit, From Left To Right: Ilex Opaca, Populus Grandidenta, Ailanthus Altisima

USED VEGETATION

Every different species has its own characteristics. Some of these characteristics are given and could be used to estimate the wave dissipation. From the species shown in table 8.1, five are identified during field visits to the bay (see figure 8.8). The three kinds of trees from which the height and the diameter of the stern are estimated are used for wave dissipation estimations. These species are: Ilex Opaca, Populus Grandidenta and Ailanthus Altisima. They are chosen for further calculation because they are likely to survive along the shorelines of the Jamaica Bay, since they are already there.

When further research would be done regarding living shorelines, the vegetation should be chosen on several requirements.

- The vegetation should be strong enough to cope with storm surges
- The vegetation should be able to cope with inundation, as the first couple of meters lie within the tidal range
- The vegetation should be already growing in the Jamaica Bay region, as it will probably survive in the future
- The chosen vegetation should be easily maintainable

8.4.2. ROUGHNESS OF VEGETATION

Where water flows along a basin perimeters, the flow loses energy. Both Manning and Chezy have researched this phenomenon. As shown in the following equation, Manning states that the velocity of water flow is inversely related to the roughness of the perimeter.

$$V = \frac{k}{n} R_h^{2/3} S^{1/2}$$

Where:
V is the cross-sectional average velocity
k is a conversion factor
n is the Gauckler-Manning roughness coefficient
R_h is the hydraulic radius
S is the slope of the water surface or the linear hydraulic head loss

In the following table, a couple of estimated Gauckler-Manning roughness coefficients are given. These are the coefficients of types of vegetation that are located in the Jamaica Bay area. These coefficients can be used to calculate the reduction of energy when water flows over inundated marshes, or living shorelines.

Description	**Manning Coefficient n**
Fresh Marsh	0.055
Intermediate Marsh	0.050
Brackish Marsh	0.045
Saline Marsh	0.035
Wetland Forest	0.150
Upland Forest	0.170
Wetland Shrub	0.070
Upland Shrub	0.080

Table 8.2: Roughness of Vegetation (Bunya et al., 2010) [53]

WAVE DISSIPATION

The Manning equation is used open channel flow calculations and assumes the flow is fully turbulent. During storm conditions, flows are likely to be turbulent. The roughness of vegetation reduces energy of water flow. In the same way, when incoming waves get in contact with the (inundated) vegetation, the energy of the waves gets dissipated (Augustin et al., 2008) [52].

8.5. CONCEPTUAL DESIGNS

Before starting the design process, a distinction is made between two areas. First of all, the Canarsie Pier area is used to calculate wave dissipation. The Canarsie Pier area is used, because there is only 95 meters of room between the shoreline and the Belt Parkway. The second area of which the wave energy dissipation is calculated is the Howard Beach area. At the southern shoreline of Howard Beach in between the shorelines and the inhabited area is approximately 350 meters of room to implement living shorelines.

8.5.1. CANARSIE PIER SHORELINES

When looking at the Canarsie Pier shorelines, the cross section (figure 8.22) shows that there is about 95 meters of space from the shore (at +0.07m NAVD88) to the Belt Parkway (at +2m NAVD88). Within this range, three optional living shorelines are given. The three options differ when looking at the slope. The three options are:

1. **Living Shoreline with Constant Slope**
2. **Living Shoreline with Natural Slope**
3. **Living Shoreline with Gentle Slope**

The three options have different effect on the wave height reduction, and also on the amount of fill material that is needed. Later on in the report, calculations can identify the effectiveness in reducing wave energy of the three options. The goal is to reduce the approximately 1 meter high waves to .2 meter. The following paragraphs will elaborate on the different options.

REQUIREMENTS

In order to meet demands from different kinds of stakeholders and still being able to protect the inland from inundation, the following requirements should be met:

- The original shoreline should not change, as no alterations can be made within the bay
- Assuming sufficient wave height reduction, the design level must be at +5.45 meter NAVD88 (Storm Surge Level + .5 meter)
- The cycling path along the shoreline should stay in tact
- The vegetation should be accessible for pruning, and removing the pruned material

8.5.2. OPTION 1: CONSTANT SLOPE

In this option, the living shoreline has the same slope throughout to whole section (see figure 8.9). As the slope at the bay side of the living shorelines is estimated to be 70 meters wide, and the highest point is about 5.5 meters high, the slope should be approximately at a 4.5 degree angle. This angle would allow for infrastructure for the maintenance of the shoreline.

Because there is no part of this option with a strong slope, it should be well resistant against erosion. However, this option does require a lot of landfill.

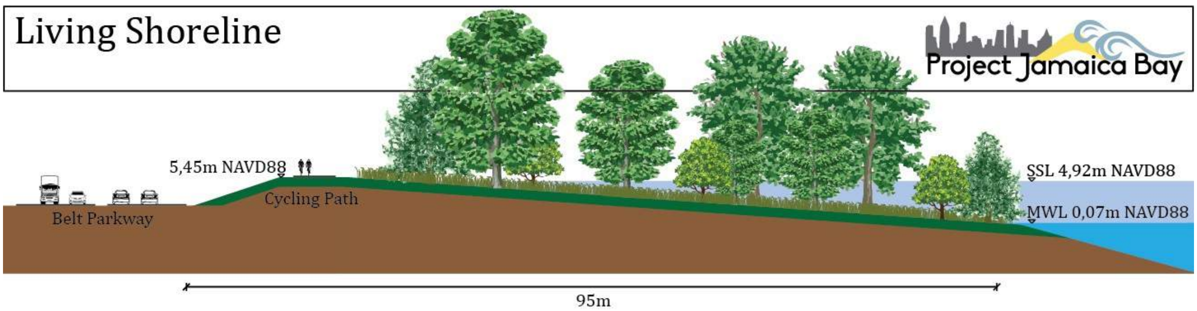


Figure 8.9: Living Shoreline Option 1

8.5.3. Option 2: Gentle Slope with Levee

In the current situation, the slope of the Canarsie Pier shorelines run from water level (+0.07 m NAVD88) to the Belt Parkway at approximately +2 m NAVD88. The second option involves the construction of a levee at the Belt Parkway side of the shoreline (see figure 8.10). Also vegetation should be planted along the shoreline to dissipate wave energy.

The advantage of this option is that it would not take a lot of altering along the shorelines. Also less fill material is needed. The disadvantage is that the relatively steep levee is likely to be more sensitive to erosion.

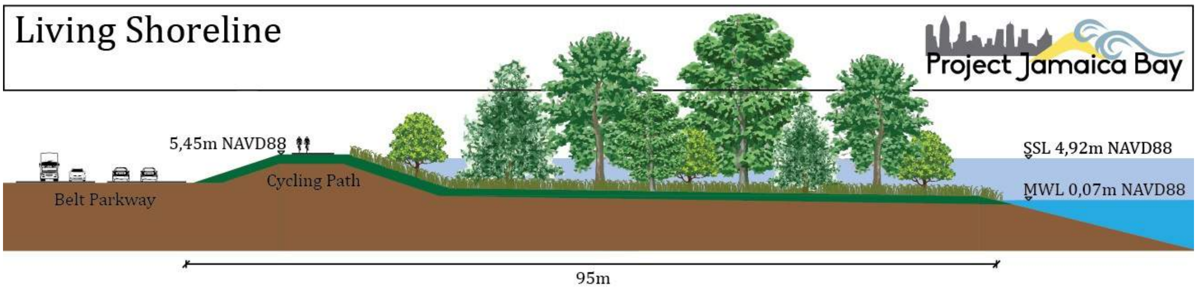


Figure 8.10: Living Shoreline Option 2

8.5.4. Option 3: Natural Slope

Calculations should point out the difference between wave height reduction of vegetation at an angle, and reduction on a relatively flat surface. This protection should be compared to the amount of fill material needed for option 1. Also the aesthetics need to be taken into account. The first option looks more like a natural area than the second option.

When looking at the advantages and disadvantages of the first two options, the third option is a combination of the first two options and could include the best things of both side (see figure 8.11). Namely, because of the more natural slope, it could be more aesthetically suiting than the second option and need less fill material than the first option. However, it is important that the level of protection is guaranteed.

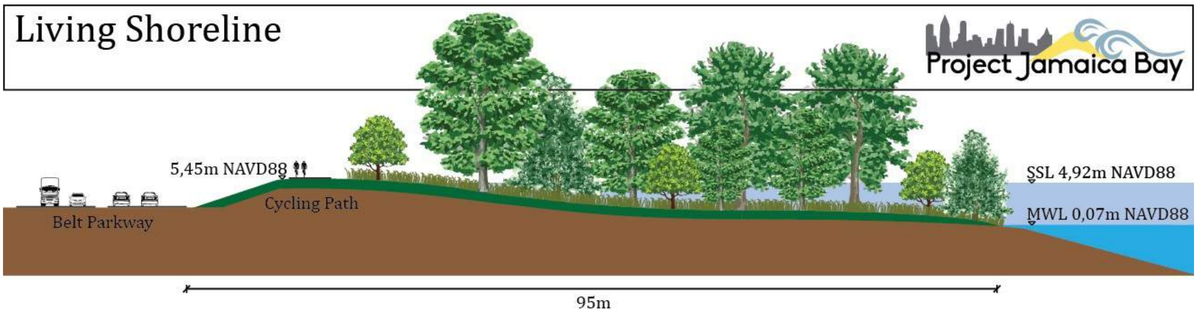


Figure 8.11: Living Shoreline Option 3

8.5.5. Cycling Path Closer to Shore

When looking at the three options, the cycling path is close tot the Belt Parkway. This is similar to the current situation. However, to make cycling along the Jamaica Bay shore more attractive, the cycling path could be move closer to the shoreline. In this way the cycling experience does not get affecting by the noisy expressway. Also the ability to cycling through nature could boost the amount of cyclist.

Figures 8.12, 8.13 and 8.14 show different locations where the cycling path could be situated. The closer the path lies to the shore, the more attractive the view of the bay gets. Also less noise from the Belt Parkway will be heard, because of the levee and the vegetation. However, also the vulnerability of the cycling path regarding storm surges should be taken into account. When including sea level rise, the cycling path should not be situated within the tidal range.

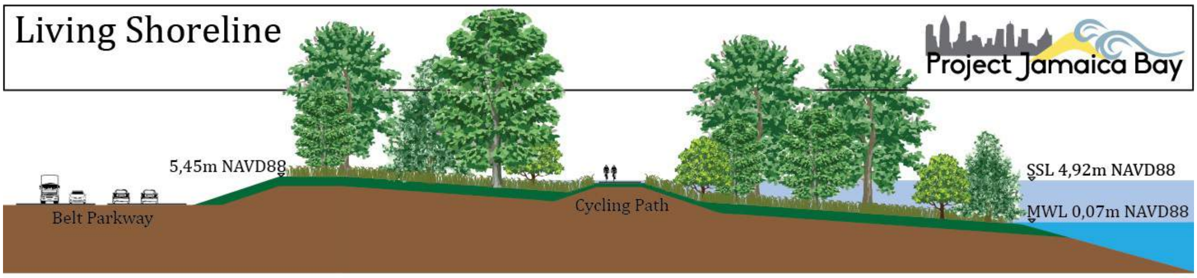


Figure 8.12: Living Shoreline Option 1 with changed Cycling Path

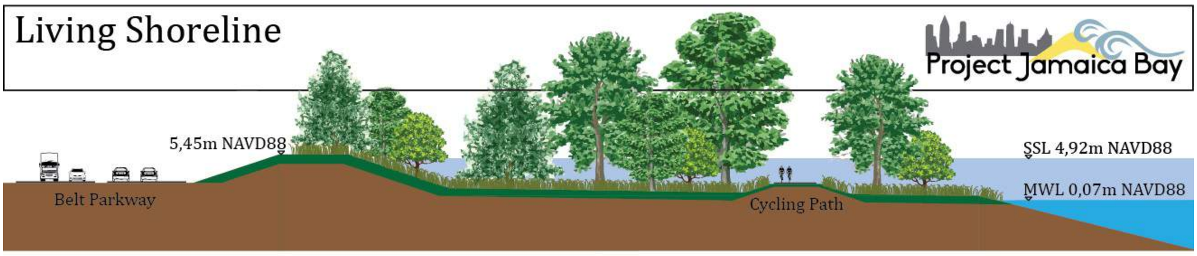


Figure 8.13: Living Shoreline Option 2 with changed Cycling Path

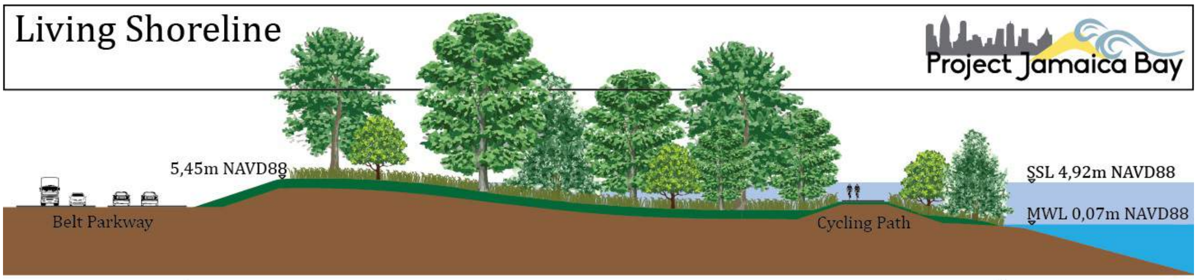


Figure 8.14: Living Shoreline Option 3 with changed Cycling Path

8.6. WAVE ENERGY DISSIPATION

Waves can be classified with respect to their wavelength in relation to the water depth or similar with the wave number multiplied by the water depth. Some of the wave characteristics change when waves propagate from deep into shallow water. Based on the wave characteristics in the Jamaica Bay, shallow-water waves have to be considered. The orbital movement of the wave will therefore be constant and linear, see figure 8.15.

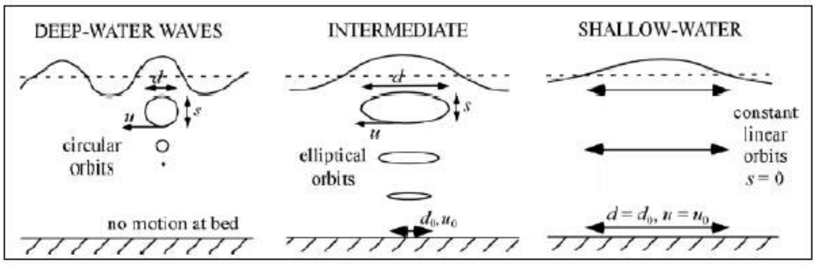


Figure 8.15: Classification for waves and their orbital movement

ANALYTICAL APPROACH

Wave attenuation depends on different characteristics of the plant: geometry, density, stiffness, degrees of freedom and spatial configuration as well as wave parameters (mainly wave height, period and direction). Waves propagate through vegetation and lose energy due to the work carried out on the vegetation (Mendez and Losada (2004)[54]). As the waves propagate, their energy E is transported. The energy transport velocity is the group velocity c_g. As a result, the wave energy flux through a vertical plane of unit width perpendicular to the wave direction, is equal to: $P = Ec_g$. An impression of this model is shown in figure 8.16.

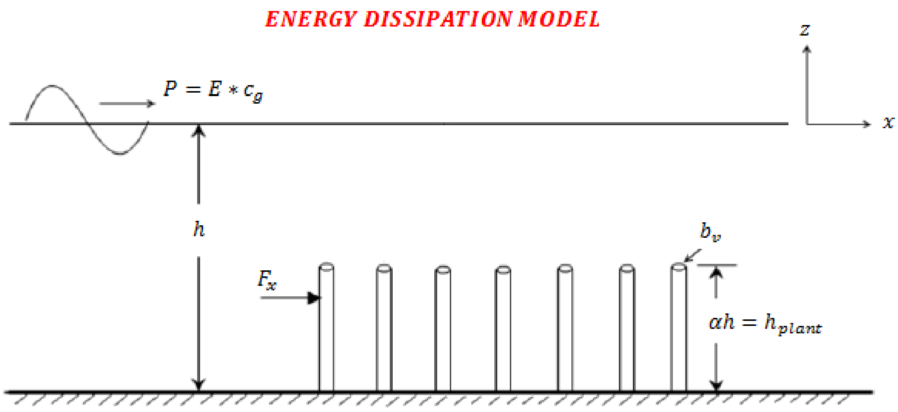


Figure 8.16: Energy dissipation by vertical rigid cylinders

If it is assumed that the linear wave theory is valid and considering (nonbreaking) regular waves normally incident on a coastline, the conservation of energy equation is reduced to:

$$\frac{\delta E c_g}{\delta x} = -\varepsilon_v \tag{8.1}$$

Where $E = (1/8)\rho g H^2$ is the energy density, H is the wave height, g is the acceleration of gravity, ρ is the water density, c_g is the group velocity, x is the onshore coordinate and ε_v is the time-averaged rate of energy dissipation per unit horizontal area induced by the vegetation. Furthermore it is assumed that the linear wave theory is valid for the waves, not to calculate the velocity in the water part but also within the vegetation area. The common numerical description of the effect of vegetation on waves is based on the representation of vegetation by vertical rigid cylinders and was derived by Dalrymple. The physical vegetation properties that are considered in his formulation are the relative vegetation height, vegetation diameter, density and the drag coefficient. He expressed the energy dissipation, which is only due to drag force, for waves propagating through a vegetation field as (Mendez and Losada (2004) [54]):

$$\varepsilon_v = \frac{2}{3\pi}\rho C_d b_v N (\frac{kg}{2\sigma})^3 \frac{\sinh^3 k\alpha h + 3\sinh k\alpha h}{3k\cosh^3 kh} H^3 \tag{8.2}$$

Herein:
ε_v = time-averaged rate of energy dissipation per unit horizontal area $[Nm^{-1}s^{-1}]$
C_D = drag coefficient [-]
b_v = plant stem diameter $[m]$
N = number of plants per square meter $[m^{-2}]$
k = wave number $[m^{-1}]$
σ = wave frequency $[s^{-1}]$
αh = vegetation depth $[m]$
h = waterdepth $[m]$
H = wave height $[m]$

The calibration parameter of Dalrymple is the drag coefficient. This is of importance for determining the wave dissipation due to vegetation. The value of the drag coefficient is depended on the Reynolds numbers and on the shape and orientation of the object. In practice, in a vegetation field the flow regime is turbulent ($Re > 2300$). Calculations of the Reynolds number for one single stem when using cylinders with a diameter equal to a mangrove tree and a Spartina plant, show the Reynolds numbers is in the range of area B (see figure 8.17). This means that the drag coefficient for one rigid cylinder has a value of around 1 (M.C. Meijer (2005) [55]). Another important factor is the water level above the vegetation. It must be noted that Dalrymple does not include reflection by plants. However, the importance of this factor is very limited (Mendez and Losada (2004) [54]).

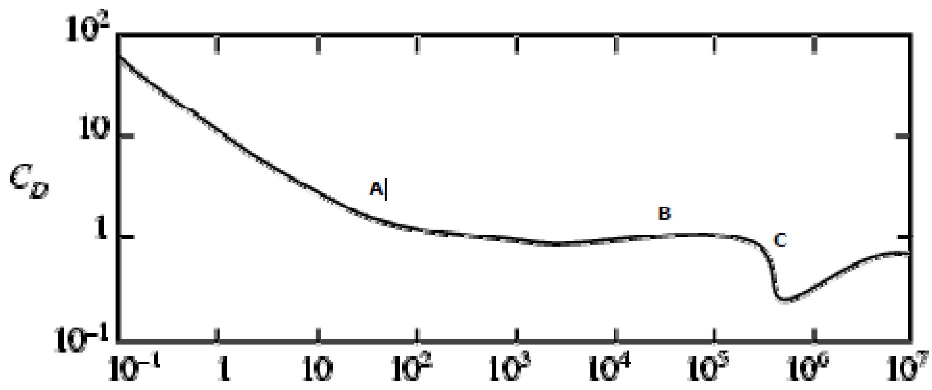


Figure 8.17: Relation between Reynolds number and drag coefficient for a single circular cylinder in flow (Battjes 1999)

HORIZONTAL BOTTOM

For the case of a horizontal bottom, combining and solving equations 8.2 and 8.1, with boundary condition: $H(x=0) = H_0$ (the wave height at the seaward limit of the vegetation field), leads to [54]:

$$H = K_v H_0 \tag{8.3a}$$

Herein:

$$K_v = \frac{1}{1+\beta x} \tag{8.3b}$$

$$\beta = \frac{4}{9\pi} C_d b_v N H_0 k \frac{\sinh^3 k\alpha h + 3\sinh k\alpha h}{(\sinh 2kh + 2kh)\sinh kh} \tag{8.3c}$$

(8.3d)

EMPIRICAL APPROACH

Also a lot of empirical research have been done regarding this subject. One of those empirical researches (CUR 200, 1999) has been done with reed. Reed is a very common used vegetation. Everywhere at the boundaries of soil and water, reed can be found. It does not matter whether it is placed in fresh or salt water. Moreover, reed grows in clay, peat and sandy soils. The following results for wave transmission have been produced (Schiereck (2012 [40]):

$$K_T = \frac{H_T}{H_I} = 1 - [1 - \exp(-0.001 N^{0.8} \frac{B}{\cos\beta})] \tag{8.4}$$

in which: N is the number of stalks per m^2, B is the width of the vegetation and β is the angle of incidence of the waves. Also the velocity is reduced due to the vegetation because the vegetation makes the bed more rough. The equivalent Chezy-value for vegetation and the Chezy-formula are:

$$C_{veg} = \sqrt{\frac{g}{0.5NDh}} \tag{8.5}$$

In this formula D is the diameter of the stalks and h is the water depth. Considering the Chezy-formula:

$$u = C\sqrt{RI} \tag{8.6}$$

with R is the hydraulic radius and I the bed slope. A first approximation of the velocity reduction is found by assuming that the water level slope is equal for the main flow and the bank.

$$\frac{u_{veg}}{u_{open}} = \frac{C_{veg}}{C_{open}} \frac{\sqrt{h_{veg}}}{\sqrt{h_{open}}} \tag{8.7}$$

Both wave damping and roughness due to planted reed are shown in figure 8.18

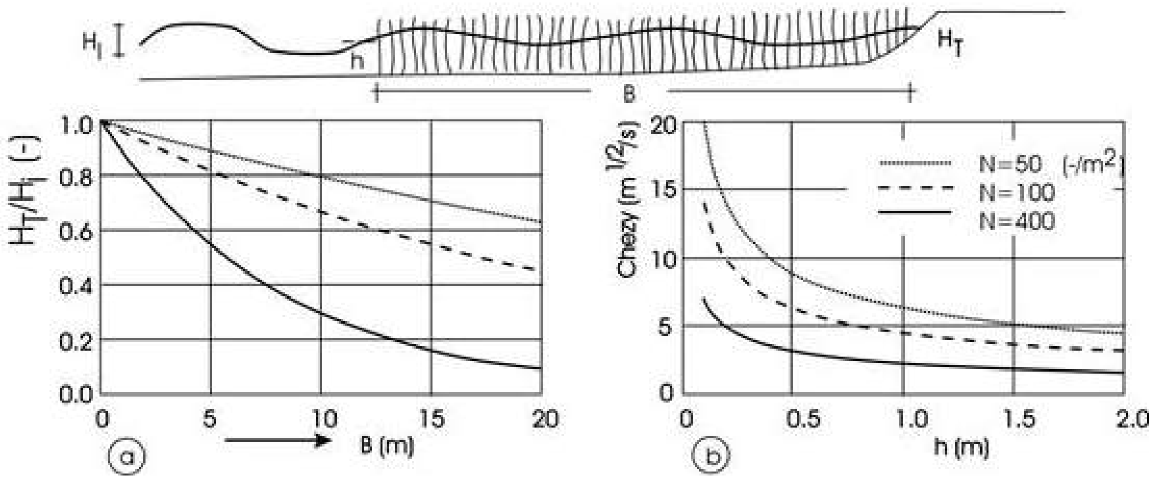


Figure 8.18: Reed wave damping and roughness

8.6.1. EROSION CONTROL

From the previous chapter it has become clear that vegetation can function as a load reductor. It is not self-evident that plants and trees reduce the erosion. The vegetation can be considered as a cylinder. The accelerated flow initiates an erosion hole around the cylinder. The roots of trees and plans appear to function as a bottom protection (Schiereck (2012 [40]). It is not very clear yet whether the roots reduces the load around the stern or serve as an additional armor of the soil. However, roots reduce the erosion around vegetation. For example, willow trees reduces scour with 40 % with roots only directly around the stem. With a root system extending much further from the stem, the reduction was approximately 75 % ((Schiereck (2012) [40]).

8.6.2. GRASS ANALYTICAL APPROACH

A grassed clay dike revetment is one of the types of revetments used with the aim of preventing erosion of a dike by braking waves. Grass can withstand a considerable wave height and high current velocities. In the Netherlands much research on the interaction of grass and strength has been conducted. A relation is derived between the erosion speed and the wave height for various types of grass. On a theoretical basis, it is assumed that there is a cubic relation between the wave height and the erosion speed.

$$E_{grass} = c_E * H_s^2 \tag{8.8}$$

Herein:
E_{grass} = erosion speed of the grass [m/s]
c_E = erosion coefficient [$m^{-1}s^{-1}$]
H_s = significant wave height [m]
The c_E can be determined by considering the quality of the grass:
good quality grass: 0.5-1.5 [$10^{-6}m^{-1}s^{-1}$]
modest quality grass: 1.5-2.5 [$10^{-6}m^{-1}s^{-1}$]
low quality grass: 2.5-3.5 [$10^{-6}m^{-1}s^{-1}$]
In figure 8.19 the erosion speed versus the wave height for the different grass qualities is illustrated. This

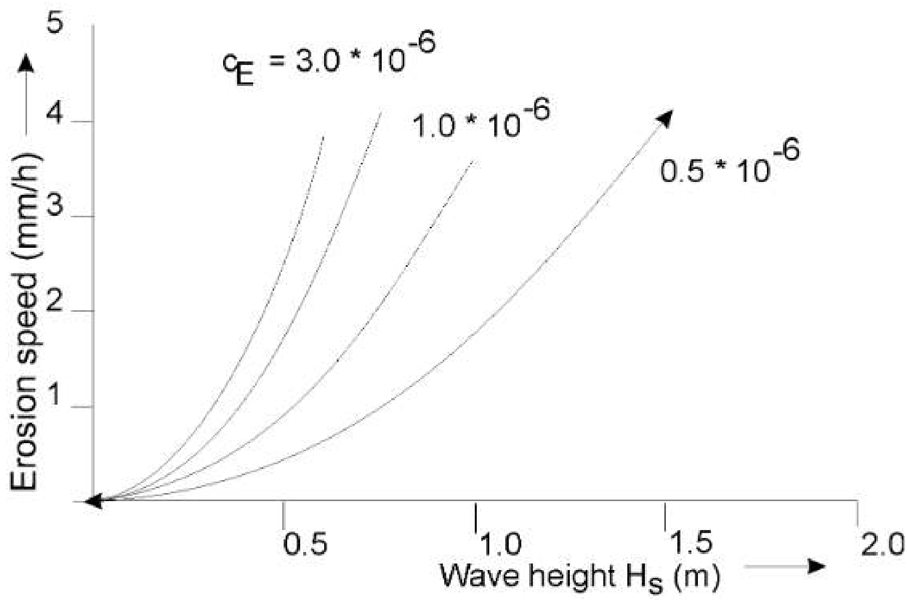


Figure 8.19: Erosion speed versus wave height for the different erosion coefficients c_f

formulation is a basis for the allowable duration of wave attack versus duration of the attack:

$$t_{max} = \frac{d}{\gamma E_{grass}} = \frac{d}{\gamma c_g H_s^2} \tag{8.9}$$

in which:
t_{max} = maximum allowable load duration
d = thickness of the turf (grass + clay layer)
γ = safety coefficient
Figure 8.20 shows the result for a normal situation (d=0.05 m and $\gamma = 2$). Grass on dikes can stand waves of H_s=1.5 m as long as the quality of the grass is good and the storm does not last longer than several hours ((Schiereck (2012 [40]). When the waves are higher than the maximum of 1.5 meter, the zone of maximum attack should be covered with an additional hard revetment (e.g. riprap) but grass can still be applied in the run up zone. According figure 8.20 good grass layers can withstand waves lower than 0.4 m for several days.

8.6.3. ADDITIONAL LOAD REDUCTORS

If the currents and waves caused by the storm exceed the values what a vegetation can restrain, the strength of the applied vegetation have to be increased. There are different ways of strengthening.

REINFORCED VEGETATION

The strength of the revetment can be increased by applying a fascine mattress. A single layer of stone is applied not to hinder the stone growth (Schiereck (2012 [40]). If the plants are not fully grown, and therefore the roots are not capable of preventing erosion, an geotextile has to be applied. An illustration of reinforced vegetation is shown in figure 8.21.

LOAD REDUCTORS

When the loads are definitely too great for vegetation to survive, a load reductor in front of the bank can be sometime a solution hence Schiereck (2012). One of those solutions is a rockfill dam. This dam is a hard structure and works as a kind of breakwater. An advantage of this measure is that the original shore can stay intact. The experimental results done with this dam structure are:

$$\frac{H_T}{H_I} = (\frac{B}{H_I})^{-0.31}(1 - e^{-0.5\xi})F_{dam} \tag{8.10}$$

F_{dam} represents the type of dam and are shown in table **??**.

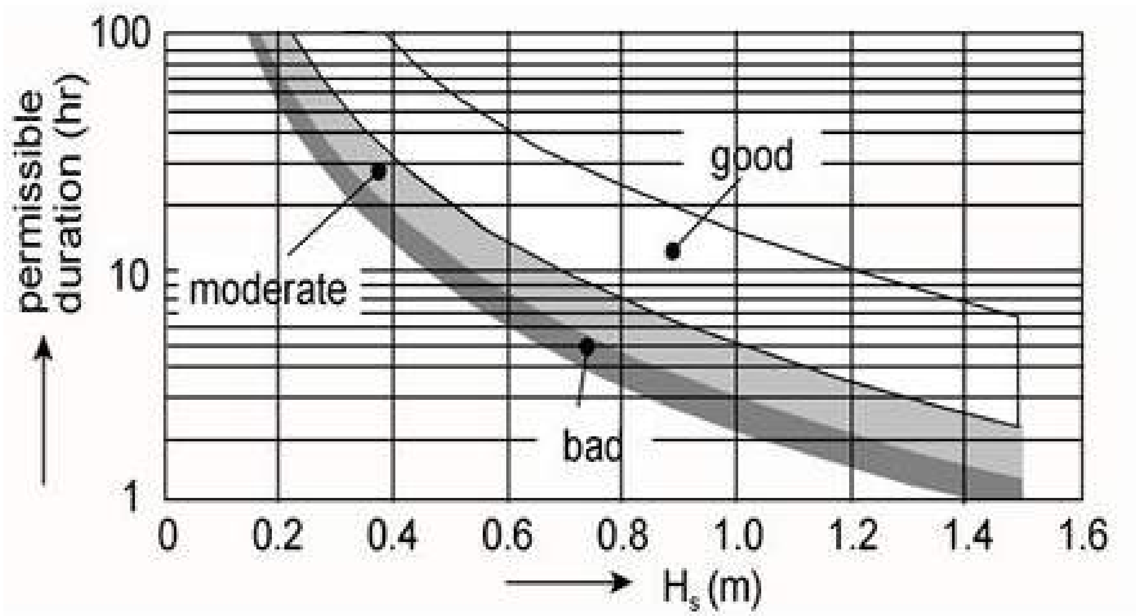


Figure 8.20: Allowable duration of wave attack versus the grass quality

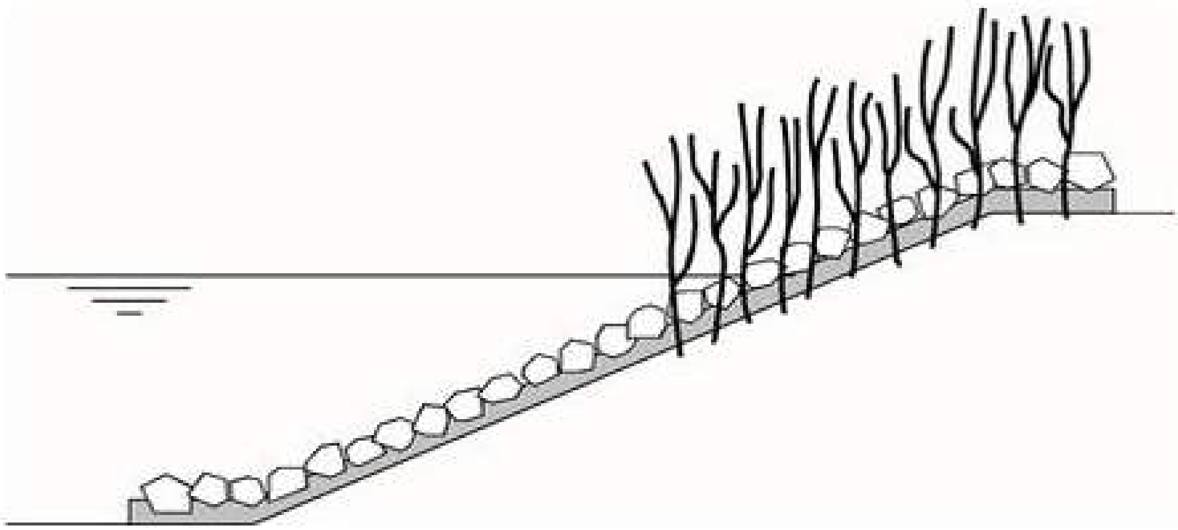


Figure 8.21: Reinforced vegetation

8.6.4. PRACTICAL APPLICATION

During this design chapter the analytical theory presented by Mendez and Losada (2004) [54] will be used. The effectiveness of Chordgrass vegetation (i.e. Spartina Alterniflora/Smooth Chordgrass/Salmarsh Chordgrass) is studied. The two areas differ in the amount of space, i.e. the available space at Carnasie Pier is much less than at Howard Beach. The theory of Mendez and Losada is based on a horizontal bed (no slope), which is in contrast to a situation on a levee. However, because of the mild slope at Canarsie Pier and Howard Beach (respectively 1/13 and 1/64) the theory of a horizontal water depth can be used, hence Mendez. The next step is to determine the constant water height which will be used for these calculations. For both areas the governing water height is +4.92 m NAP (including 0.65 m sea level rise). In this chapter a (rounded) water height of +5 m NAVD88 will be used. Calculation will be done based on two different options. Within option 1, a steep slope based on the required levee height is considered. Option 2 is based on the current situation; the mild slope which is currently present plus an additional levee to retain the water height during storm conditions.

Dam type	Rock	Gabions	Closed asphalt or pitched blocks)
F_{dam}	0.64	0.7	0.8

Table 8.3: Different F_{dam} values of the corresponding dam types

8.6.5. CANARSIE PIER

When considering the banks near Canarsie Pier, an height cross-section is made and shown in figure 8.22. The 0 NAVD88 line is defined as the shoreline. The wave height (H_0) is 0.98 m. Furthermore the water levels

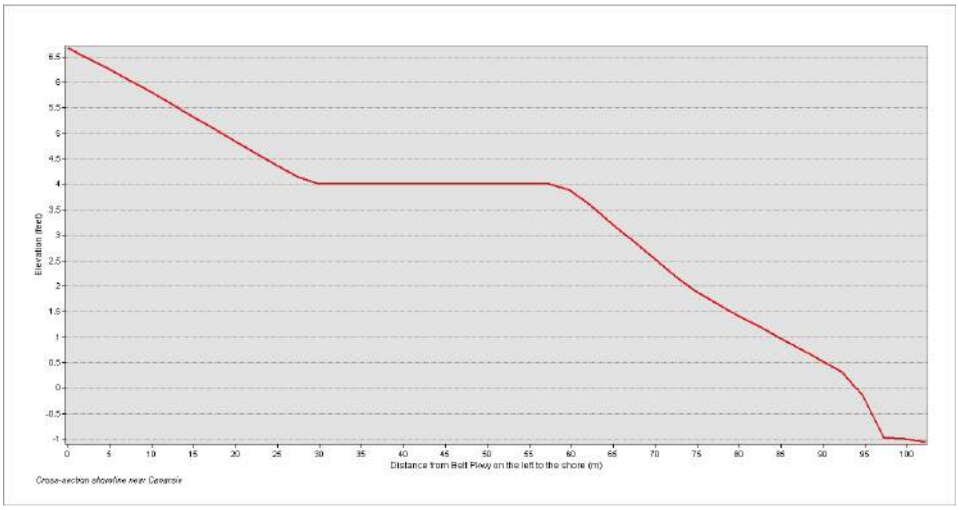


Figure 8.22: Cross-section shoreline near Canarsie Pier

(h) are respectively +2.5 m NAVD88 for option 1 and +4.0 m NAVD88 for option 2 (including sea level rise). The two considered options for Canarsie Pier are shown in figure **??** and figure **??**. Firstly the wave reduction is studied by applying Spartina Alterniflora (Smooth Cordgrass). Typical characteristics of this vegetation are: b_v = 1 cm and h_{plant} = 1.0 - 2.4 m (Augustin et al. (2008)[52]). A photo of this grass is shown in figure 8.23. Furthermore Augustin et al. state that the common density (N) is between 100-600 m^{-2}. To keep sufficient

Figure 8.23: Spartina Alterniflora

space available for constructing an inner slope next to Belt Parkway, a width of 70 m will be considered to construct a (possible) living shoreline. Applying a constant water depth of 2.5 m and three different vegetation densities, the Maple calculation results are shown in table 8.4 for $h_{plant} = 1.5m$ and in table 8.5 for $h_{plant} = 2.0$. Furthermore in figure 8.24 it is shown how the wave height is reduced with the onshore coordinate for $N = 300\ m^{-2}$ and $h_{plant} = 1.5$. Furthermore the governing wave period is 2.4 s and the shallow water equations are used to calculate the wave height.

Density [stems per m^2]	H [m] when x = 70 m	reduction [%]
100	0.48	50
200	0.32	67
300	0.24	75
600	0.14	86

Table 8.4: Maple calculation results with Spartina Alterniflora with $h_{plant} = 1.5m$ and $h_{water} = 2.5m$

Density [stems per m^2]	H [m] when x = 70 m	reduction [%]
100	0.35	64
200	0.21	78
300	0.15	84
600	0.08	91

Table 8.5: Maple calculation results with Spartina Alterniflora with $h_{plant} = 2.0m$ and $h_{water} = 2.5m$

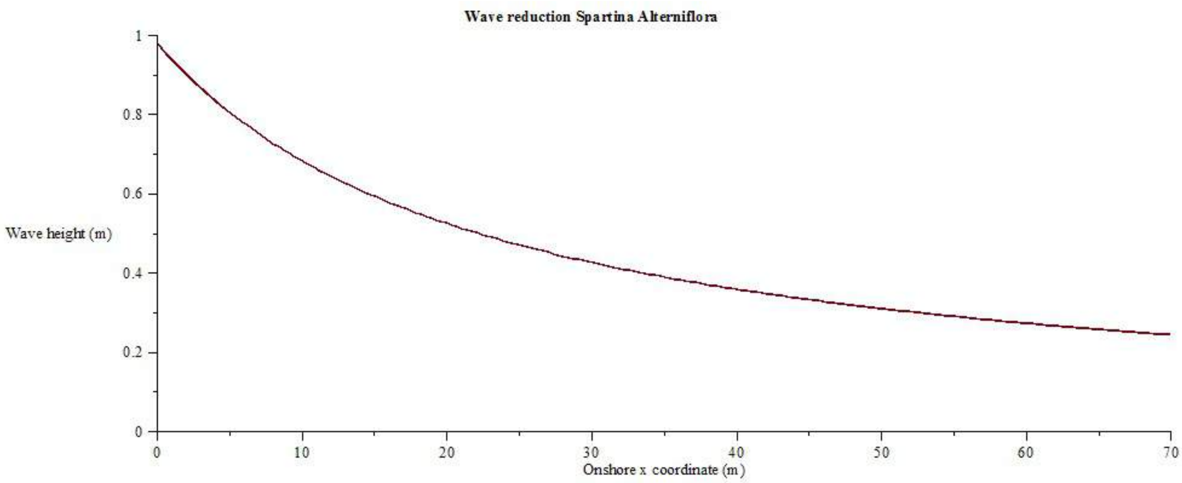


Figure 8.24: Wave reduction by Spartina Alterniflora versus bank length with N = 300 m^2, $h_{plant} = 1.5m$ and $h_{water} = 2.5m$

The next step is to study the wave reduction for option 2; applying a (constant) water depth of $h_{water} = 4.0\ m$. The same hydraulic parameters and vegetation diameter is used in this calculation. Again two different plant heights are used, 1.5 m and 2.0 m. The Maple calculation results are shown in table 8.6 and 8.7.
The plot, when applying N = 300 m^{-2}, $h_{plant} = 1.5m$ and $h_{water} = 4.0\ m$ is shown in figure 8.25.

8.6.6. HOWARD BEACH

Secondly, the possibility of constructing living shorelines at Howard Beach is considered. At Howard Beach there is much more area available than at Canarsie Pier. An height cross-section is made and shown in figure 8.26.
The 0 NAVD88 line is again defined as the shoreline. The wave height (H_0) and the water level height (h_0) are respectively 0.95 m and +4.92 m NAVD88 (including sea level rise). To keep sufficient space available for constructing an inner slope next to the neighborhoods of Howard Beach, a width of 350 m will be considered to construct a (possible) living shoreline. The same Maple scripts are used but obviously with the other values. The water height will be rounded, like in the previous chapter, to +5.0 m NAVD88.

Density [stems per m^2]	H [m] when x = 70 m	reduction [%]
100	0.81	17
200	0.69	29
300	0.60	39
600	0.43	56

Table 8.6: Maple calculation results with Spartina Alterniflora with $h_{plant} = 1.5m$ and $h_{water} = 4.0m$

Density [stems per m^2]	H [m] when x = 70 m	reduction [%]
100	0.74	25
200	0.59	40
300	0.49	50
600	0.33	66

Table 8.7: Maple calculation results with Spartina Alterniflora with $h_{plant} = 2.0m$ and $h_{water} = 4.0m$

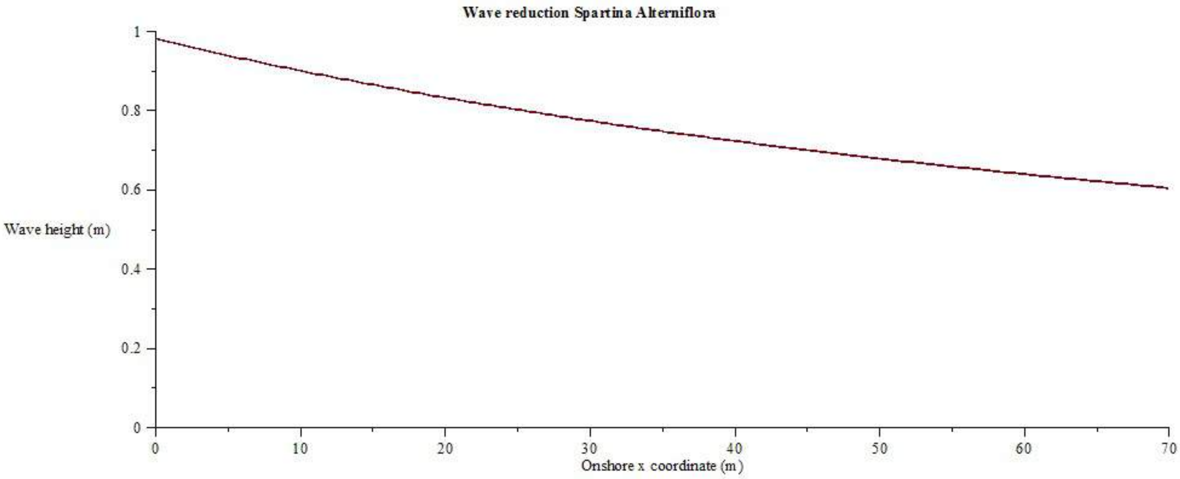


Figure 8.25: Wave reduction by Spartina Alterniflora versus bank length with N = 300 m^{-2}, $h_{plant} = 1.5m$ and $h_{water} = 4.0m$

SPARTINA ALTERNIFLORA/CHORDGRASS

In the first calculation for Howard Beach, the applied vegetation height is $h_{plant} = 1.5\ m$ with $h_{water} = 2.5\ m$, the diameter of the stem is again 1 cm. The calculations are done in Maple and the results are shown in table **??** and in table **??**. The Maple plot for $h_{plant} = 1.5\ m$ and $N = 300\ m^{-2}$ are shown in figure 8.27.

The next step is to study the wave reduction for option 2; applying a (constant) water depth of $h_{water} = 4.0\ m$. The same hydraulic parameters and vegetation diameter is used in this calculation. Again two different plant heights are used, 1.5 m and 2.0 m. The Maple calculation results are shown in table 8.10 and 8.11. Furthermore a plot is shown in figure 8.28.

Density [stems per m^2]	H [m] when x = 350 m	reduction [%]
100	0.16	84
200	0.09	91
300	0.06	94
600	0.03	97

Table 8.8: Maple calculation results with Spartina Alterniflora with $h_{plant} = 1.5m$ and $h_{water} = 2.5m$

Density [stems per m^2]	H [m] when x = 350 m	reduction [%]
100	0.1	90
200	0.05	95
300	0.04	96
600	0.02	98

Table 8.9: Maple calculation results with Spartina Alterniflora with $h_{plant} = 2.0m$ and $h_{water} = 2.5m$

Density [stems per m^2]	H [m] when x = 350 m	reduction [%]
100	0.48	51
200	0.32	68
300	0.24	78
600	0.14	86

Table 8.10: Maple calculation results with Spartina Alterniflora with $h_{plant} = 1.5m$ and $h_{water} = 4.0m$

Density [stems per m^2]	H [m] when x = 350 m	reduction [%]
100	0.37	62
200	0.23	77
300	0.17	83
600	0.09	91

Table 8.11: Maple calculation results with Spartina Alterniflora with $h_{plant} = 2.0m$ and $h_{water} = 4.0m$

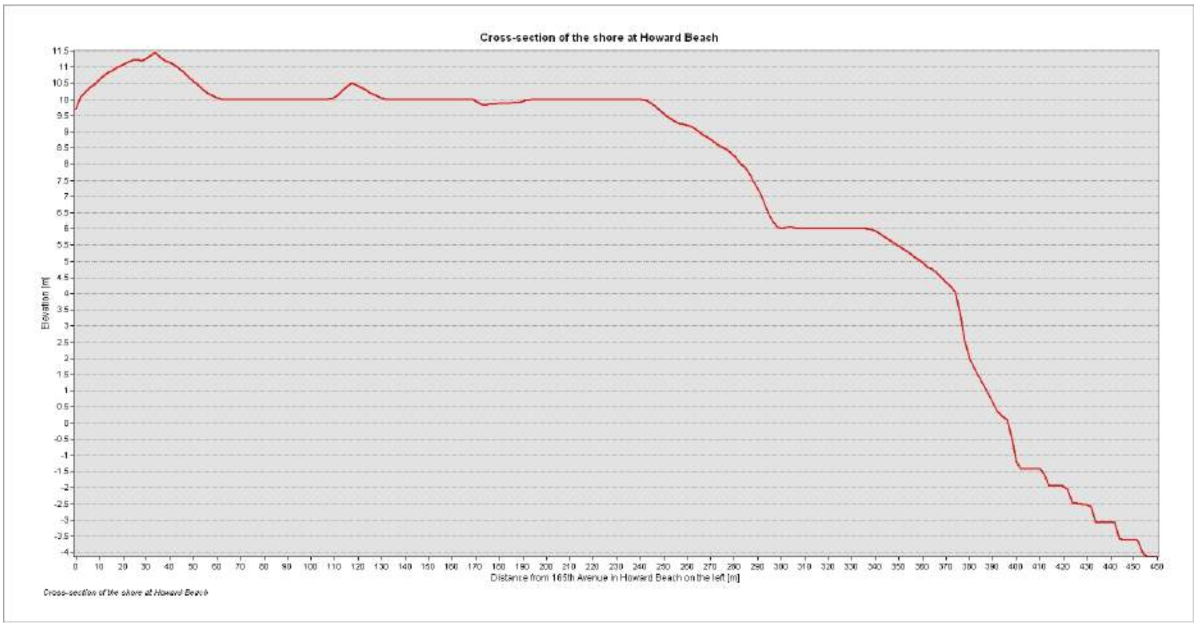


Figure 8.26: Height cross-section at Howard Beach

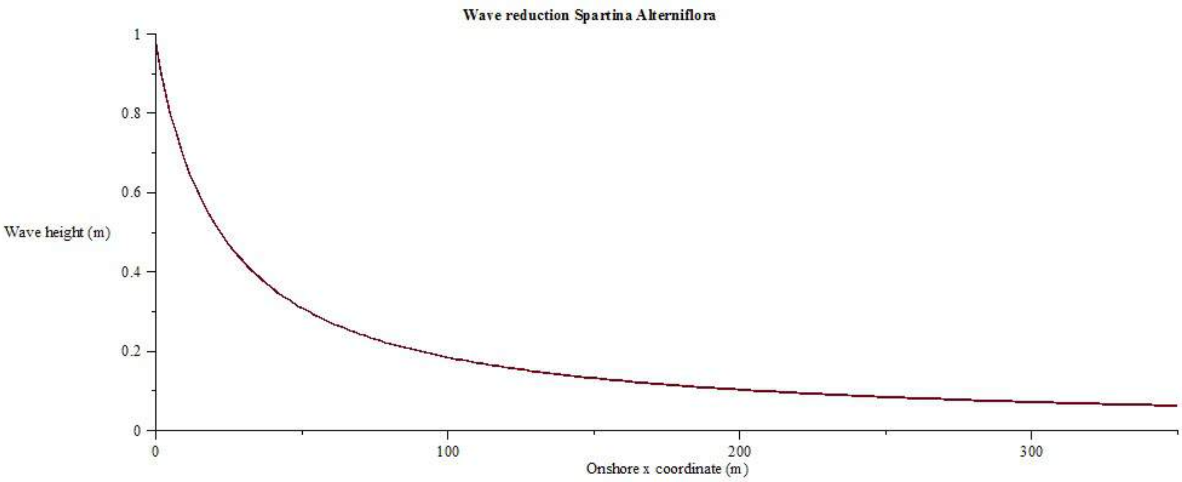


Figure 8.27: Wave reduction by Spartina Alterniflora versus bank length with N = 300 m^2, h_{plant} = 1.5m and h_{water} = 2.5m

8.7. CONCLUSIONS

From the previous chapters it can be concluded that the wave energy is better and thus faster dissipated when applying Spartina Alterniflora vegetation on a steeper slope because the average water depth is lower in this case (2.5 m versus 4 m). For the situation at Canarsie Pier the wave height reduction for option 1 (steep slope) is 75 % and for option 2 (gentle slope) is 40 %. It must be noted that option 1 is much more expansive because it requires a lot of landfill. At Howard Beach the situation is different because there is more space available in contrast to Canarsie Pier. Therefore option 2 will be chosen here. For option 2 the reduction is already 75 % because of the available space (350 m).

Furthermore, the density of the vegetation plays an important role, a denser packed vegetation decreases the wave energy significantly. However, it must be noted that the shoaling effect not has been taken into account. When waves enter shallow water they slow down. Under stationary conditions, the wave length is reduced. The energy flux must remain constant and the reduction in group (transport) velocity is compensated by an increase in wave height (and thus wave energy density). This effect has not been taken into account in these calculations. Also breaking of the waves has not been taken into account in these calculation. Due to the interaction with the stems, the waves will break and loose therefore energy. However, this has not been taken

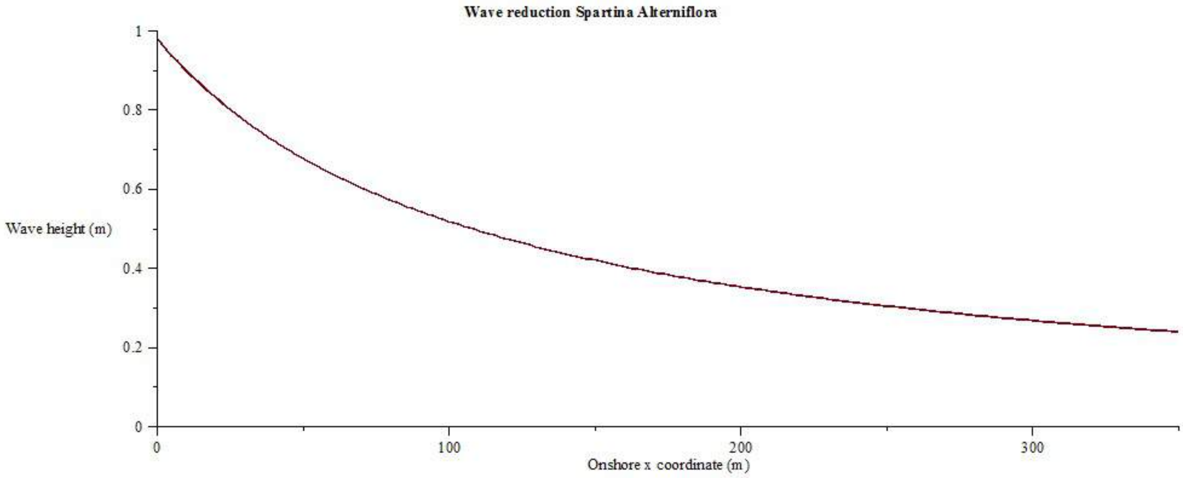


Figure 8.28: Wave reduction by Spartina Alterniflora versus bank length with N = 300 m^2, h_{plant} = 1.5m and h_{water} = 4.0m

into account. Furthermore also the wave energy dissipation by trees is calculated during this study. However, because the dissipation by trunks and leaves and the breaking of the waves by the stems (which is much higher for trees than for chord grass) is not taken into account, these 'tree calculations' were not reliable.

When looking at the safety of the Jamaica Bay area as a whole, it should be noted that the same boundary conditions should be used for all of the measures. Also, the measures should be connected in a way that guarantees the safety of the hinterland. The report elaborates on different measures that can be implemented to secure the perimeter of the Jamaica Bay area. The area analysis shows there is a variable amount of space to implement a coastal protection measure throughout the Atlantic side of the peninsula. Therefore a dune would not suffice. Both the energy impact of the storm and the hydraulic level is taken into account. Beach nourishments, dune creation and dunes with a hardened core are researched. Also, when the bay side of the Rockaway Peninsula is taken into account, the area analysis shows several different situations. It is found that there is a limited amount of space available for measures. Therefore raising Beach Channel Drive is proposed in this particular area. The proposed solutions integrate multiple functions or take up a small amount of space, like flood walls. When looking at further perimeter measures, the report also accounts for solutions for JFK Airport. The boundary conditions show that within a one mile radius no bird habitat zone can be constructed. Also because pilots need a clear vision of the runway, no measures can be taken that are permanently above ground level. Therefore temporary measures like self-closing flood barriers are proposed. The Jamaica Bay area encompasses a lot of infrastructure which disrupt the continuation of the shorelines. Hence, there are a couple of exceptions when looking at perimeter flood protection measures. The report briefly gives possible solutions for all of the exceptions within the area. The different creeks are elaborated as well as Floyd Bennett Field and Broad Channel. For each of these exceptions, different options of protection are given and sketches are made on how they would look like.

9

Storm Surge Control for Jamaica Bay

9.1. Introduction

Restoration of the bay can be an important measure against flooding of the surrounding area. In the past, several studies have been done on the Jamaica Bay wetlands. According to Hartig et al. (2001) [19] a degradation of the salt marshes inside Jamaica Bay can be seen over the past decades. They state that between 1959 and 1998 the land area has decreased with 12%, or roughly 0.3% per year.

This view is also shared by the New York State Department of Environmental Conservation (2001) [56]. NYSDEC say that from 1994 to 1999 an estimate 220 acres of salt marsh were lost at a rate of 44 acres per year. And, between 1924 and 1999 nearly half of the bay's vegetated marsh islands have disappeared.

PlaNYC believes this declining of salt marshes is due to pollution, alteration due to dredging, sediment deprivation, tidal changes, and the loss of freshwater tributaries. Subsequently, as of 2006, nourishment operations have been done by the U.S. Army Corps of Engineers to four marsh islands: Elder Point East, Elders Point West and Yellow Bar Hassock Rulers Bar Marsh Island. A total of 232 acres are recovered up to 2012.

The bay gives an opportunity to take measures against inundation of the surrounding area, without interfering in the urban environment. A possible solution can be sought in placement of sand. The integration of geosynthetic tubes will be investigated. If possible, they could provide a solid base of the marshes. Resulting in sustainable marshes. The dynamic nature of the marshes must be taken in to account. The effects of the modified marshes on reducing storm surge height and wave height will be investigated, regarding the tidal prism and basin capacity.

9.2. Methodology

Solutions will be sought in such a way that a qualitative verdict can be made about wetland restoration for flood mitigation and wetland sustainability. The bay is subject to a complex system of factors which play a role in the total state of the bay. In this chapter, an attempt is made to evaluate these different factors separately. If a factor of influence is defined, a test setup is elaborated to see the influence of this particular factor on the system. In this way the factor is being isolated. In the beginning stage, the different test cases are tackled with rule of thumb like calculations, later on, these calculations will be checked and extended with results from Delft3D modeling. After all considered factors are evaluated, a verdict can be made about focus points for integrating wetland restoration regarding flood risk mitigation.

Configurations, which will be distilled from the rule of thumb calculations, will be modeled in Delft3D. To get insight about to what extend wetlands can contribute to flood risk mitigation, several storm surge events will be modeled. For example, running different test cases concerning sea level rise.

9.3. FETCH LENGTH

One of the advantages of marsh islands is that they can shorten the fetch length. The fetch length influences both wind generated waves and wind set-up. These two processes influence the water level near shore. This section will elaborate on salt marsh configurations especially designed to reduce the effect of wind generated waves and wind set-up. Fetch is the distance to upwind coastlines (see figure 9.1).

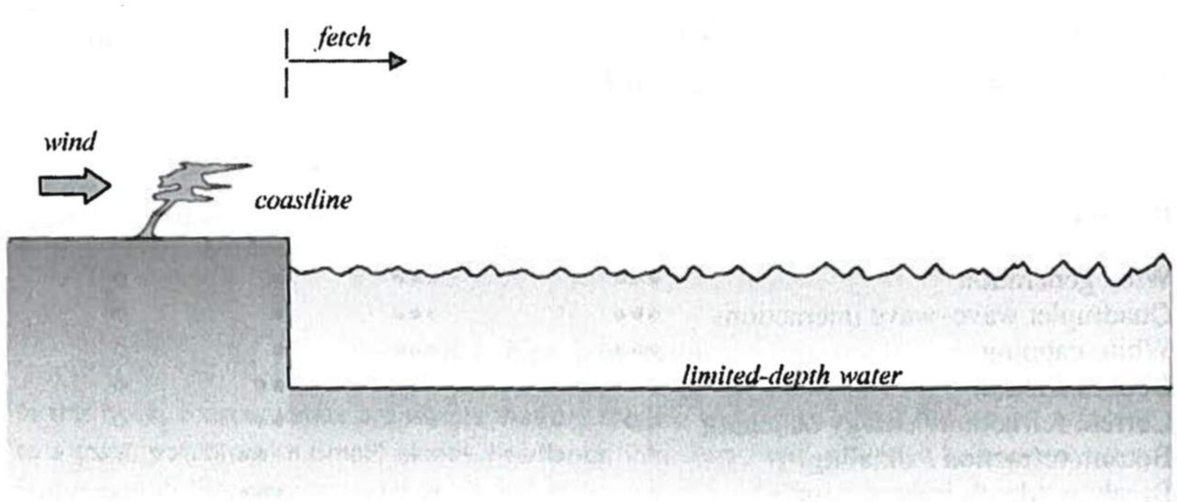


Figure 9.1: Illustration of fetch for limited-depth water (Holthuijsen (2009))

9.3.1. MEAN WATER DEPTH

Another important parameter that influences wind generated waves and wind upset is the water depth. Because the focus of this section is on fetch length, the water depth is approximated by a constant, averaged water depth. This mean water depth is determined by using the DEM (Digital Elevation Model) that is also used for the Delft3D model. Seven profiles have been extracted from this model (see figure 9.2) and the average depths per profile have been averaged.

From these cross sections an averaged depth of 6 feet (1.83 m) has been determined. Next to this average water depth, the storm surge level has to be taken into account. From table 3.3 it has been deduced that the average storm surge level within the bay is about 12.55 feet (3.83 m). This means:

$$d = 18.55 \text{ feet} = 5.66 \text{ meter} \tag{9.1}$$

and from equation 9.7 it can be calculated that the dimensionless water depth for this situation is:

$$\tilde{d} \approx 0.043 \tag{9.2}$$

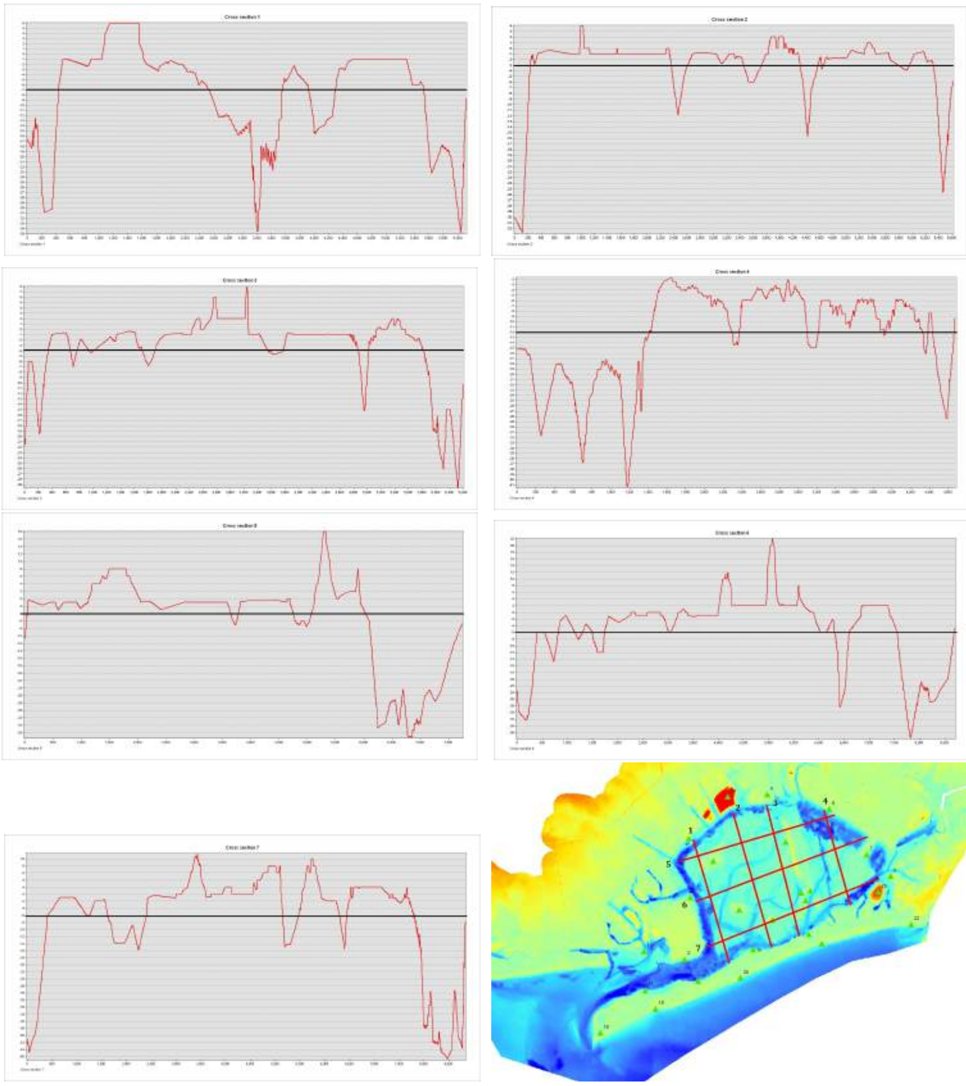


Figure 9.2: Seven cross sections extracted from DEM with locations of the cross sections. Y-axis shows depth in feet and X-axis shows the distance in meters

9.3.2. FETCH LENGTH LIMITING CONFIGURATIONS

This subsection will elaborate on the different configurations that will be considered. The wind direction will be eastern because this was the wind direction . This means that the following configurations will be so that they optimally reduce the fetch length for a southeastern wind. It is assumed that there are no marsh islands currently and that there are no restrictions in placing the islands. The marsh islands will assumed to be bars without volume (like walls with an infinite small thickness) placed perpendicular to the wind direction.

Configuration 0: No marsh islands

This configuration is the reference situation for the other configurations. For this situation the fetch length is the length across Jamaica Bay for a southeastern line. This distance is determined to be about $F \approx 7500$ m.

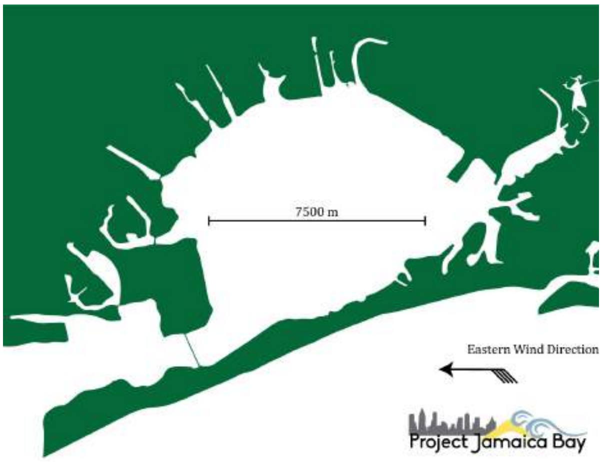


Figure 9.3: Configuration 0

Configuration 1: One marsh island

Configuration 1 contains only one marsh island, which divides the fetch length into two equal parts. This leads to a new fetch length of: $F \approx 3750$ m.

Configuration 2: Two marsh islands

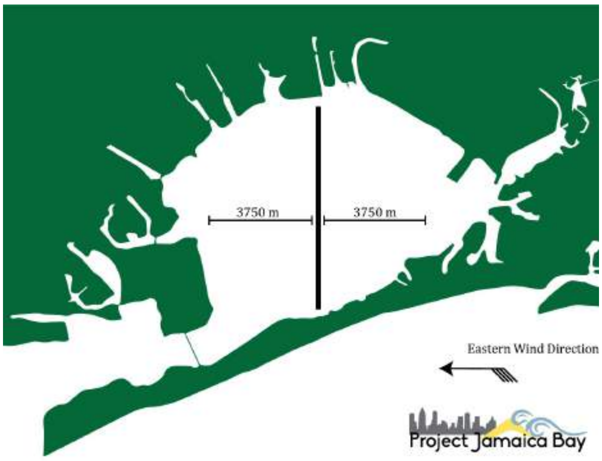
Configuration 2 contains two marsh islands, which divide the fetch length into three equal parts. This leads to a new fetch length of: $F \approx 2500$ m.

Configuration 3: Three marsh islands

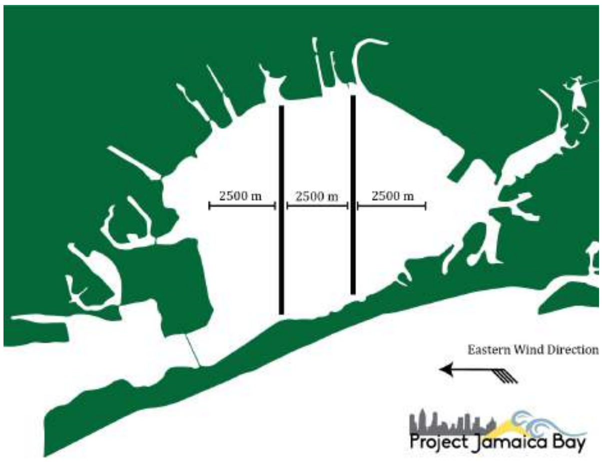
Configuration 3 contains three marsh islands, which divide the fetch length into four equal parts. This leads to a new fetch length of: $F \approx 1875$ m.

Configuration 4: Four marsh islands

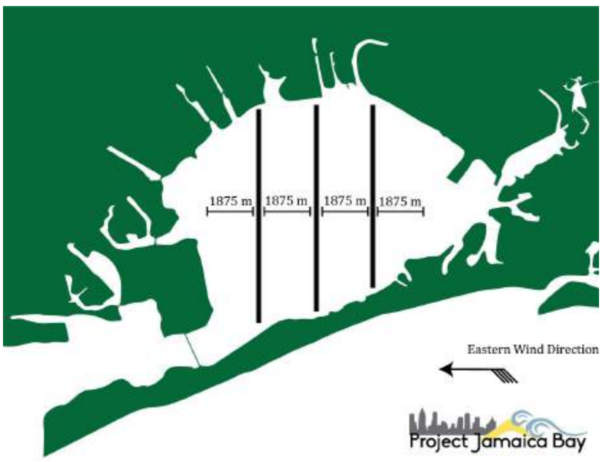
Configuration 4 contains four marsh islands, which divide the fetch length into five equal parts. This leads to a new fetch length of: $F \approx 1500$ m.



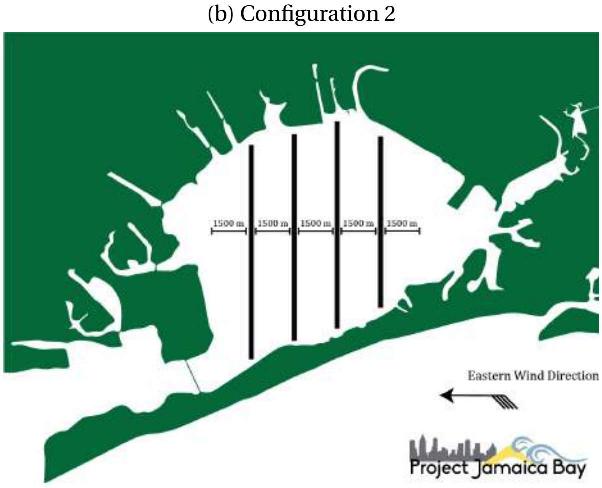
(a) Configuration 1



(b) Configuration 2



(c) Configuration 3



(d) Configuration 4

Figure 9.4: Overview of configurations

9.3.3. WIND GENERATED WAVES

SVERDRUP-MUNK-BRETTSCHNEIDER METHOD

Short waves are mostly generated by wind. The length of the fetch determines for a large part the wave height. Next to fetch length, the wave height is dependent on the wind speed, water depth (only for limited-depth water) and the duration. For the theory used in this section it is assumed that both the coastline and the duration are infinitely long. This means that the wave height is only dependent on wind speed (usually at 10 meters above water level), water depth and fetch length. This is shown by the Sverdrup-Munk-Brettschneider method (equations 9.3 and 9.4) (Holthuijsen (2009) [57]).

$$\tilde{H} = \tilde{H}_\infty \tanh\left(k_3 \tilde{d}^{m_3}\right) \tanh\left(\frac{k_1 \tilde{F}^{m_1}}{\tanh\left(k_3 \tilde{d}^{m_3}\right)}\right) \tag{9.3}$$

$$\tilde{T} = \tilde{T}_\infty \tanh\left(k_4 \tilde{d}^{m_4}\right) \tanh\left(\frac{k_2 \tilde{F}^{m_2}}{\tanh\left(k_4 \tilde{d}^{m_4}\right)}\right) \tag{9.4}$$

where $\tilde{H}$ is the dimensionless wave height, $\tilde{T}$ is the dimensionless wave period, $\tilde{d}$ is the dimensionless water depth, $\tilde{F}$ is the dimensionless fetch length, $\tilde{H}_\infty$ and $\tilde{T}_\infty$ are the limit values for deep water and k_1, k_2, k_3, k_4, m_1, m_2, m_3 and m_4 are tunable coefficients that have to be determined from observations. The formulas for the dimensionless parameters are given by equations 9.5 to 9.8 (Holthuijsen (2009) [57]).

$$\tilde{H} = \frac{gH}{U_{10}^2} \tag{9.5}$$

$$\tilde{T} = \frac{gT}{U_{10}} \tag{9.6}$$

$$\tilde{d} = \frac{gd}{U_{10}^2} \tag{9.7}$$

$$\tilde{F} = \frac{gF}{U_{10}^2} \tag{9.8}$$

Young & Verhagen (1996a) added two extra parameters, p and q, to control the transition to a fully developed sea state from a young sea state. The coefficients are determined by Breugem & Holthuijsen (2006) (Holthuijsen (2009) [57]). This gives the following:

$$\tilde{H} = \tilde{H}_\infty \left[\tanh\left(k_3 \tilde{d}^{m_3}\right) \tanh\left(\frac{k_1 \tilde{F}^{m_1}}{\tanh\left(k_3 \tilde{d}^{m_3}\right)}\right)\right]^p \tag{9.9}$$

$$\tilde{T} = \tilde{T}_\infty \left[\tanh\left(k_4 \tilde{d}^{m_4}\right) \tanh\left(\frac{k_2 \tilde{F}^{m_2}}{\tanh\left(k_4 \tilde{d}^{m_4}\right)}\right)\right]^q \tag{9.10}$$

Coefficients	
k_1	4.41×10^{-4}
k_2	2.77×10^{-7}
k_3	0.343
k_4	0.10
m_1	0.79
m_2	1.45
m_3	1.14
m_4	2.01
p	0.572
q	0.187
$\tilde{H}_\infty$	0.24
$\tilde{T}_\infty$	7.69

Table 9.1: Coefficient values according to Holthuijsen (2009)

With formulas 9.9 and 9.10 and table 9.1 the wave height can be determined for different fetch lengths. According to the boundary conditions the wind speed is U_{10} = 90 km/h = 25 m/s and comes from a southwestern direction and the water depth is taken at d = 5.66 m. The wave height and wave height reduction will be determined for multiple configurations of marshlands. It will be assumed that the marshlands are always (partly) above water to make sure that the fetch starts over again upwind from every island.

To determine H and T, formulas 9.9 and 9.10 have to be rewritten to:

$$H = \tilde{H}_\infty \left[\tanh\left(k_3 \tilde{d}^{m_3}\right) \tanh\left(\frac{k_1 \tilde{F}^{m_1}}{\tanh\left(k_3 \tilde{d}^{m_3}\right)} \right) \right]^p \cdot \frac{U_{10}^2}{g} \tag{9.11}$$

$$T = \tilde{T}_\infty \left[\tanh\left(k_4 \tilde{d}^{m_4}\right) \tanh\left(\frac{k_2 \tilde{F}^{m_2}}{\tanh\left(k_4 \tilde{d}^{m_4}\right)} \right) \right]^q \cdot \frac{U_{10}}{g} \tag{9.12}$$

FULLY DEVELOPED WIND WAVES

According to Vrijling et al. (2011) [25] there are a few ways to get a first estimate of the wave height. They state that theoretically waves break when the steepness is about $H/L = 1/7$. Next to this, depth plays a role in the breaking of waves. It has been determined that an individual wave breaks when $\frac{H}{d} \geq 0.78$. In this section the estimate for breaking waves in a spectrum will be used. The estimate is given by equation 9.13. Obviously, the fetch length does not play a role in this estimate. The theory assumes some sort of fully developed wind waves.

$$\frac{H_s}{d} = 0.4 \sim 0.5 \tag{9.13}$$

This equation can easily be rewritten to equation 9.14 in order to deduce the significant wave height for a particular water depth. This theory assumes that the waves are fully grown (fully developed state).

$$H_s = d \cdot (0.4 \sim 0.5) \tag{9.14}$$

In section 9.3.1 it has been deduced that a good estimate for the mean water depth is: d = 18.55 ft. ≈ 5.66 m. With this assumed water depth and the governing factor of 0.5 this would give a significant wave height of:

$$H_s = d \cdot 0.5 \approx 2.83\ m \tag{9.15}$$

However as can be seen from figure 9.2 there are places that are a lot deeper that this estimation. It can bee seen from this figure that one of the deepest places is about 45 feet deep, which is about 13.72 meter. With this governing situation the significant wave height would be:

$$H_s = d \cdot 0.5 \approx 6.86\ m \tag{9.16}$$

But because this theory assumes some sort of fully developed state of waves and this high water depth is only found in narrow, deep channels, the real situation is likely to be more like the wave height given by equation 9.15. The wave heights calculated with the Sverdrup-Munk-Brettschneider method are significantly less than the wave heights calculated with this estimate. Even with the full fetch of 7500 m the waves height H_0 is only half of the significant wave height given by equation 9.15. Probably the waves are not fully developed within the bay and the wave heights determined with the Sverdrup-Munk-Brettschneider method will be used.

INFLUENCE FETCH ON WIND GENERATED WAVES

To determine the influence of the fetch length, four different configurations are defined and they will be compared to the situation without marsh islands. Using formulas 9.11 and 9.12 the wave heights and periods can be calculated. The results are shown in table 9.2. As can bee seen from this table and equation 9.15, the first estimate, that only takes the mean water depth into account, gives really high results compared to the Sverdrup-Munk-Brettschneider method.

Configurations	Fetch length (m)		Wave height (m)		Wave period (s)	
Configuration 0	F_0	7500	H_0	1.40	T_0	4.21
Configuration 1	F_1	3750	H_1	1.11	T_1	3.51
Configuration 2	F_2	2500	H_2	0.94	T_2	3.15
Configuration 3	F_3	1850	H_3	0.84	T_3	2.91
Configuration 4	F_4	1500	H_4	0.76	T_4	2.74

Table 9.2: Wave height and period for different fetch lengths

9.3.4. WIND SET-UP

THEORY

Next to wind generated waves, wind set-up is another important aspect related to fetch length. According to Vrijling et al. (2011) [25], wind fields can influence the water level considerably by damming up the water in shallow seas, deltas, closed off creeks and lakes. This is called wind set-up. Figure 9.5 shows wind set-up for a lake.

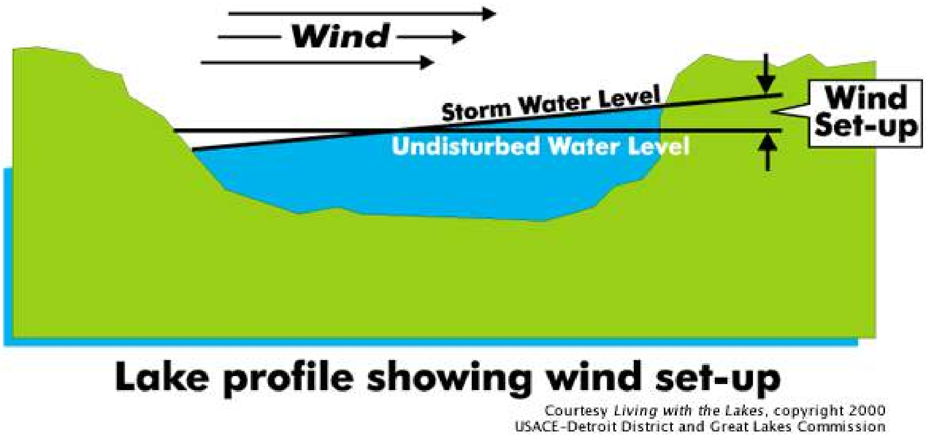


Figure 9.5: Impression of wind set-up in a lake (USACE-Detroit District and Great Lakes Commission)

The wind set-up can be calculated by using the balance of forces. According to this method the wind set-up increases with increasing fetch length and wind velocity and decreasing water depth. This method is shown by figure 9.6 (Vrijling et al. (2011) [25]).

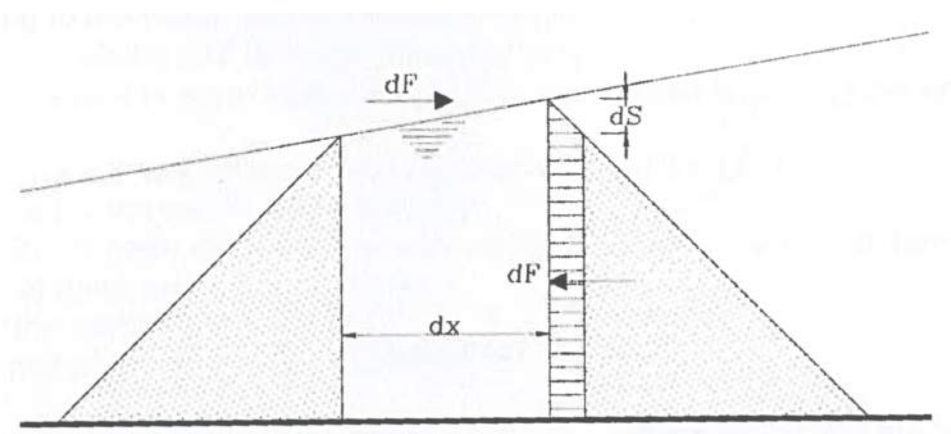


Figure 9.6: Balance of forces to calculate wind set-up (Vrijling et al. (2011))

In equilibrium, the wind set-up can be approximated by formula 9.17.

$$\frac{dS}{dx} = C_2 \frac{u^2}{gd} \tag{9.17}$$

where S is the total wind set-up in meter, C_2 is a constant ($3.5 \cdot 10^{-6} \leq C_2 \leq 4 \cdot 10^{-6}$), d is the water depth in meters and u is the wind velocity in meter per second. The fetch length is included by x (Vrijling et al. (2011) [25]).

INFLUENCE FETCH ON WIND SET-UP

For the given fetch lengths (configurations 0-4) the wind set-up can be calculated by using formula 9.17. The results (with $C_2 = 3.75 \cdot 10^{-6}$ and $u^2 = U_{10}^2$) are shown by table 9.3.

Configurations	**Fetch length (m)**		**Wind set-up (m)**	
Configuration 0	F_0	7500	S_0	0.32
Configuration 1	F_1	3750	S_1	0.16
Configuration 2	F_2	2500	S_2	0.11
Configuration 3	F_3	1875	S_3	0.08
Configuration 4	F_4	1500	S_4	0.06

Table 9.3: Wind set-up in meters for configurations 0-4

9.3.5. EVALUATION INFLUENCE FETCH LENGTH

From sections 9.3.3 and 9.3.4 can be seen that the fetch length can have a significant influence on the water conditions near the shore (or marsh). Both wave conditions and wind set-up are influenced by the fetch length. The reductions in wave height, wave period and wind set-up are shown in table 9.4. It must be noted that these reductions are in case of the idealized situation with a constant water depth of 5.66 meter, constant eastern wind with a velocity of 90 km/h, a base situation with no islands and configurations with islands which are always above water level and without volume.

Configurations	**Fetch length (m)**		**Wave height reduction relative to H_0 (m)**		**Wave period reduction relative to T_0 (s)**		**Wind set-up reduction relative to S_0 (m)**	
Configuration 0	F_0	7500	$\triangle H_0$	-	$\triangle T_0$	-	$\triangle S_0$	-
Configuration 1	F_1	3750	$\triangle H_1$	0.29	$\triangle T_1$	0.70	$\triangle S_1$	0.16
Configuration 2	F_2	2500	$\triangle H_2$	0.46	$\triangle T_2$	1.066	$\triangle S_2$	0.21
Configuration 3	F_3	1875	$\triangle H_3$	0.57	$\triangle T_3$	1.30	$\triangle S_3$	0.24
Configuration 4	F_4	1500	$\triangle H_4$	0.64	$\triangle T_4$	1.47	$\triangle S_4$	0.25

Table 9.4: Wave height, wave period and wind set-up reduction for the different configurations (0-4) of marsh islands in order to reduce the fetch length

The maximum reduction in wave height (for these configurations), that can be reached by shortening the fetch from 7500 m to 1500 m, is $\triangle H_4 = 0.64$ m. For this reduction four marsh islands have to be built. The reduction in wind set-up is less and the maximum reduction for configuration 4 is $\triangle S_4 = 0.25$ m.

9.4. SHALLOWING OF INLET

Instead of using sand solely for wetland creation, from a flood risk mitigation point of view, it is interesting to use sand to fill deep channels. In the following elaborations the influence of the inlet is sought out. Calculation methods are used from Open Channel Flow (2007) [58]. In the overview map depicted below in figure 9.7 it can be seen that especially in the inlet a deep and broad channel is to be found. This deep channel gives way for high flows of water. The interaction of tides and the bay is influenced by the cross sectional shape and long length of the inlet, modification in such could subsequently lead to a mitigation of flooding.

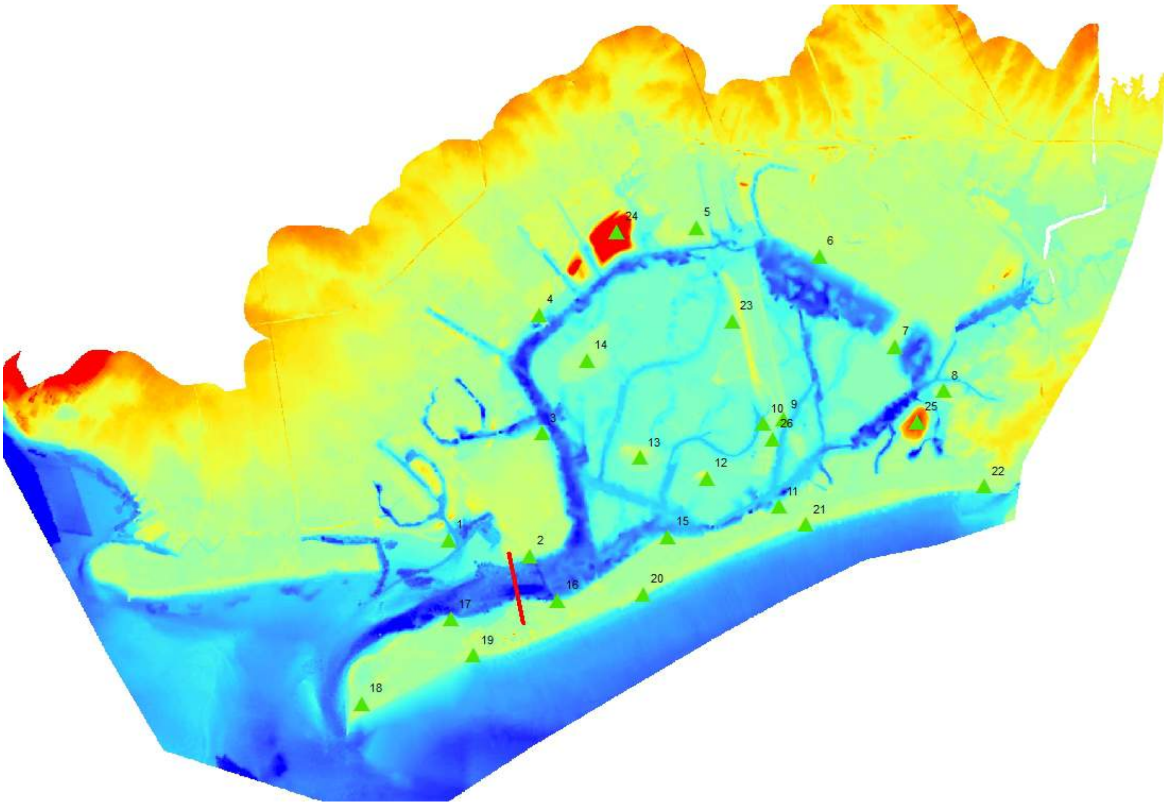


Figure 9.7: Rockaway Inlet Overview (ArcGIS) [6]

9.4.1. THE RIGID COLUMN APPROACH

An approach is used in which the bay has solely a storage function. The bay has to be relatively short and closed. Then the bay's inertia and friction factors can be neglected. This leads to a water level in the bay that is horizontal. The channel between the sea and the bay forms a connection and has a transportation function. It can have a resistance and inertia component. The storage in the connection is not essential, meaning $\frac{\delta Q}{\delta x} = 0$. The water inside the connection is assumed not to be subject to strain in longitudinal direction. Therefore, the theory is better known as the "rigid column approach".

For the approach it is needed to comply to a ratio of inlet length and wave length of 1/20. The wave length is a storm surge is a lot bigger then the 6 kilometer length of the inlet, so this requisite holds for the "rigid column approach". On the other hand long enough that both the inertia of the flowing water as the resistance should be taken into account.

The equation of motion for such a connection, neglecting the transitions, is given below;

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A_s}\right) + gA_s\frac{\partial h}{\partial x} + c_f\frac{|Q|Q}{A_sR} = 0 \tag{9.18}$$

We simplify the connection to a prismatic connection. Next to $\frac{\delta Q}{\delta x}$ we can also neglect $\frac{\delta A}{\delta x}$, and subsequently we can neglect the advection term and inertia term. This means that all the remaining terms are not dependable on x. Integration over x results in;

$$l\frac{dQ}{dt} + gA_s[h(l) - h(0) + \Delta H_f] = 0 \tag{9.19}$$

with ΔH_f being the friction loss, give by;

$$\Delta H_f = c_f\frac{|Q|Q}{gA_s^2R}l = c_f\frac{l}{R}\frac{|U|U}{g} \tag{9.20}$$

In the transitions we can say there are quasi stationary conditions. At the inflow transition a short acceleration region can be seen, therefore this part is approached with Bernoulli, neglecting the velocity height at sea or in the bay. This mean the water level decrease is equal to the velocity height in the connection. Notice that this is not a loss of energy but a conversion of potential to kinematic energy. At the outflow transition of the connection kinematic energy is lost. Then the water level at the end of the connection is equal to the water level inside the bay, and also equal to the inertia loss;

$$\Delta H_i = \frac{U^2}{2g} \tag{9.21}$$

Therefore the total decay in the connection is given by the following equation 9.22.

$$h_z - h_k = h(0) - h(l) + \Delta H_v \tag{9.22}$$

Now we can substitute this into equation 9.19, subsequently getting expression for the total decay between the sea-end and the bay-end;

$$h_z - h_k = \frac{l}{gA_s}\frac{dQ}{dt} + W \tag{9.23}$$

In this equation, W is the total loss, also introducing $\chi = 1/2 + c_f l/R$:

$$W = \Delta H_i + \Delta H_f = \chi\frac{|U|U}{g} = \chi\frac{|Q|Q}{gA_s^2} \tag{9.24}$$

Using the following volume balance, we now have a system of equations. This is an first order differential equation, which can be solved with MATLAB.

9.4.2. APPROXIMATION OF INLET

To see what kind of influence the inlet has on the bay we have to define a few parameters. Using cross sectional figure 9.8 of the inlet, taken at the red line in figure 9.7, the cross sectional area A_s of flow and wet perimeter P can be estimated. For simplification the cross sectional profile is considered to have a dual rectangular figure, as depicted in green in the figure. The deeper rectangular of the two represents the channel, whereas the shallower part are the banks. From these, the hydraulic radius R can be deducted, see equation 9.27.

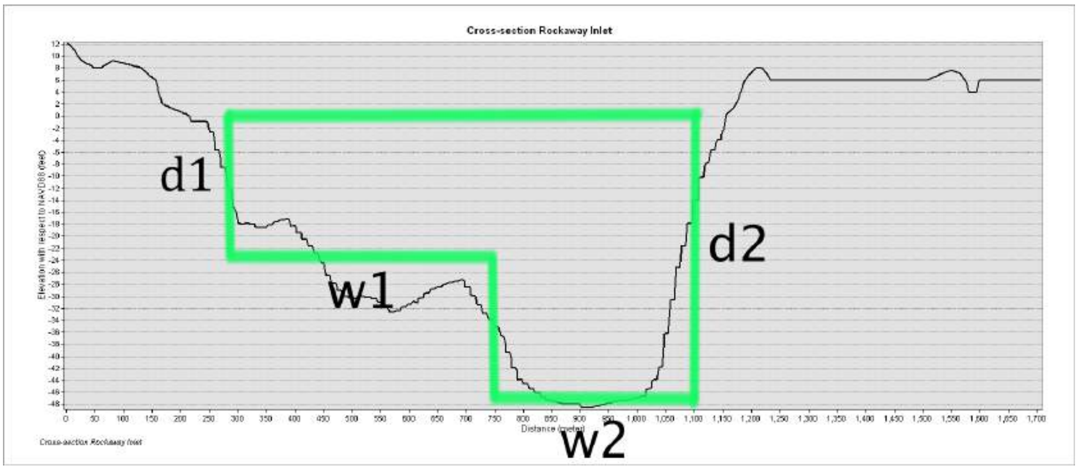


Figure 9.8: Rockaway Inlet Overview (ArcGIS) [6]

$$
\begin{aligned}
l &= \text{inlet length} &= 6[km] \\
d1 &= \text{depth 1} &= 7.31\ [m] \\
d2 &= \text{depth 2} &= 14.62\ [m] \\
w1 &= \text{width 1} &= 550[m] \\
w2 &= \text{width 2} &= 350[m]
\end{aligned}
$$

$$A = 14.63 \cdot 350.00 + 7.31 \cdot 550 = 9141[m^2] \tag{9.25}$$

$$P = 14.63 + 350 + 7.32 + 550 + 7.31 = 929.26[m] \tag{9.26}$$

$$R = \frac{A}{P} = \frac{9141}{929.26} = 9.84[m] \tag{9.27}$$

To get a feel about the influence of the inlet, three cross sectional profiles are considered. The current depth of the channel is over 14 meters. The recreational boats which make use of the channels in Jamaica Bay do not need a drought deeper then about 7 meters. Therefore, one option is to shallow the inlet half its current depth. The third option will be again taking half the depth away. The different options are elaborated in table 9.5. There is no modification in channel width. This is to have sufficient space for boats to maneuver.

	d1 [m]	d2 [m]	w1 [m]	w2 [m]	A [m2]	P [m]	R [m]
option base	7.31	14.63	550	350	9047	929	9.74
option 1	3.65	7.31	550	350	4566	914	4.99
option 2	1.83	3.66	550	350	2285	907	2.52

Table 9.5: Dimensions of considered configurations

9.4.3. INFLUENCE OF INLET SHALLOWING

Using the method described in chapter 9.4.1 a qualitative estimation is made about the influence of the inlet on storm surge mitigation. For this, a time series is used of Sandy as input to test three scenarios. This time series is taken from NOAA [59]. A time step of 6 minutes is used, since this is the smallest time step provided. Every scenario incorporates one of the options for the inlet defined in the previous chapter. The coupled system from chapter 9.4.1 is evaluated, and gives a value for the water level in the bay. Subsequently, a time series from within the bay is used to validate the calculated value. This time series is taken by USGS [60].

In figure 9.9 the results are shown for the base option using the "Rigid Column Approach". This is the configuration with the simplified dimensions of the inlet. What can be taken from this figure is that the relatively simple approach gives a good approximation. Depicted in blue is the calculated value for the water level in the bay, and depicted in green is the measured value by USGS [60]. The values do not completely match, but they are in the same order of magnitude. Therefore, we use this model to give a qualitative estimation about the influence of shallowing of the inlet.

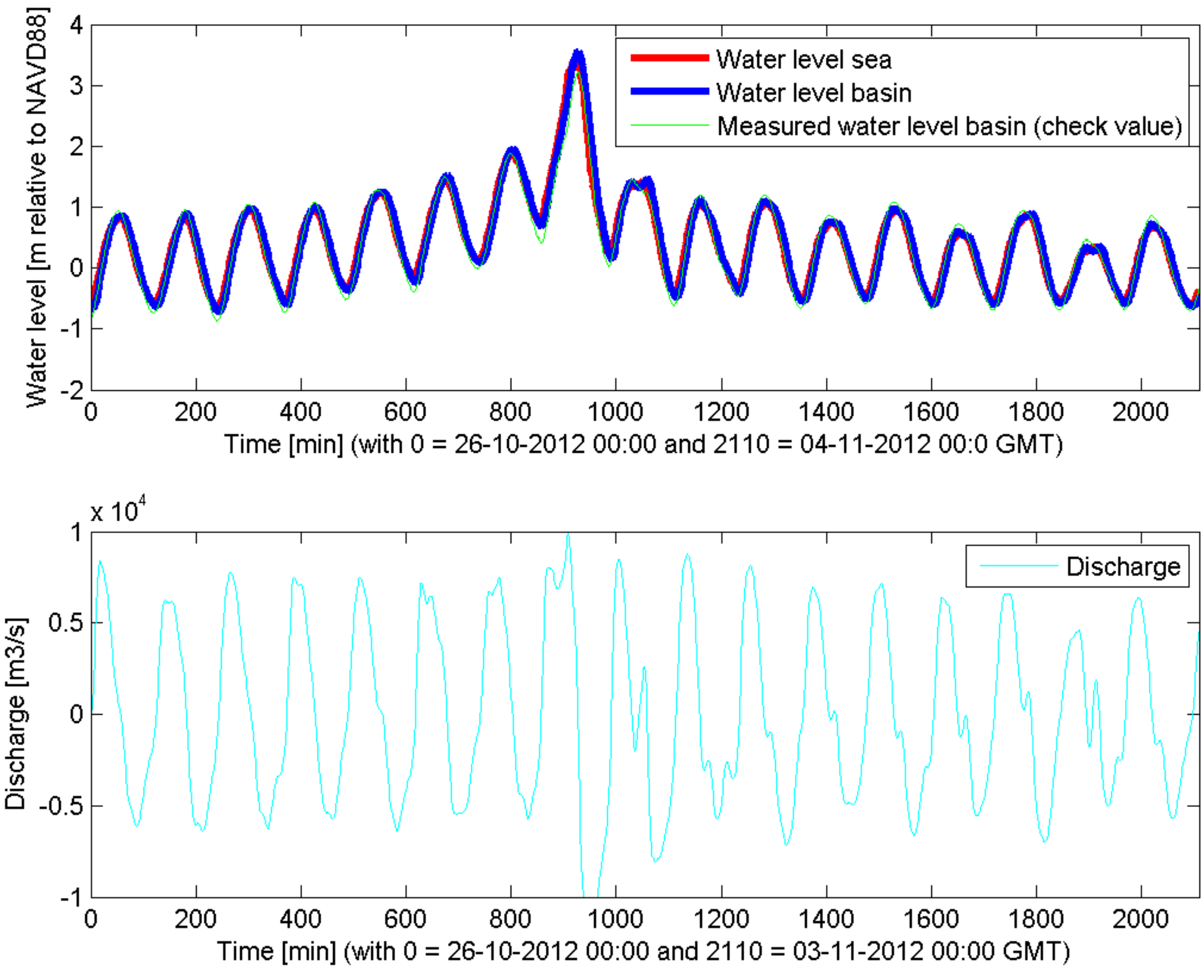


Figure 9.9: Base option

Shallowing the inlet to half its original depth can be considered a feasible option. With an depth of just over 7 meters, the draught would be sufficient for boats to navigate threw the channel. What follows from figure 9.11 is that a reduction in storm surge level can be accomplished in the bay by shallowing the inlet. Also, the figure clearly shows a delay, meaning the peak in the bay is at a later stage then the peak at sea.

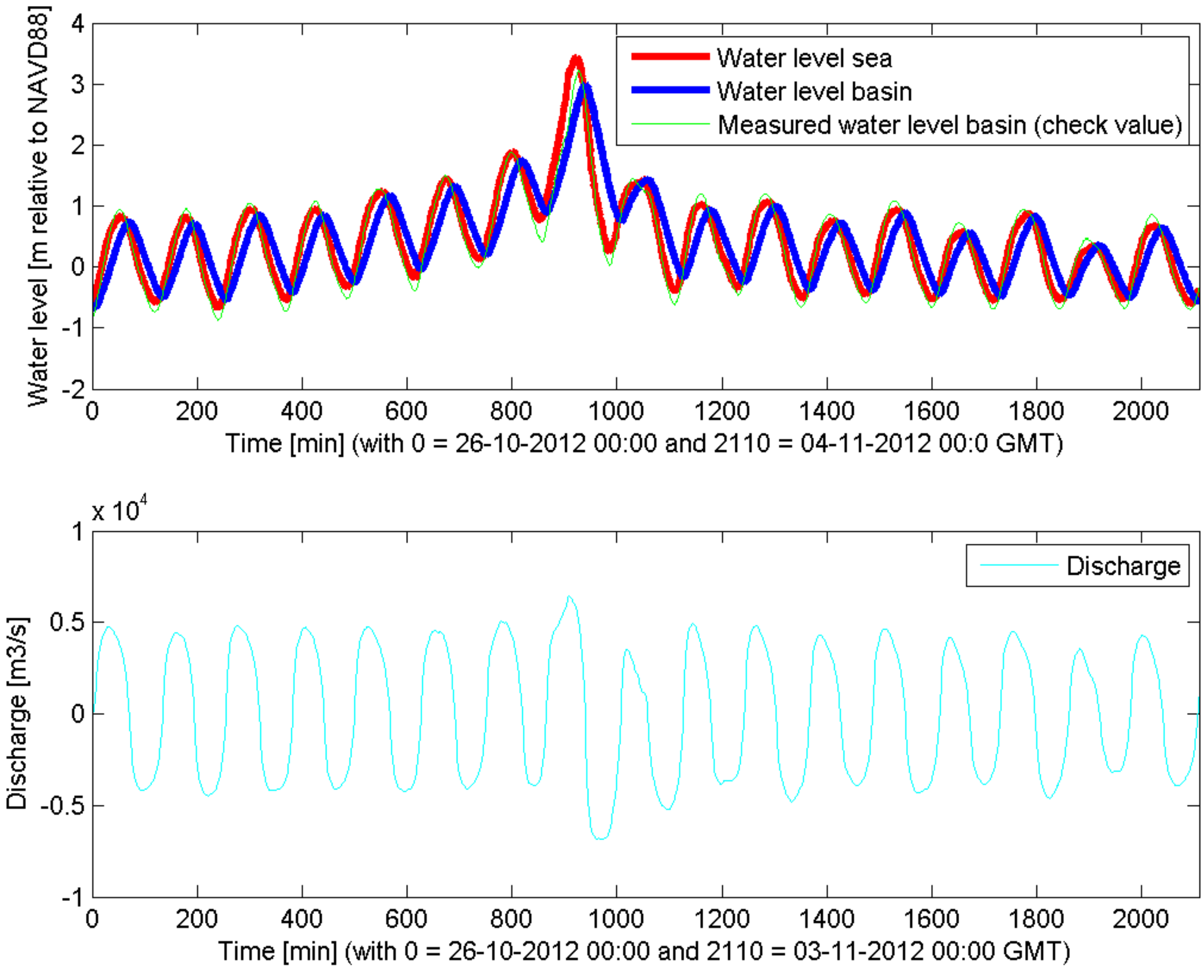


Figure 9.10: Option 1

To emphasize the influence of the inlet on the storm surge level in the bay, option 3 is considered. This is a scenario where the inlet is shallowed to a quarter of its original depth. As seen in figure 9.11, this results in a significant reduction of storm surge level in the bay. Therefore, if this effect is desired, shallowing of the inlet is a option which should be considered. Please do realize that with a shallower inlet, the discharge is also affected. This implies that water quality will be influenced due to a suspected decrease in refreshment rate.

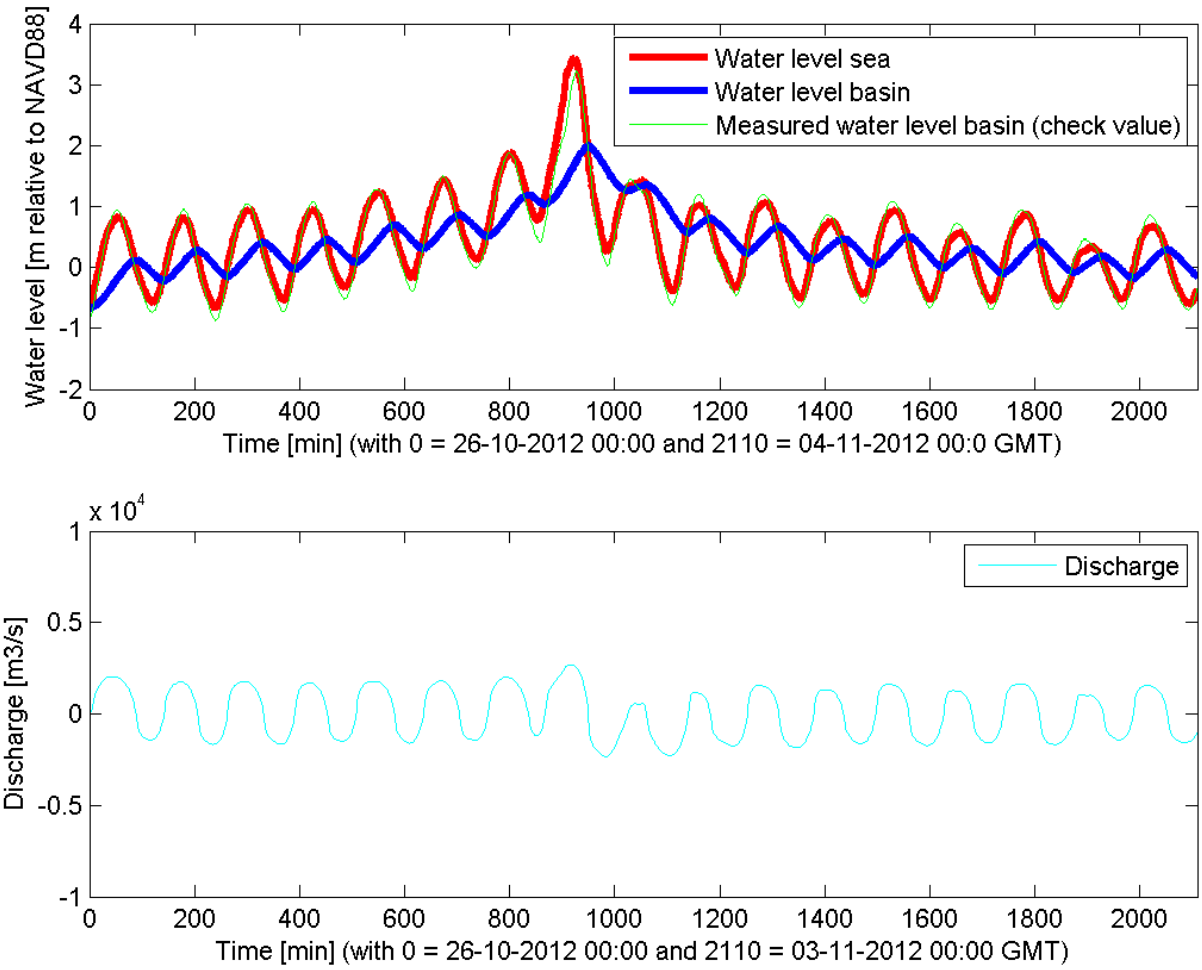


Figure 9.11: Option 2

9.5. INFLUENCE OF BAY SIZE

Another parameter which can be altered in this approach is the surface area of the bay. When wetlands are created, a reduction of surface area is introduced. The current surface area the bay is about 60 square kilometers. The figure 9.12 below shows a configuration in which 2.5 square kilometers of wetlands are created. What can be seen from this figure is that none of the characteristic values show any significant change compared to the current situation depicted in figure 9.9 on page 147.

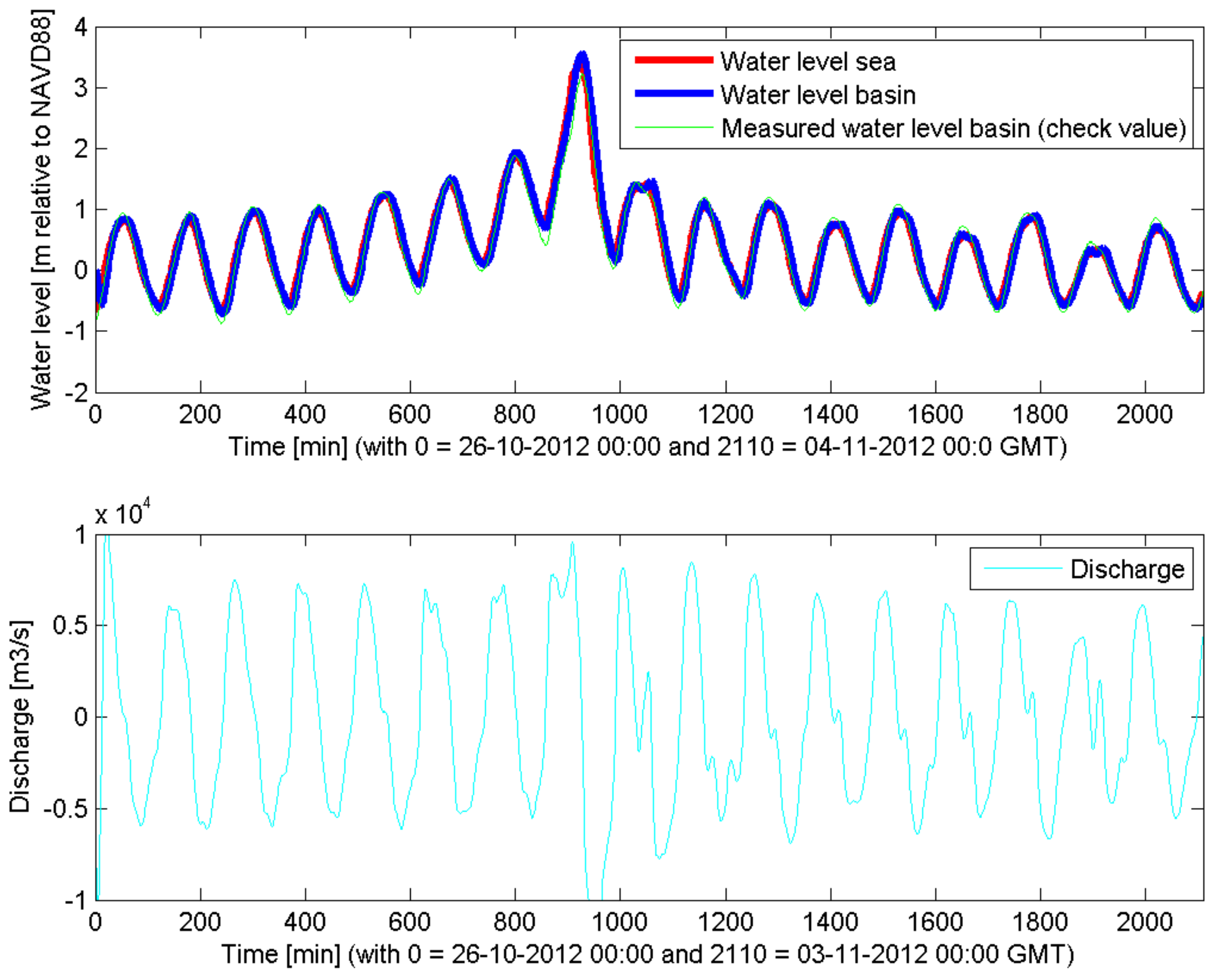


Figure 9.12: SSL with a surface area of 57.5 km^2

In the next figure 9.13 the results are shown for the situation where half of the bay's surface area is filled. Therefore, the total surface area will be 30 square kilometers. This test is done to see to what extent a surface area reduction has on storm surge levels in the bay. Although the tidal prism has decreased by a change in half the current surface area, the water level in the bay is hardly affected.

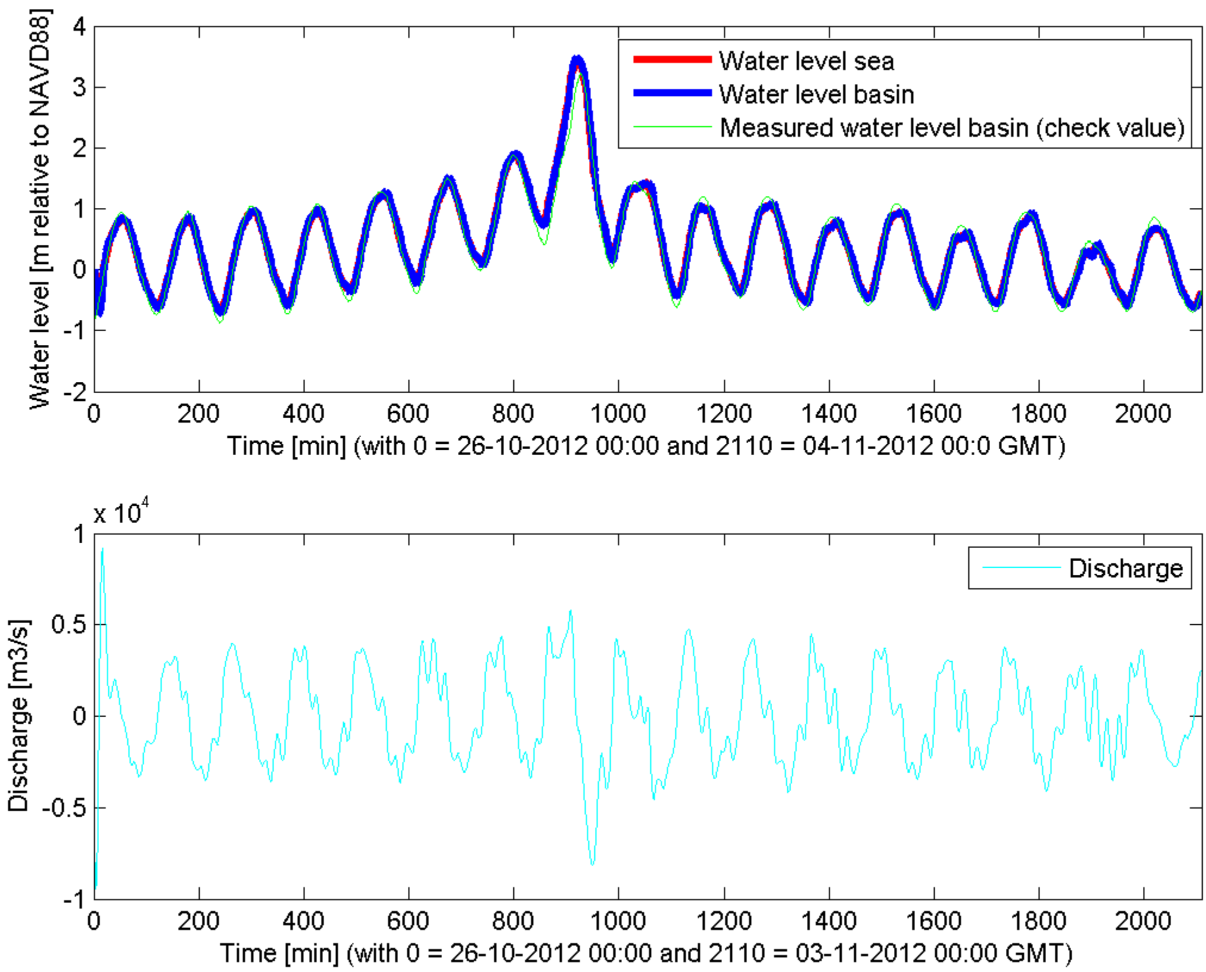


Figure 9.13: SSL with a surface area of 30 km^2

9.6. EVALUATION

From sections 9.3.3 and 9.3.4 can be seen that the fetch length can have a significant influence on the water conditions near the shore (or marsh). Both wave conditions and wind set-up are influenced by the fetch length. It must be noted that these reductions are in case of the idealized situation with a constant water depth of 5.66 meter, constant eastern wind with a velocity of 90 km/h, a base situation with no islands and configurations with islands which are always above water level and without volume. The maximum reduction in wave height (for these configurations), that can be reached by shortening the fetch from 7500 m to 1500 m, is $\triangle H_4 = 0.64$ m. For this reduction four marsh islands have to be built. The reduction in wind set-up is less and the maximum reduction for configuration 4 is $\triangle S_4 = 0.25$ m.

Modifications to the inlet of the bay are cover in section 9.4. Shallowing the inlet has a significant effect on the storm surge level in the bay. The depth in the current navigation channel of the inlet exceeds the needed draught for boats by far. In general, it holds that more shallowing means a lower water level in the bay.

Regarding the surface area of the bay, touched upon in section 9.5, minimal changes in storm surge level are expected when the surface area is altered. Even when the bay is reduced to half its size, no significant change is expected.

10

Sustainability of Jamaica Bay

10.1. Introduction

A study was conducted by the Gateway National Area, National Park Service, U.S. Department of the Interior and the Jamaica Bay Watershed Protection Plan Advisory (2007) [15]. For this report, the conductors made use of field observations, satellite imagery and aerial photography 2003 obtained by GNRA, and aerial photography obtained from DEC for the years 1951, 1974, 1989, 2003, and (for selected marshes) 2005. The research has pointed out that a decrease of 63 percent of vegetated salt marsh islands can be noted between 1951 and 2003. In the periods 1951-1974 and 1974-1989 the rate of loss was 17 acres/year and 18 acres/year respectively. For the last period 1989-2003 this was 33 acres/year. What can be concluded is an acceleration of marsh island loss in the past 60 years, especially in the period 1989-2003. This infers that this rate is not nearing an equilibrium, and might however result in total loss of marsh islands. Even sooner then the previously projected 2024.

In response, the USACE is restoring marsh islands within Jamaica Bay. In 2006-2007 they restored about 40 acres at Elders Point East and in 2010 they restored about 40 acres at Elders Point West. They also planted vegetation in these areas to help prevent them from eroding. Subsequently the USACE restored another 87 acres of marsh island; in 2012 Yellow Bar Hassock, Black Wall and Rulers Bar were restored. For Yellow Bar Hassock 160,000 cubic meters of dredged material from Ambrose Channel and Rockaway Inlet was used. The project made beneficial use of dredged material from the ongoing New York - New Jersey Harbor deepening project. In the list below the projects and restored acres are summarized. This information is publicized by the USACE [56].

wetland	acres recovered	year	method
Big Egg	2	2003	
Elders East	40	2007	
Elders West	40	2007	
Yellow Bar Hassock	44	2012	
Black Wall	20	2012	
Rulers Bar	10	2012	

Table 10.1: Option 2 [56]

The previous shows the fact of alteration in the bay. In this chapter an attempt is made to analyze this process and provide design directions the Jamaica Bay.

10.2. TIDAL PRISM THEORY

In order for the bay to have stable marsh islands and stable banks, the bay must be in morphological equilibrium. This chapter will describe the theory, the current situation and the effects that the marsh island configurations could have. The tidal prism is the storage volume of the estuary between low tide and high tide level.
With empirical relations the stability of the various morphological unit of the basin can be described. Some of these units are the entrance and cross-sectional area of the entrance of the basin, the sand volume stored in the ebb-tidal delta, the tidal channels and the tidal flats in the basin (Bosboom & Stive (2013) [33]). the following sections will elaborate on each of them shortly. For the full theories see see Bosboom & Stive (2013) [33] chapter 9.

10.2.1. ENTRANCE OF THE BASIN AND ITS CROSS-SECTIONAL AREA

According to Bosboom & Stive (2013) [33] a tidal inlet is not fixed but dynamic and governed by factors, e.g. tidal currents, storms, the tidal prism and littoral sediment transport. The first one that studied this dynamic inlet and the cross-sectional area inlet is Escoffier (1940). The cross-sectional area of the inlet can vary significantly.

Escoffier related u_e (the maximum cross-sectionally averaged entrance channel velocity for a given estuary or inlet) to the hydraulic radius (R), its cross-sectional area (A_e) and the tidal range in the estuary (Δh). He combined the variables for a given inlet, e.g. the channel bed roughness, its length, the surface area of the inlet and the tidal range at sea, into a single parameter (x), in such a way that when the entrance cross-section increases, x also increases. The relation between u_e and x is found by Escoffier and shown in figure 10.1.

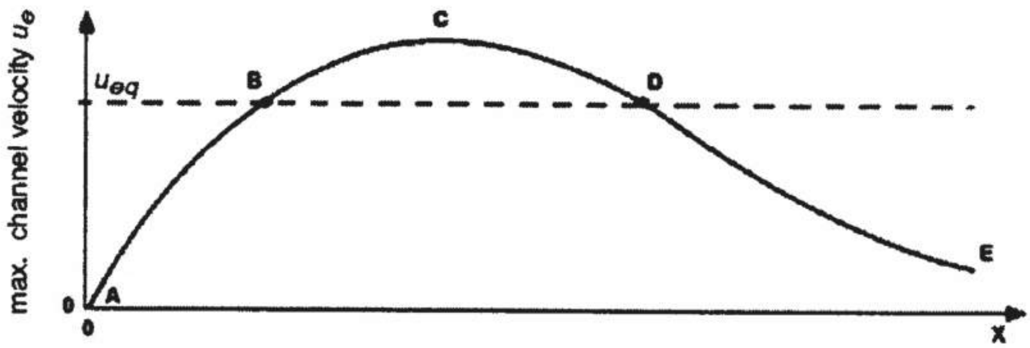


Figure 10.1: Channel velocity geometry relationship (Bosboom & Stive (2013))

Figure 10.1 is called a closure curve. The next thing he did was introducing the concept of an equilibrium maximum velocity (u_{eq}). If $u_e \leq u_{eq}$, the velocity is too low to keep the inlet open and the inlet will close due to sedimentation. For first order estimations, this u_{eq} can be taken independent of the cros-section. If $u_e = u_{eq}$ (points B and D), this equilibrium can be stable (D) and unstable (B). B is unstable because if x gets smaller because of deposited sand, u_e also becomes smaller and the inlet closes eventually. If x gets bigger than B, u_e will move towards point D. Point D is stable because for small changes the situation will return to D.

Escoffier's curve assumes that u_{eq} only depends on the sediment diameter and that a good estimate is $u_{eq} \approx 3$ feet/second (≈ 0.9 m/s). The maximum cross-sectional averaged entrance velocity $u_e = \hat{u}_e$ can be related to the tidal prism P via equation 10.1 (and in a stable situation $u_e = u_{eq}$).

$$\hat{u}_e = \frac{\pi \cdot P}{A_e \cdot T} (= u_{eq} \approx 0.9 \text{ m/s for a stable situation}) \tag{10.1}$$

T = is the tidal period.

From this basic principle the relation shown in figure 10.2 has been deduced. On the x-axis is the cross-sectional area given and on the y-axis the annual mean ebb-tidal sediment transport in the entrance (TR). M is the mean annual influx of sediment.

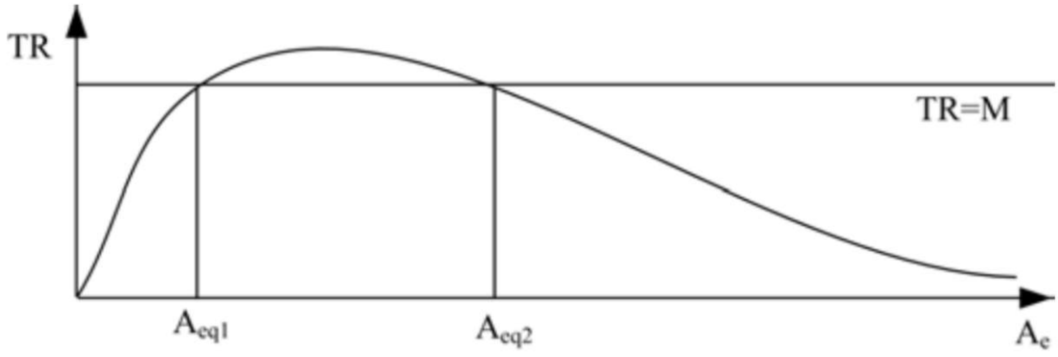


Figure 10.2: Equilibrium cross-sectional areas (Bosboom & Stive (2013))

10.2.2. THE EBB-TIDAL DELTA: SEDIMENT VOLUME

The ebb-tidal delta stores a large volume of sand and with that has an important function in the stability of the inlet and basin. The relation between the volume of sand in the ebb-tidal delta (outer delta) and the tidal prism has been determined empirically. Figure 10.3 shows the relation that was first derived for outer deltas in the U.S.A. The relation is shown in equation 10.2.

$$V_{od} = C_{od} \cdot P^{1.23} \tag{10.2}$$

with V_{od} is the sand volume store in the outer delta and C_{od} is an empirical coefficient.

Changes in the tidal prism or wave conditions may result in changes in the volume of stored sand in the outer delta. If the ebb-tidal delta becomes sediment starved, sand will erode from adjacent beaches, the basin or offshore to restore the equilibrium situation. Erosion of the tidal gullies is probably one of the the biggest suppliers of sand. Because flow velocities will increase, the tidal channels will erode and the eroded material will be deposited in the outer delta (Bosboom & Stive (2013) [33]).

10.2.3. TIDAL CHANNELS AND TIDAL FLATS

In the previous section it has been shown that the volume of sand stored in the ebb-tidal delta and the cross-sectional area of the inlet can be related to the tidal prism. From data of a tidal channel in the Wadden Sea, and later from other locations as well, it has been determined that also the along a channel the flow area is related to the tidal prism. This relation is given by equation 10.3.

$$A_{MSL} = C_A \cdot P_{AB} \tag{10.3}$$

with A_{MSL} is the equilibrium flow area in a certain cross-section AB of the basin, measured below mean sea level in m^2, P_{AB} is the tidal prism landward of the cross-section AB under consideration, in m^3 and C_A is an empirical coefficient. The flow area below MSL could be considered as the channel cross-sectional area A_e and the flats are then defined as being higher than MSL.

When the flood-tidal delta covers the whole basin, the relation between the channel volume and the tidal prism has been determined empirically. The relation is given by equation 10.4.

$$V_c = C_V \cdot P^{\frac{3}{2}} \tag{10.4}$$

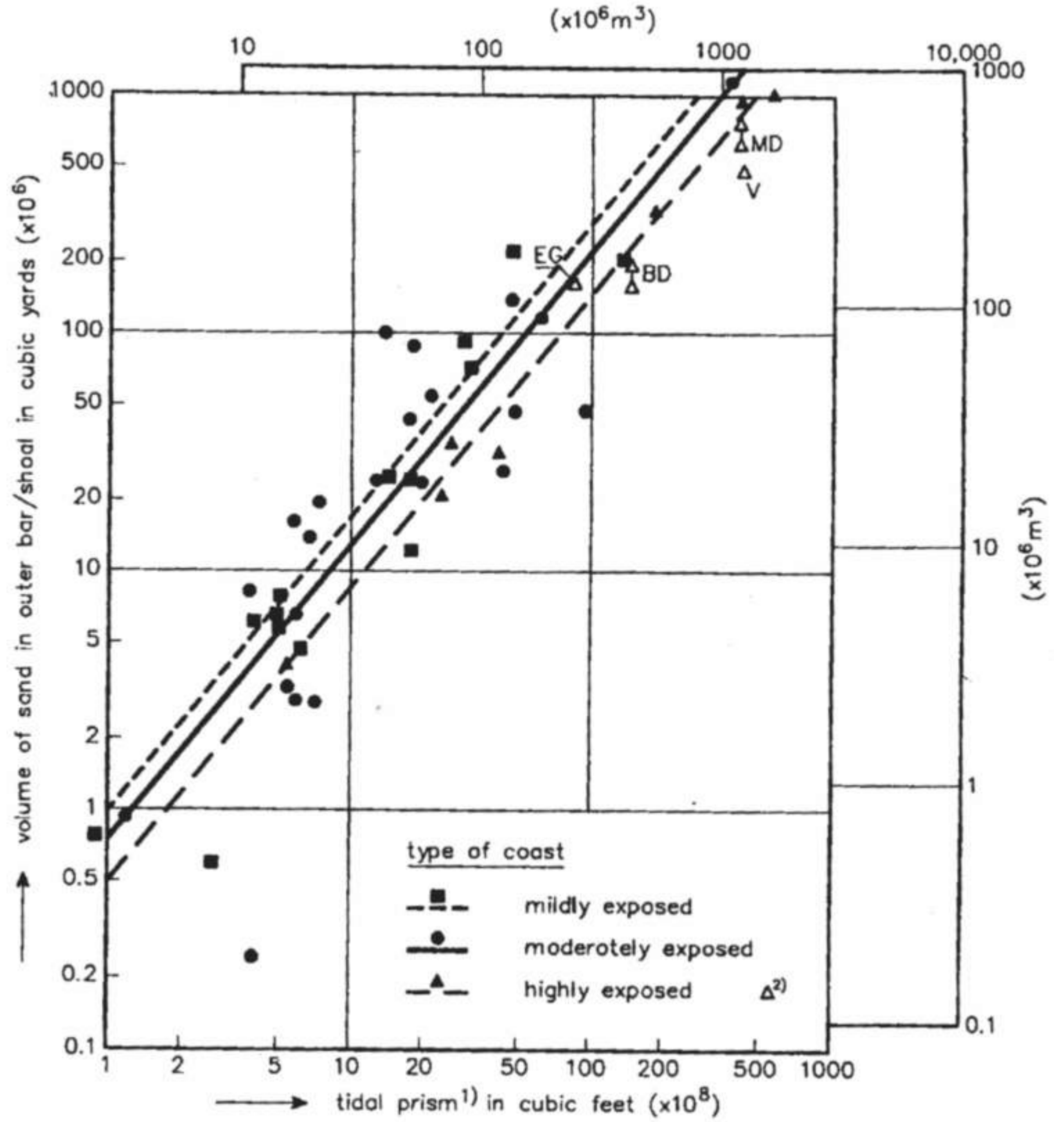


Figure 10.3: Empirical relationship between the volume of sand in the outer delta and the tidal prism (Bosboom & Stive (2013))

with V_c is the equilibrium total channel volume below MSL in m^3, P is the tidal prism in m^3 and C_V is an empirical coefficient. The relation is also shown by figure 10.4.

From figure 10.4 and equation 10.4 it can be suggested that an increase in tidal prism could result in erosion, and thus increase, of the tidal channels. However, it could also be suggested that shallowing the channels will lead to a decrease in tidal prism (Bosboom & Stive (2013) [33]).

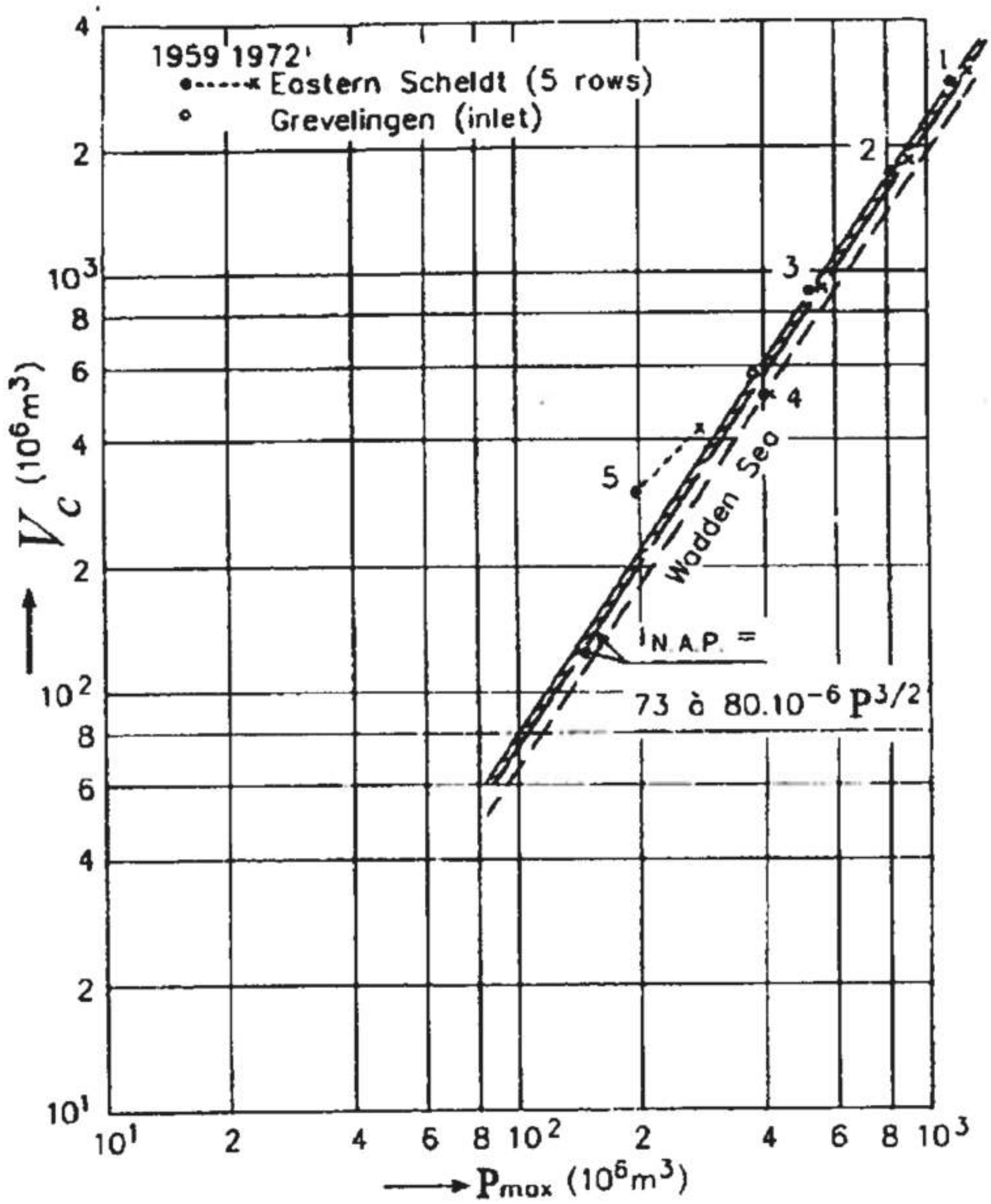


Figure 10.4: Channel volume (y-axis) versus mean tidal prism for the Wadden Sea and For Eastern Scheldt and Grevelingen (Bosboom & Stive (2013))

10.2.4. THEORY APPLIED TO JAMAICA BAY

Taking a closer look to our area of study, we try to apply the theories covered in the above chapters. The area is visualized in figure 10.5. The inlet of Jamaica Bay is subject to the theory discussed in chapter 10.2.1. The theory about the ebb-tidal delta sediment volume, treated in chapter 10.2.2, can be seen as the flats outside of the bay, confined by the box "outer delta" in figure 10.5. Lastly, in chapter 10.2.3, an equilibrium between tidal prism and tidal channels/flats remains, which is confined by the box "Basin". The next chapter will explain how these mechanisms influence each other, and reflect on Jamaica Bay.

Figure 10.5: Visualization of equilibrium mechanism for Jamaica Bay

10.2.5. CHANGES IN DYNAMIC EQUILIBRIUM

In the previous sections it has been tried to give a short overview of some of the mechanisms that influence the stability of a tidal basin. This section will discuss possible consequences of changes in the dynamic equilibrium of a basin. Possible changes can be for instance accretion of new land or closure of part of the basin. Restoration of marsh islands could be seen as accretion of new land.

Figure 10.6 shows the effect of accretion of new land within a tidal basin. Both the relation between V_{od} and P and the relation between V_{MSL} and P are shown in this figure. Due to the accretion of new land the tidal prism decreases with a volume of ΔP. As a result of this decrease in tidal prism, both V_c and V_{od} also decrease in volume with respectively the volumes a and b. Volume a is the volume of tidal channels within the basin that has to be filled with sediment and b is the volume of sediment that becomes available to the basin. If $b \geq a$, the outer delta can supply enough sediment to fill in the channels and if $b > a$ the extra volume of sediment will be deposited on adjacent coasts or possibly within the bay. In the case that $b < a$ the outer delta cannot supply all the sediment that is needed to fill the channels and additional sediment is required. This sediment can be supplied by erosion of adjacent coasts or possibly from within the basin. It is important to keep in realize that changes in this complex system will probably result in a new equilibrium situation. It must be noted that these relationships only give an indication of the new equilibrium and that they do not give any information about how the adaption will take place and what time this will take (Bosboom & Stive (2013) [33]).

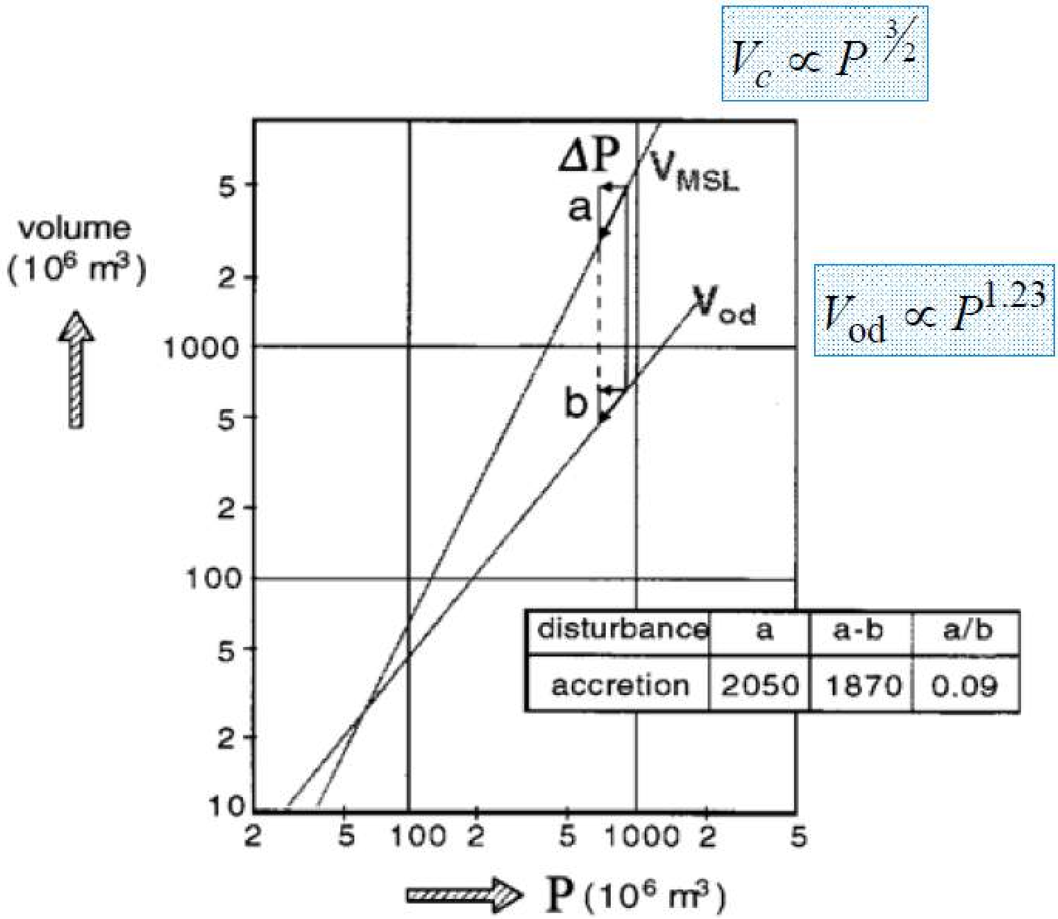


Figure 10.6: The effect of accretion of new land within the basin. The y-axis gives the volume (V_{od} or V_{MSL}) and the x-axis shows the tidal prism (Bosboom & Stive (2013))

10.3. Past and current developments and future possibilities

In this section an overview will be given about the bay dynamics. In the first paragraph "Past Salt Marsh Degradation" changes in the bay in the past will be evaluated. The next paragraph will focus on the "Current Situation". Lastly, "Future Possibilites" are pointed out in the last paragraph.

10.3.1. Past Salt Marsh Degradation

In the past, several studies have been done on the Jamaica Bay wetlands. According to Hartig et al. (2001) [19] a degradation of the salt marshes inside Jamaica Bay can be seen over the past decades. They state that between 1959 and 1998 the land area has decreased with 12%, or roughly 0.3% per year. In this study the ground field work has been compared with previous remote sensing observations for several marshes in the bay. The report points out that a process of erosion can be defined as slumping and inward retreat of peat along banks of creeks and island edges. It is noted that the process of marshland loss looks similar to loss of wetland in Louisiana and Chesapeake Bay, however, the causing mechanisms may differ. The most critical factor to be pointed out is the general sediment deficit, others would be dredging for navigation channels, wave action due to boat traffic and excessive waterfowl grazing. *Note: this section is copied from the literature study. More information about the salt marsh degradation is given in section 2.6 and in the literature study section C.4.4.*

According to the above described theory, a couple of causes for salt marsh degradation could be suggested. We think the following three causes or some of them could have contributed to the degradation of the salt marshes:

1. The fixed banks of the inlet

2. Dredging of the outer delta

3. The deep (dredged) channels in the basin

The following paragraphs will elaborate on each of them.

THE FIXED BANKS AND DREDGING OF THE INLET

In section *Entrance of the Basin and its Cross-sectional Area* on page 154 it has been discussed that the inlet of a tidal basin should be dynamic. A dynamic entrance of a tidal basin is able to adjust itself to the a new situation of something changes. From equation 10.1 can be seen that the cross-sectional area of the inlet and the tidal prism are related. A rewritten version of equation 10.1 shows this (see equation 10.5). It can be seen that an increase in tidal prism volume (and with that an increase in velocity) leads to an increase in the cross-sectional area of the inlet. This increase in cross-sectional area would eventually lead to a decrease in velocity and with that return to an equilibrium situation. About the same could happen for a decrease in tidal prism volume: the velocity decreases and with that sediment settles in the inlet, decreasing the cross-sectional area of the inlet. When the area of the inlet decreases the velocity increases again and the system goes to a new equilibrium. It must be noted that for these things to happen the starting situation must be point D (see figure 10.1) and the decrease in cross-sectional area (and thus x) may not be that big that $x < B$ (B is unstable).

$$A_e = \frac{\pi \cdot P}{\hat{u}_e \cdot T} \tag{10.5}$$

Because of the fixing of the banks of Rockaway Inlet (with houses, revetments, bridges, etc.) and the dredging this adjustment cannot take place anymore. Both situations (an increase and a decrease in tidal prism) and the relation to the salt marsh degradation will be discussed as if they happen on their own.

Increase in Tidal Prism Volume

As has been suggested above, if the tidal prism volume increases, the velocity of the water increases. Normally this would lead to an increase of the cross-area of the inlet. However, because of the fixed banks of the inlet, this will not happen and the inlet cannot return to an equilibrium situation. It is reasonable to assume that this increase velocity in the inlet leads to increased velocities in the basin. This could lead to erosion of the salt marshes.

Decrease in Tidal Prism Volume

If the tidal prism volume decreases, the velocity of the water in the inlet decreases allowing sediment to settle in the inlet. Normally this would lead to a smaller cross-sectional area of the inlet and the velocity in the inlet would return to the equilibrium velocity. Shipping through Rockaway Inlet does not allow for cross-sectional area of the inlet to decrease and for that reason the Inlet is being dredged. Because the system wants to return to an equilibrium situation it will keep moving sand to the inlet. part of this sand could be supplied by the Basin (salt marshes) and this could be seen as a reason for the salt marsh degradation.

DREDGING OF THE OUTER DELTA

The relation between the tidal prism volume and the volume of stored sediment in the outer delta is given in section `The Ebb-tidal Delta:  Sediment Volume` on page 155. The relation is shown in figure 10.3 and equation 10.2. It can be seen that the theory suggests that in increase in tidal prism leads to an increase in the volume of sediment stored in the outer delta. For Jamaica Bay it is assumed that the outer delta (or ebb-tidal delta) is located in Lower Bay because it is usually situated outside of the inlet (see figure 10.7). Because of shipping purposes parts Lower Bay are dredged (for example Ambrose Channel). This dredging means that sand is taken from the outer delta, decreasing the volume of sediment stored in the outer delta (V_{od}). Because it is assumed that the system wants to return to an equilibrium situation two things can happen: the tidal prism volume decreases and/or sand is transported to the outer delta. These two event will be discussed as if they happen separately below.

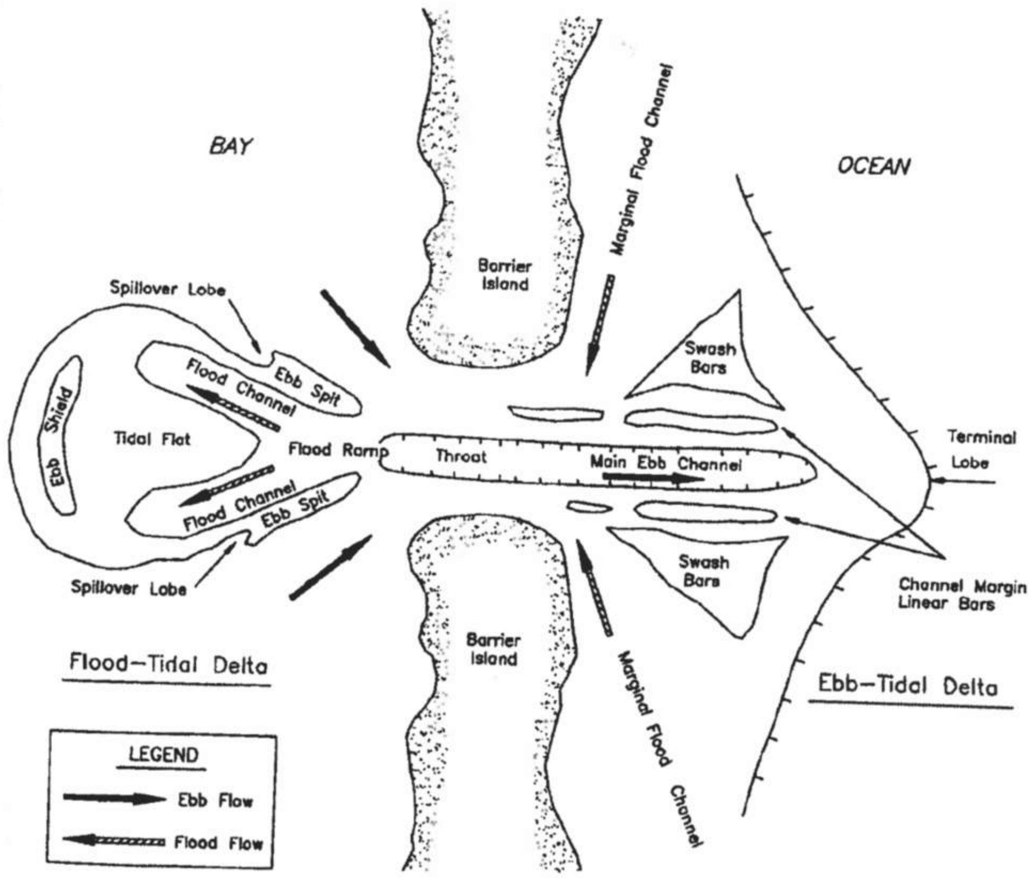


Figure 10.7: An illustration of the ebb-tidal delta (outer delta) and flood tidal delta (Bosboom & Stive (2013))

Decreasing Tidal prism Volume
From figure 10.6 can be seen that if the tidal prism decreases it is expected that the channel volume within the basin also decreases. For this sediment has to be transported to the channels and settle in the channels. Normally, sediment becomes available from the outer delta because of this decrease in tidal prism. Possible other sources are the basin itself and adjacent coasts. Because of the sand being dredged from the outer delta, it is not available for decreasing the channel volume. This means that the sediment needs to come from the other two sources. By erosion of the the marsh islands, sediment would become available to fill the channels and this could be a reason for the salt marsh degradation.

Sediment Transport to the Outer Delta
The other thing that could happen due to the dredging of the outer delta is that sand is transported to the outer delta. The theory suggests that for a certain tidal prism there is an equilibrium volume of sediment stored in the outer delta. So if sediment is taken from the outer delta (by dredging) the system wants to restore this by transporting sand to the outer delta. This sand can come from adjacent coasts and from the basin (marshes). If sediment is taken from the marshes this would partly explain why the salt marshes have been degrading.

THE DEEP (DREDGED) CHANNELS IN THE BASIN
As can bee seen from figure 2.14, Jamaica Bay contains several navigation channels. From these channels Beach Channel and North Channel are dredged channels within Jamaica Bay. The effect of this dredging will be discussed according to the theory given in the previous section `Tidal Channels and Tidal Flats` see page 155.

This theory suggests that the tidal prism and the volume of the tidal channels are related to each other by the relation given in equation 10.4. This means that for a certain tidal prism there should be an associated equilibrium tidal channel volume. By dredging the channels within Jamaica Bay the tidal channel volume increases. In order for the system to come to a (new) equilibrium situation two things can happen (and perhaps happen at the same time): the tidal prism can increase in volume and/or the system will deposit sediment in the channels to decrease the volume of the tidal channels. Both events will be discussed separately and as if they happen on their own.

Increase in Tidal Prism Volume
If the tidal prism volume increases the volume of sand in the outer delta is also expected to increase (see figure 10.3). This means that extra sand is needed for the outer delta and can be supplied from multiple sources. Usually one of the biggest suppliers of sand in this situation is the erosion of the tidal channels (see the theory given in section `Entrance of the Basin and its Cross-sectional Area` on page 154. Other possible sources are the adjacent coasts and the basin. Because the sand from the channels has been dredged it is not available for the outer delta. This means that most of the sand has to come from the basin and the adjacent coasts. The basin could supply sand by erosion of the marsh islands. The above described reaction could be considered as one of the reasons that the marsh islands have been degrading in the past.

Deposition of Sand in the Channels
Because the system wants to return to an equilibrium situation, another possibility could be that the system will try to shallow the channels again. The theory of an equilibrium situation suggests that for a certain tidal prism there is an associated tidal channel volume. If the channel volume, by dredging, increases, the system wants to restore this by transporting sediment into the channels. This sediment can come from the outer delta, adjacent coast or from within the bay (marsh islands). Because it is assumed that the tidal prism did not change, the volume of sediment stored in the outer delta will not change. This would mean that the extra sediment must come from adjacent coasts or the basin. If the sediment is supplied by the marsh islands this means erosion of the marsh islands.

EVALUATION
From these reasonings it could be suggested that all of the three causes could have contributed to the salt marsh degradation. Because all of the above events happened at the same time and also other events happened (filling in parts of the bay, water pollution, etc.), it is really hard to really explain what happened. The above given reasonings and suggested causes should therefore be treated with care. The systems that play a role for a tidal basin system are really complex and not well understood. The reasonings should only be used as if it could have happened like stated and not be used as the single one truth.

10.3.2. CURRENT SITUATION
An brief overview is given about the current state regarding the inlet of the Jamaica Bay and the wetlands stability inside of the bay.

INLET STABILITY
The Port Authority of New York & New Jersey has said that in recent years little to no dredging has been done in the inlet of the bay. Monitoring of the seabed has shown that the inlet is not subject to significant alterations. Where in the past, dredging was needed to keep a certain water depth to let boats safely maneuver threw the channel, now the required depth maintained by the morphodynimcs them self. The inlet is believed not to silt, and also not to scour. One might say that the inlet is in a balance. Escoffier believes there is a balance to be found for an inlet, see equation 10.1.

Which is remarkable in this case, is that the cross sectional area A_e has not changed in the past years, because this was maintained due to dredging. From Escoffier's curve, seen in figure 10.1, follows that usually the cross sectional area changes until an equilibrium is reached (or instability followed by a closure). Therefore, other factors from equation 10.1 (maybe) have had an impact on this equilibrium. Tidal prism P can have changed overtime, due to numerous factors in- and outside of the bay, in such a way that the equilibrium flow velocity u_{eq} has been reached. From figure 10.1 follows that the progression of the graph has shifted upwards, so that the cross sectional area A_e has reached the intersection of $TR = M$, making it an equilibrium point.

Another aspect that not has to be neglected is that the equilibrium flow velocity u_{eq} has changed, under the assumption that the currently active tidal prism and cross sectional area did not change in time and are now in equilibrium. From the theory, the flow velocity is estimate to be about 0.9m/s, however, this may not be the case at the Jamaica Bay. An other equilibrium velocity may comply better with the system.

WETLAND STABILITY

Another threat to the salt marsh islands is sea level rise. Historically, the bay's sediment capacity has been in balance with relative sea level rise. However, if sea level rise would exceed the historical sediment accretion rate of the bay, this would lead to more frequent inundation of the marshes. This has been noted as a serious threat to the well being of its vegetation, hence marsh erosion. Analysis, done by the U.S. Global Climate Change Research Program [61], suggest that with sufficient mineral sediment supply, the wetland could survive. The sediment such be rich in minerals so plant growth can be stimulated. Also, Hartig, et al. (2001) [19] points out that the growth of wetlands in the Jamaica Bay is about 2.2 mm/yr. This figure is also believed by the Army Corps of Engineers they state during the interview done leading up this report. This would mean that for the moment marshes are not in immediate threat of sea level rise, since this is approximately 1.1 mm/yr, see chapter 3.2.3.

What an interesting point for discussing is, where this sudden supply of sediment is coming from? As discussed in chapter 2.6, several studies show that marshland degradation had taken place threw out the twentieth century. Now in recent years, the created marshes are keeping pass with sea lever rise, without additional nourishment. Newly made wetlands, generally, result in a lower tidal prism. Since tidal prism is proportional to channel volume and ebb tidal delta volume, see equation 10.2 and equation 10.4, an decrease is to be expected in those variables as well. In an system without much interference from man made structures and a sufficient sediment supply, this sediment is expected to get into the system by the upstream longshore current and the ebb tidal delta. Both these factors of influence are believed to be (partially) cut off.

At the far end of the spit at Breezy point, a groyne is built, to widen the beach due to accumulation of sand, but also preventing excessive sediment flow downstream of this groyne, and subsequently the bay. Also, one can hardly speak of an natural ebb tidal delta since hardening of the shoreline and dredging prevents natural formation of such an delta. However, one could link the bay need for sediment to the former silting inlet. Maybe the need of sediment in the bay has shifted the demand from the inlet to the marshes. If this would be the case, this would hardly be an permanent solution, since the system is too dynamic.

10.3.3. FUTURE POSSIBILITIES

Looking into the future, ways must be considered how to make and maintain balance in the bay. If we neglect this task, future events can not be overseen. In practical, erosion might occur and future floodings may be worse, both resulting in damage of the area.

MAKE THE INLET DYNAMIC AGAIN

According to the theory given by Bosboom & Stive (2013) [33] the inlet to a tidal basin should be dynamic. In section **??** the possible effects from fixing the banks of the inlet and/or dredging of the inlet have been discussed. It has been shown that the fixing of the banks and/or dredging of the inlet could be related to salt marsh degradation. Because of these, probably negative, effects the possible results of making the inlet dynamic again will be discussed here. Making the inlet dynamic again can lead to both positive and negative effects. They will be discussed below.

Possible Positive Effects:

A tidal basin must be seen as a dynamic system that wants to be in equilibrium and because of that the different changes due to changing circumstances. One of the parts of this dynamic system is the inlet. If the inlet is dynamic and can adjust to changes, the system could possibly reach a new equilibrium (due to sedimentation or erosion of the inlet) and with that more sustainable marshes. The possible positive impacts of both events are given below:

1. **No more dredging of the inlet**
   If the equilibrium needs a shallower and/or narrower inlet, it will probably transport sediment into the inlet. By removing this sediment by dredging the inlet, the inlets demand for sediment will not be met and more sediment will be transported to the inlet. If the dredging stops the inlet could become

shallower and/or narrower and the sediment demand could be met, stopping the transport of sediment into the inlet. With this the system (and marshes) could become more stable and sustainable.

2. **Removing stabilizing features along the inlet**
   If the equilibrium needs a larger cross-sectional area of the inlet, the inlet is likely to expand and become broader (if possible). This will lead to lower velocities in the inlet and with that probably to lower velocities in the bay. Lower velocities in the bay can lead to lower erosion rates inside the bay. Furthermore, the sediment that is eroded from the inlet will be available for the basin and ebb tidal delta. So by removing the stabilizing features along the inlet, the inlet would be able to expand again and this could have a number of positive effects on the sustainability of the marshes and system.

Possible Negative Effects:
Making the inlet dynamic again can have multiple negative effects related to erosion or sedimentation of the inlet. They will be discussed in the following enumeration.

1. **Less possibilities for shipping**
   If the equilibrium needs a shallower inlet and the inlet is not dredged anymore the inlet will become shallower. A shallow inlet can be explained as beneficial to the system (see the above reasoning). However, the inlet is used for shipping and a shallow channel could endanger this function of the inlet. If so much sand is deposited that the inlet becomes too shallow for boats to navigate in the inlet this could be explained as a negative effect.

2. **A closed inlet and bay**
   If it is decided to stop dredging the inlet, Ecoffier's theory and his closure curve (see figure 10.1) becomes relevant again. If the situation occurs that so much sediment is put in the inlet that the inlet moves from D to left of B, the inlet will want to close. Without dredging, the inlet will eventually close and a closed system will be created. This could be explained as unwanted or negative.

3. **Losing properties or even breaching Rockaway Peninsula**
   If all stabilizing structures are removed and the inlet wants to expand, erosion of the banks will occur. Without stabilizing structures the erosion of the banks could reach properties (houses or infrastructure) and destroy them. In the extreme situation that equilibrium demands a much broader inlet it could, theoretically, even happen that Rockaway Peninsula would be breached near Breezy Point. This could also be explained as a negative effect of making the inlet dynamic again.

Because it is uncertain what will happen when the inlet is made dynamic again, more research should definitely be done beforehand.

REMOVE THE GROYNE AT THE TIP OF BREEZY POINT

As has been discussed in section **??** the groyne located at the end of Rockaway Peninsula, Breezy Point influences the alongshore sediment transport. The alongshore sediment transport is from east to west. So sediment that possibly would go around the peninsula into the basin is being caught by the groyne. An obvious solution to restore balance and/or add extra sediment to the system is the removal of the groyne. The possible positive and negative effects will be discussed here.

Positive:
The positive effect of the removal of the groyne could be restoring the alongshore sediment transport. With that, extra sediment could be transported into the system and maybe stored in the basin, inlet or ebb-tidal delta. Furthermore, the sand that is captured in front of the groyne will probably also become available for the system (or at least parts of it). So the removal of the groyne could lead to an extra sand input in the system.

Negative:
A negative effect of the removal of the groyne could be erosion of the beaches near the end of Rockaway Peninsula, Breezy Point. Because the alongshore sediment transport is restored and sediment is not stopped at the groyne erosion will take place until a new equilibrium for the coast exists.

EXPANDING THE ISLAND

Another thing that can be done to create more islands is create islands by nourishing them. The possible effects of these new or expanded islands will be discussed in this section. For expansion of the islands two situations have to be discussed: expanding the islands on tidal flats and expanding the islands (partly) in the tidal channels. Both of the situations will be elaborated on below.

Expanding the islands on the tidal flats:
Figure 10.6 shows what will happen when new land is created (accreted) and no channel volume is filled. From this figure can be seen that the tidal prism volume will decrease and this will result into two things: the volume of sediment stored in the outer delta decreases and becomes available (volume b) and the volume of tidal channels decreases (volume a). Volume a has to be filled in with sediment. From equations 10.2 and 10.4 can be seen that the volume of sediment needed to fill in the channels (a) is larger that the volume that becomes available from the outer delta (b). This means that additional sediment is needed to fill the channels. As already mentioned in section 10.2.2 this sediment comes from adjacent beaches or the basin (or marshes). So it could be that part of the volume of sediment nourished for expanding the islands gets eroded and deposited in the channels. So it could be concluded that creating marsh islands on tidal flats is not the best solution.

Expanding the islands (partly) in the tidal channels:
If, during the expanding or creation of marsh islands, some tidal channels get filled or partly filled the tidal channel volume goes down (for example by volume c). So if you take the same figure that is used in the previous situation `Expanding the islands on the tidal flats`, the tidal prism volume decreases due to the extra islands. This leads to a decrease of sediment in the outer delta (volume b) and a decrease in channel volume in the basin (volume a). However, in this situation, the decrease in tidal channel volume is (partly) delivered by the creation of islands (volume c). If holds $a - c \leq b$ the sediment available from the outer delta is enough to fill the required channel volume. In the case that $b > a - c$, the extra sediment becomes available for the adjacent beaches or basin (marshes). In the case that $a - c > b$, the volume of sediment available from the outer delta is not enough to fill the required volume of tidal channel volume and extra sediment is needed, either from adjacent beaches or from the basin (marshes). Because of the very complex processes it is probably really hard to determine what a good amount of channel fill is.

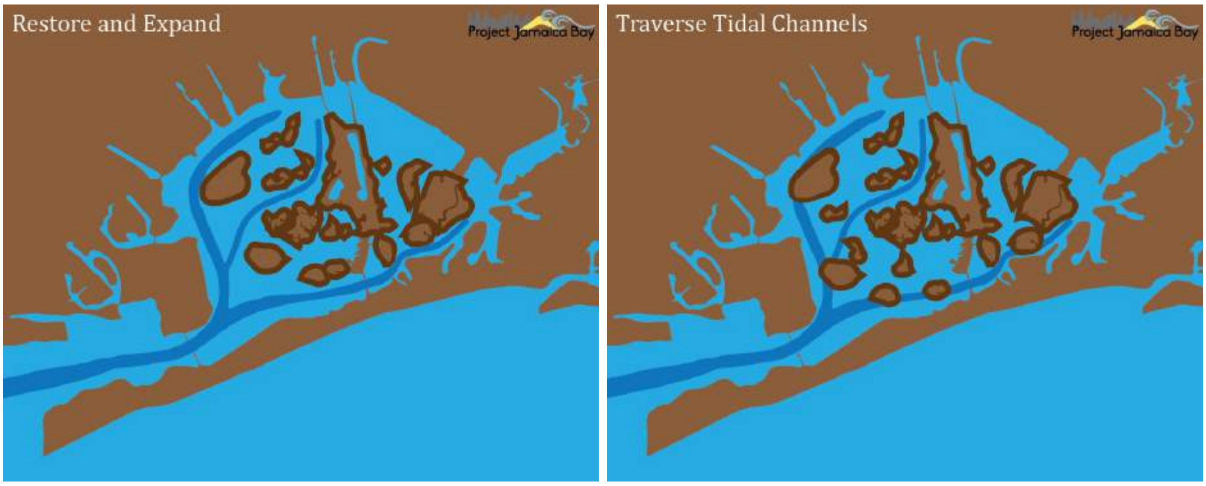


Figure 10.8: Left: Restore and expand; Right: Expand partly in the tidal channels

SHALLOWING OF THE BAY

Another factor to be looked at is the depth of the bay. Changing through-flow surface area or storage capacity of the bay can have great impact in the morphodynamics.

Shallowing channels
An option to be looked at is shallowing of the channels in the bay. When we look at equation 10.4, it follows

that the tidal prism is proportional to the total volume of the channels. When the volume of channels is reduced, subsequently a reduction is to be expected in tidal prism. An reduction in tidal prism leads to lower overall velocities in the bay, and less erosion. Accretion of wetlands is more likely, because of low flow velocities, sediments have more time to settle. Looking at figure 10.6, a decrease in tidal prism is not the only thing to be expected. Because, a part of the channel volume is taken by the modification, also a decrease along the y-axis should occur. Therefore, if designed correctly, a more favorable ratio of a/b can be established. If the need for sediment a is smaller then the supply of sediment b from the outer delta, an overall sediment supply will be given to the bay.

If looked at the water depth figure 2.2 in chapter 2.2 on page 8, what can be seen is that a lot of deep channels are to be found in the Jamaica Bay. These channels were dredged in the past to secure sufficient draft for boats. Taking the current traffic of boats into account, many of these channels are far deeper then needed. Recreational boats require a maximum draft of about 7 meter, whereas channels along the perimeter of the bay exceed this depth by several meters. In this study it has not made clear if the channels are being used for larger vessels, however, looking at the current shipping routes, and reduction of specific depth at many location should be feasible.

Shallowing inlet

Another point of attention is the inlet of Jamaica Bay. Already touched upon in previous sections of this chapter, the possibilities of this part of the system are discussed here. The past has shown that the inlet is as much dynamic as the bay itself. Interfering with this system ought not to be done, unless the effects of doing so are closely observed. Again, following from equation 10.1, it can be seen that tidal prism P and cross sectional area A_e are closely related. Following from the theorem, if one factor is changed, the other should change accordingly, until an equilibrium is met.

Like said before, a reduction in tidal prism is wanted to reduce erosion in the bay, therefore, reducing the cross sectional area of the inlet can have an positive effect on this. If in the future the tidal prism of the bay is reduced in any way, deposition of sediments would occur in the inlet. Letting the inlet silt integrating extensive monitoring to maintain required draft, instead of dredging, can have a positive effect on the system as a whole. Again, it seems that there is no need to have an inlet with a specific depth of about 14 meters. Although it seems this equilibrium is forced by the tidal prism, reducing the cross sectional area by human interference can have a positive effect for reduction of tidal prism. Dumping an amount of sand in the inlet can lead to an overall reduction of the cross sectional area, however it must be sought out if this amount of sand can not be used in a more beneficial way somewhere else in the system. However, an addition of sand in the inlet, is an addition of that amount of sand in the system of both the inner- and outer delta. Also, other structures can be considered to reduce the cross section area of the inlet to give nature a helping hand.

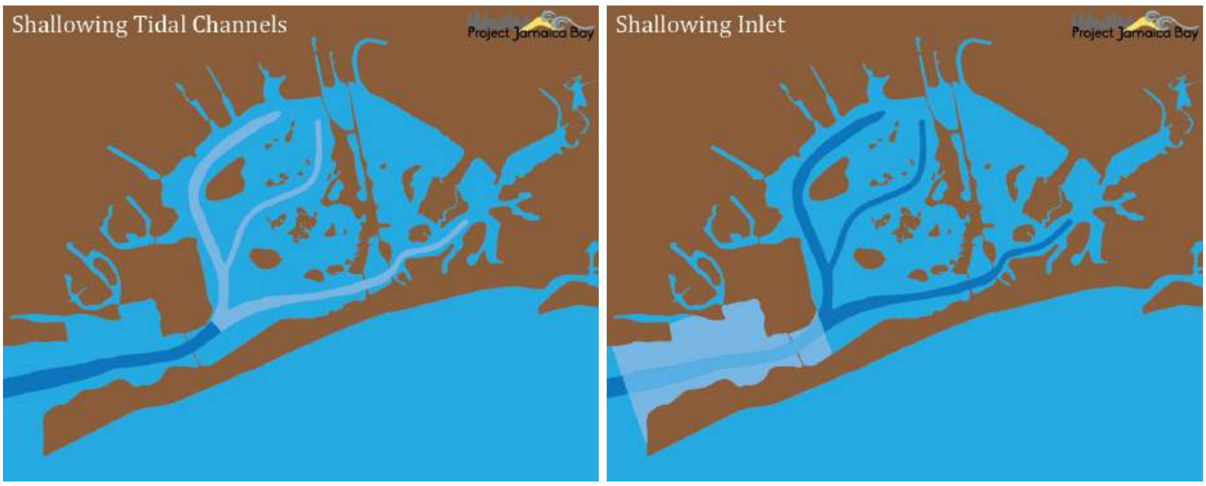


Figure 10.9: Left: Shallowing channels; Right: Shallowing Inlet

RESTORE EBB TIDAL DELTA (OF NIET MEER BAGGEREN)

Theories treated in this chapter also point out an relation between the tidel prism P and the volume of the outer delta V_{od}. Natural coastal bay systems show that there is interaction between sediment found in- and outside of the bay. Tidal movement forces sediment in and out of the bay, deposition of sediments is taking place at high and low tide when flow velocities are lowest in the system.

In this case, the system of in- and outflowing sediment maybe disrupted, due to dredging (also outside of the bay). In a hypothetical case in which sediment that has flown out of the bay, is dredged outside of the bay, could still be a sediment loss of the system as a whole. Then the system will strive to a new equilibrium, subsequently taking sediment from elsewhere in the system. If, the outer delta is reduced, and thereby the channel is deepened, prism and flow velocity might increase, resulting in a larger outflow of sediment.

NOTE: the shallowing of the tidal channels and inlet is also studied by Orton et al. (2012) [62].

10.4. POSSIBLE MEASURES FOR WETLAND RECREATION

During the previous restorations for wetlands, several techniques have been applied to return the wetlands in a sustainable state. In this chapter, three techniques are highlighted.

10.4.1. SAND NOURISHMENT

A more conservative method of restoring wetlands is by using rainbowing or a dredging pipe in combination with a sand berm. An enclosure is made using a sand berm, inside sand is dumped to create an island. The enclosure is used to reduce wave impact and tidal movement. The technique was used for the reconstruction of Elders West, see figure 10.10. The project succeeded to restore 40 acres of wetland using 302 cubic yards of sand. The total cost was $17,200,000. Because this technique is fairly simple and relatively successful, the same method was used to restore Yellow Bar Hassock, Black Wall and Ruller Bar.

Figure 10.10: Restoration of Elders West using sand berm (USACE [63])

10.4.2. COCONUT COIR LOGS

One way to create wetlands is by using coir logs. Coir logs are made from tightly bound cylinders of coconut fibers which are held together by a netting made from coir twine, these are natural fiber material. The main purpose of coir logs is a temporary physical protection against erosion, they serve as toe protection of a restoration wetland. When a perimeter is build using coir logs, the enclosed area can be protected from low velocity water flow. Usual dimensions of coir logs are between 3 to 6 meters in length and 0.30 to 0.50 meter in diameter. The coir log is biodegradable, and because natural fiber material is used, little harm is done to the environment. The product deteriorates in 2 to 6 years, this figure is dependable on the specific coir product and to what extent the measure is subject to water flows and other environmental factor, such as temperature and acidity level. After instalation, it is possible to saturated the coir log and/or grow vegetation on it. If vegetation can root itself within the time the coir logs deteriorates, the logs substrate can serve as a continued erosion control measure.

REFERENCE PROJECT COIR LOGS: ELDERS POINT - JAMAICA BAY

Coir logs have already been used within Jamaica Bay during the restoration of the marsh islands Elders Point East and Elders Point West. In 2006 the restoration of Elders East was completed. In total 43 acres (249,000 cyds) of marsh island were restored. The restoration of Elders West was completed in 2010 and during this project 40 acres (302,000 cyds) were restored. For both islands coir logs were used. A configuration of coir logs was used as a base for the island (see figure 10.11). The coir logs were used to maintain the sand while vegetation was still not strong enough to maintain it. On Elders East 7000,000 plants were planted and on Elders West 200,000 plants. The restoration of Elders East cost $ 13,000,000 and Elders West cost $ 17,200,000.

Figure 10.11: Elders point East is restored with coir log (USACE [63])

The steps followed by the USACE for rebuilding the Elders Point islands were:

1. Sand delivery
2. Containment of the sand (using coir logs)
3. Grading of the islands
4. Transplanting of plants
5. Planting new plants

The result of this project can be seen in figure 10.12.

Figure 10.12: The result of the restoration of the Elders Point islands, photo shot from an airplane on October 18, 2010 (USACE [63])

INSTALLATION

Installation of coir logs must be done during the dry time of the riverbed. It cannot be installed in the wet. First the log has to be fixated in the riverbed, therefore a trench needs to be dug of about 2/3 the size of the log. Then the logs need to be securely anchored to the subsoil using wooden or live stakes. Nylon or coir twine is used around the wooden stakes and the logs to firmly fixate them to the substratum. Also, nylon and coir twine is used to tie adjacent logs to one and other. After installation, the soil needs to be compacted to ensure stability. To ensure consistency, both upstream and downstream ends of the log span need to be embedded into a bank.

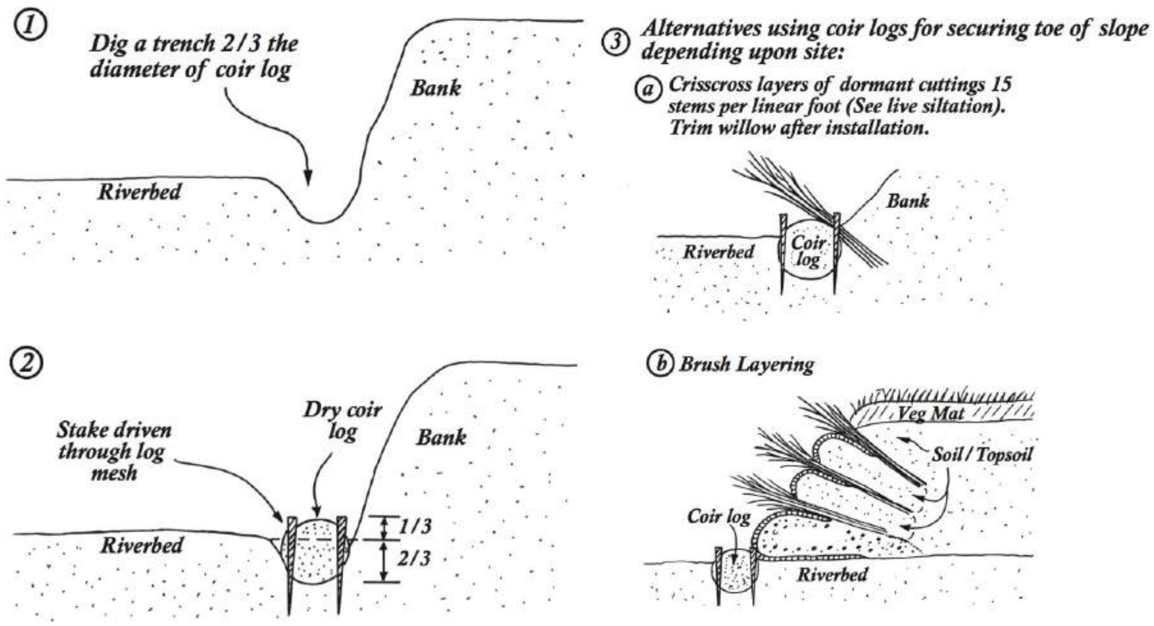


Figure 10.13: Instalation of coir logs step-by-step [?]

CONSIDERATIONS

If one would compare coir logs to a synthetic erosion control, stabilization or filtration product, natural fiber product offer several advantages. Because of the materials is fully natural and biodegradable materials, this material does not harm the environment ecological quality. The material does not pose a threat to surrounding wildlife in the area. The logs demand little to no maintenance. Onces the logs are installed, they can be left alone to a certain extent. When the log starts to biodegrade, the fibers and the subsoil will lead to an enriched environment.

10.4.3. GEOTEXTILE TUBES

Another innovative measure which has made a lot of development during the past two decades are geotextile tubes. In essence this measures consist of a water permeable, sand-sealed geotextile filled with sand or other granular materials. Length can usually vary from 25 to 100 meter, whereas height is up to approximately 7 meters, dependable on the materials used. Thanks to improvement in both design and application, tubes are more and more used for marine applications, both for temporary as permanent solutions. It can function as a temporary dike or breakwater, but also as permanent groynes, breakwaters, dune toe protection, submerged reefs, containment dikes or core structures.

A good example how geotextile tubes can contribute to wetland recreation is this project at the Starvation Cove, Galveston, TX. Here a large scale tube breakwater system was build for shoreline protection followed by wetland restoration [**?**]. What clearly can be seen in the picture depicted on the right in figure 10.14 is that wave impact is reduced on the wetlands by using a breakwater. Also, tubes have showed that they cope well with high hydraulic loads induced by hurricanes. Both tubes from Starvation Cove and in Cancun, Mexico, were exposed to unexpected loads, and only received minor post-hurricane damage.

Installation of geotextile tube breakwater system for shoreline protection followed by wetland restoration Cancun tubes served as submerged breakwater in front of the coast. During a cateogry 5 hurricane Dean. Ernosto Gray: not single tube or scour apron was damaged

Figure 10.14: Wetland creation at Starvation Cove, Galveston, TX [**?**]

To give an example in what way tubes can incorporate green envisions into their function from an engineering point of view this project at Reeuwijkse Plassen is shortly highlighted. The geotextile tubes were used to protect the inland shoreline from wave impact. To preserve the green surroundings, the top of the tube was sprigged with native vegetation. Six months after installation, the top was covered with vegetation. In this way new habitat was created for wildlife, see figure 10.15.

Figure 10.15: Geotextile Tubes for shoreline protection with vegetation by tencate [**?**]

FABRICATION AND INSTALLATION

A tube is first fabricated at a facility. The geotextile is made from polypropylene (PP), a thermoplastic polymer. This plastic is mold into fibers at high temperatures. The fibers are subsequently woven, resulting in a fabric which can be used for a geotextile tube. The fabric delivers tensile strength along the woven pattern. Next, the fabric will be sown in such a way a tube is made. Only filling ports need to be attached to the tube, before the tube is rolled and ready for delivery on site.

When the tube is put in place in the dry, the tube is unrolled at the location. Now a mixture of water and sand needs to be pumped into the tube. Hoses are attached to the filling ports to pump the fill material. This mixture usually has a ratio of 1 (solid) to 4 (water) or 1:5, dependable on the sediments used. Sometimes a polymer needs to be added to the mixture to get the desired amount of solids in the slurry (sand-water mixture). When a filling percentage of about 70% to 80% is reached, the filled height is about half of the flat width of the geotextile tube. Higher filling percentage can be reached, but require a higher tensile force requirement of the geotextile. And although a great height is reached, extra care needs to be taken in to account for rolling of the tube and vertical/horizontal stability.[38]

During filling, the slurry blocks the pores of the tube's fabric to some extent, and therefore reduces permeability and leads to overpressure. Thanks to the overpressure, the water will pore out of the tube, subsequently relieving the textile a bit of its stress. Consolidation of the fill material will take place. The process is depicted in figure 10.16. To prevent a possible tear in the tube, the contractor should be aware not to overfill the tube. Also from designing point of view, the seam must be of adequate strength. Whereas many may think this is a critical point in the tube, the seam is usually not a problem because it will exceed the tensile strength of the textile.

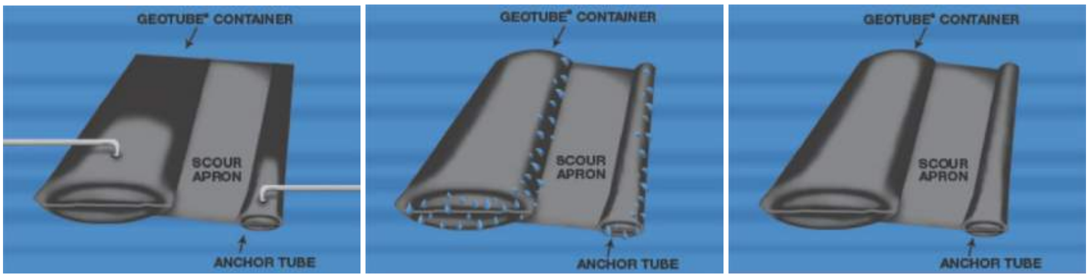


Figure 10.16: three steps in filling a tube by tencate [**?**]

To provide stability of a tube, anchor tubes are used to firmly fixate a tube in its position. this can be used in both a land or marine application. This anchor tube will be dug into the subsoil, ensuring the system's placement. Another point of concern is scour. Especially in coastal environments, scour is a threat to hydraulic structures. Eroding sand can jeopardize the systems stability. Along the tubes, scour aprons are used to minimize scour around the tube. In this way, the subsoil is held in place, and stability can be guaranteed when designed adequately.

Staking of tubes is also possible if a certain height needs to be reached. It is advised to have one tube with an bigger circumference rather than staking, regarding stability. However, several projects have shown that staking should not be a problem, also in marine environments. Staking has been applied for groynes at Stella Maris Ecuador, (temporary) dikes at Incheon bridge Korea and dams at Morocco Dam [**?**], see figure 10.17.

Figure 10.17: Staked tube application [**?**]

CONSIDERATIONS

From a technical point of view geotextile tubes are attractive, since no rocks need to be used. Making structures out of sand is less labor intensive then compared to rock. Also, relatively small equipment can be used. A downside of tubes can be that maintenance, or at least monitoring, is needed. When a tube is exposed to UV radiation, the textile can deteriorate rapidly. Also, a textile can be punctured by sharp objects. All these problems can be fixed easily, but a close eye is needed.

As shown in several project, tubes can be used for an array of functions. As it can function as a temporary shoreline protection or as permanent foundation of structures, some interesting combination for wetland creation can be envisioned. Tube breakwaters can be used to minimize wave impact and inundation during wetland creation, but tube can also be used as a base for high marshlands. The geotextile can prevent erosion from the hinter lying wetland to some extent. And although some might say this artificial island may not be a natural, if it can improve the ecology value of the area, this is an option that needs to be considered. Also, regarding flood risk mitigation, creating and preserving wetlands can have a positive effect regarding flood risk mitigation, see chapter **??**.

From a economical point of view, sand is generally cheaper then stone. What is particularity interesting is beneficial use of dredge material. Since the study area is near to the New York-New Jersey Harbor Estuary, dredge material from channels can be used in geotextile tubes. This option needs to be sought out by the Port Authority, National Park Service and a geotextile supplier. Up until now, only clean sand can be used for wetland restoration, which can be a significant cost driver. If a geotextile supplier can guarantee the durability of its geotextile, a leap in efficiency can be made, both economical as environmental purposes.

10.4.4. EVALUATION & POSSIBILITIES

The later two applications in this chapter show that with the help of innovative measures, wetlands can be created in a more efficient and sustainable way. Conventional nourishment methods, like dumping sand, have shown not to be less efficient regarding fill material (and maybe in cost). If an increase in environmental value is wanted by stakeholders, they should consider if striving for a natural bay does coincide with a ecological rich bay. Looking at the modifications and alterations of the bay during the past century, one can hardly speak of a natural system. However, this does not mean a divers system for both flora and fauna can not be realized. For instance, an artificial island can contribute to ecology and sustainability of the bay, or even with respect to flood risk mitigation. Therefore, such options should be considered by all parties involved.

11

HYDRODYNAMIC MODELING

This chapter will elaborate on the modeling part of our research on Jamaica Bay. Modeling the Jamaica Bay is a powerful way to test the measures and see what happens with the water level (and waves) during a design storm with a return period of 1/100 years inside the Jamaica Bay. The different objectives of the model, the methodology and setup and the results of the simulations will be explained.

11.1. INTRODUCTION

Our research focuses on flood risk mitigation of the Jamaica Bay area. Some measures has been investigated in the previous chapters. This introduction will briefly go into different modeling suites which could be used for hydrodynamic modeling. First of all, the model that is used, Delft3D, will be explained and a comparison with ADCIRC, a different model for storm surge simulations, will be made.

11.1.1. DELFT3D

The modeling software which will be used during this project is called Delft3D. Delft3D is a powerful modeling suite developed by Deltares (formerly known as WL Delft Hydraulics) in Delft, the Netherlands. The software simulates two-dimensional and three-dimensional flow, waves, sediment transport and morphology, water quality, salinity and ecology. The framework of the suite makes use of several modules, grouped around a graphical user interface, which have the ability to interact with each other. The software has areas of application ranging from flows due to tides, wind or wave induced currents to sediment transport of cohesive and non-cohesive sediment and water quality phenomena inclucing ecological modeling. Delft3D is mostly used for the modeling of natural environments like coastal ares, estuaries and river areas. Delft3D is widely used world-wide for coastal processes and is very suitable for an estuary like Jamaica Bay (Deltares, 2011 [64]; Deltares, 2011 [65]).

Delft3D can used as a storm surge model, but has a whole range of other features. If Delft3D is used as a storm surge model, the model will be run in 2D.

Delft3D became open-source software in 2011 and it is under constant development, for example currently Deltares is working on a flexible, unstructured mesh module, called D-FLOW FM, while nowadays only rectangular and curvilinear grids are possible.

FLOW MODULE

The FLOW module is the main module of the Delft3D modeling suite. It is a simulation program which can simulate two-dimensional and three-dimensional flow. It calculates non-steady flow and transport phenomena due to tidal, meteorological or wave forcing on a rectangular or curvilinear grid, fitted on boundaries (Deltares, 2011 [64]). In this project the model was run in 2D.

WAVE MODULE

The wave generation and propagation into a model is simulated with the SWAN wave module of Delft3D. The wave conditions in nearshore (and offshore) are subsequently calculated. This module is coupled with the hydrodynamic flow module (Deltares, 2011 [66]).

11.1.2. DELFT3D VERSUS ADCIRC

ADCIRC (The ADvanced CIRCulation model) is a different model for oceanic, coastal and estuary waters. ADCIRC is software for finding solutions of free surface circulation and transport problems. Like Delft3D it can solve problems in both 2D and 3D. ADCIRC makes use of the finite element method in space with highly flexible unstructured grids, which makes it very efficient in terms of calculation time. Most common applications of ADCIRC are predicting of storm surges and flooding and modeling tides and wind driven circulation (The University of North Carolina at Chapel Hill [67]). For the use of predicting flooding due to storm surges ADCIRC takes the tides and wind pressure due to the storm into account. Short waves in the domain are calculated with SWAN, which can be coupled to the hydrodynamics like in Delft3D as well. ADCIRC is used a lot as a flood prediction model in the United States of America, while Delft3D is common in the Netherlands, as well as other parts of Europe and the world.

In comparison with ADCIRC Delft3D is very different, but for the purpose of tidal or flood predictions in 2D both models are very comparable. Delft3D is not more accurate or helpful for this purpose than ADCIRC. An advantage of ADCIRC is that is already supports flexible and unstructured meshes, which Delft3D Deltares has been developing lately for Delft3D. Both models work with depth integrated 2D flows (2DDI). Besides used as a flood model, Delft3D can be used for many more applications, in contrast to ADCIRC. For example the sediment transport and morphology, water quality and salinity can be taken into account. And because the Jamaica Bay has a lot more problems than flooding, for example water quality, salinity and erosion problems, Delft3D is very interesting tool for use in the Jamaica Bay. And therefore probably more interesting for this area. During this project other functions than hydrodynamic flow modeling will not be used, but this model could possibly lay groundwork for future research, for example on sediment transport and morphology or water quality in Jamaica Bay. Furthermore Delft3D uses an implicit scheme and therefore the time step in a calculation can be larger in general than in ADCIRC which uses an explicit scheme.

11.1.3. DELFTDASHBOARD

According to Deltares is DelftDashboard "a standalone Matlab based graphical user interface for setting up models. The interface is coupled to Delft3D. The coupling with Delft3D FLOW is fully implemented, but coupling with other modules of Delft3D modeling suite is still under development" [68]. The graphical user interface DelftDashboard is a very simple tool to use and could be used for setting up the model during this project.

11.2. OBJECTIVES

There are a few objectives to this modeling during this project. Measures have been designed in the previous chapters, both perimeter measures and measures regarding the development of the marsh islands. All these measures have certain functions they try to fulfill, for example stopping the surge height during a 1/100 year storm, lowering the waves and surge height and improving the sustainability of the tidal basin system and marsh islands. Using simple calculations and rules of thumb these functions have been checked. But to test the measures for their functionality in a good and qualitative manner some modeling should to be done.

The objectives for the modeling during this project are the following:

1. Do a qualitative analysis of the effectiveness of several different solutions for salt marsh islands on the storm surge level in the Jamaica Bay

   In chapter 9 some considerations are being made regarding the restorations of the salt marshes and the possible advantages it has reducing the storm surge level. Using the Delft3D model it can be checked if those considerations were true and if some designs are beneficial regarding reducing the surge height in the Jamaica Bay. The design of the marshes, both high and low, and the roughness values of the marshes come in play as well.

   Different sea level rise scenarios could be applied to see the effect on the model output, to make conclusions even stronger. However, this has not been done with this project.

2. Do a qualitative analysis of the effectiveness of the several different solutions and designs on the sus-

tainability of the tidal basin system and the marsh islands itself

Chapter 10 discusses a theory about the sustainability of a tidal basin system with a outer delta, and inlet and a inner delta. This theory could be applied to the Jamaica Bay. Several considerations are discussed to improve the sustainability of the system and therefore the sustainability of the marsh islands. For example it could be useful to shallow the inlet of Jamaica Bay to reduce the tidal amplitude inside the bay and increase the sustainability. With the model it can be checked whether the considerations were true and whether the designs are effective. Different results can be compared.

3. Lay groundwork to expand research on Jamaica Bay with this detailed Delft3D model, for example on morphology, water quality or ecology

   Both morphology and water quality could be very interesting to investigate in the Jamaica Bay area, but it will not be done during this project. Examples of interesting morphology subjects are the disappearing marsh islands inside the Jamaica Bay and the outside of the Rockaway Peninsula, where alongshore sediment transport from the east to the west occurs.

These objectives will be pursued using Delft3D, which could be supplied to the project team by Delft University of Technology. Furthermore Deltares, one of the sponsors of the project could be of support with the hydrodynamic modeling.

In the next paragraphs the methodology and model setup will be discussed.

11.3. METHODOLOGY

To achieve the goals listed in the previous section, a process-based high resolution model in a depth-averaged configuration (2D) will be made using Delft3D. The deterministic mathematical model solves the three-dimensional shallow water equations and the continuity equations by use of an implicit finite-difference-scheme (Deltares, 2011 [65]).

Several steps need to be carried out to pursue the objectives:

A high resolution digital elevation model is needed. This elevation model was supplied to the project team by ARCADIS US. Section 11.4 will explain more about this digital elevation model.

The following thing is to define a computational grid for the hydrodynamic calculation, and subsequently a bathymetry (a depth) file.

A small scale model will be made, using a single domain. Open boundaries along the grid should be defined and boundary conditions should be forcing the model. Because the domain is small, it would be very difficult to extend the Delft3D model into deep enough water to propagate a surge from a storm adequately. And since the measures are designed for the 1/100 year storm surge levels according to FEMA, we need a forcing at the boundary that comes from a storm that approximates the 1/100 year inundation according to FEMA. It was chosen to use Sandy waterlevels to force the boundary of the small scale model. More on this schematization and boundary conditions in section 11.5.

The model will be calibrated for tides using tidal predictions inside Jamaica Bay by NOAA. The storm surge model for Jamaica Bay cannot be calibrated because no good observations inside Jamaica Bay are available during Superstorm Sandy.

With Sandy waterlevel time series from the large scale basin model in ADCIRC forcing the open boundaries, a FLOW storm surge model will be run. When making the simulation time long enough, far longer than the storm surge scope of Sandy, the tidal signal could be validated as well.

The model has forcing from large scale processes. The water level in the bay is primarily determined by this seaward boundary. But also local conditions play a role in this, for example wind setup due to local wind. In this small scale model local wind is incorporated, by means of a wind time series during Sandy.

Then, a FLOW storm surge model will be run with different configurations of marsh islands to give a qualitative judgment on the reduction of the surge levels. The roughness of the marsh islands plays a big part in this. More on this will be explained later. The proposed solutions are mostly large scale, conceptual solutions. The bathymetry of domain has been adapted using the QUICKIN tool in Delft3D, prior to the new calculations. For instance the inlet has been shallowed by 0.5 or new marsh islands have been created. More on this is explained in section 11.7.

Next, a FLOW tidal model will be run with different solutions implemented regarding the sustainability of the system and the marsh islands to test the solutions giving in the chapter 10. The proposed solutions from this chapter are largely the samen as the solutions for reducing the storm surge. Also these measures will be implemented with QUICKIN in Delft3D. See section 11.8.

An interesting model test would be to see the effect of the solutions on the wave height in the bay. This WAVE model, coupled with the existing FLOW model will not be made during this project, but it is certainly recommended to make such a model during future research.
All results will be processed with the tool Quickplot within the Delft3D modeling suite.

11.4. DIGITAL ELEVATION MODEL

The digital elevation model (DEM) used in this project is provided by ARCADIS US, and made by the Federal Emergency Management Agency (FEMA). This DEM is part of development of terrain data for storm surge modeling in FEMA region II, as a result of the National Flood Insurance Program. The study incorporated all counties near the coast of New Jersey and the five boroughs of New York City. The effort was completed in June 2011. The data for the DEM's was obtained from topographic and bathymetric sources. (FEMA, 2011 [6])

This Jamaica Bay model is according to experts in the field the best known DEM for the area. The DEM of the Jamaica Bay has a horizontal resolution of 2m, which is a high resolution. The vertical datum is NAVD88, in feet. The horizontal datum is NAD83, in meters (this was originally in feet, but ADCIRC, for which several high resolution DEM's were created, requires metric units for horizontal datum). The DEM has been processed for the purpose of using it in Delft3D by the project team. The vertical units have been changed to meters, with a positive z-value in downward direction.

A plot of the DEM before the vertical units have been changed can be seen in the figure 11.1 below, which is plotted using ArcGIS software.

Note: The DEM in this Jamaica Bay area has a slight shift of about 50 meter with regards to for example aerial photography. For as far as some experts at ARCADIS US (who worked together with FEMA on the latest Flood Maps) know, the coordinates were not correctly projected from some other systems when the DEM was created. Even with this error the data set is the best available DEM for Jamaica Bay.

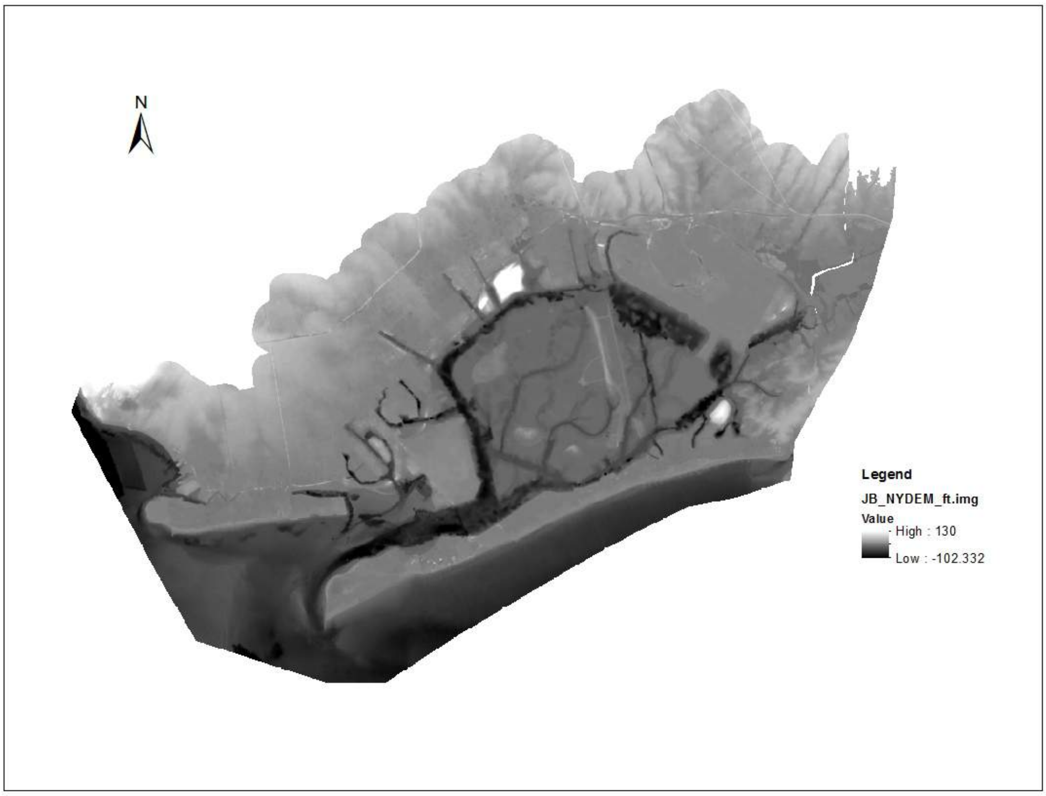


Figure 11.1: Digital Elevation Model of Jamaica Bay, elevations are in feet (FEMA, 2011 [6])

11.5. NUMERICAL MODEL SETUP

How the FLOW model is set up will be discussed in this section.

11.5.1. MODEL SCHEMATIZATION

The model of Jamaica Bay is a small scale model. To simulate a big storm like a hurricane and to propagate the storm surge from deep enough water to shallow water in the bay correctly we need to impose forcing boundary conditions in the small scale model from a storm simulated with ADCIRC. This allows the storm to push from deep water into shallow water. The boundary condition from ADCIRC accounts for processes that the large scale model from ADCIRC is able to capture that the small scale model is unable to.

The two mechanisms that cause a surge in Jamaica Bay are flow through the Rockaway Inlet and flow over the Rockaway Peninsula. For the domain offset we need to account for both mechanisms. The proposed boundary conditions are a water level constituent forcing along these boundaries. The two surge mechanisms can be seen in figure11.2.

Along the boundary of the domain a water level and tidal constituent will be forcing the boundary. An general example of a this idea can be seen in figure 11.3. The domain of the model will be different than this general idea, more in this will be explained later.

A 1/100 year storm is the design storm for the discussed measures. Water levels due to a 1/100 year storm roughly correspond to the water levels during Sandy. And because the water levels during Sandy are available, this storm is chosen. Therefore the water level time series of hurricane Sandy will be forcing the boundary of the small scale model.

Once the boundaries in the Delft3D are defined, hydrographs from ADCIRC for Sandy will be extracted and used as a Delft3D time series water level boundary for simplicity.

Figure 11.2: Storm surge mechanisms Jamaica Bay)

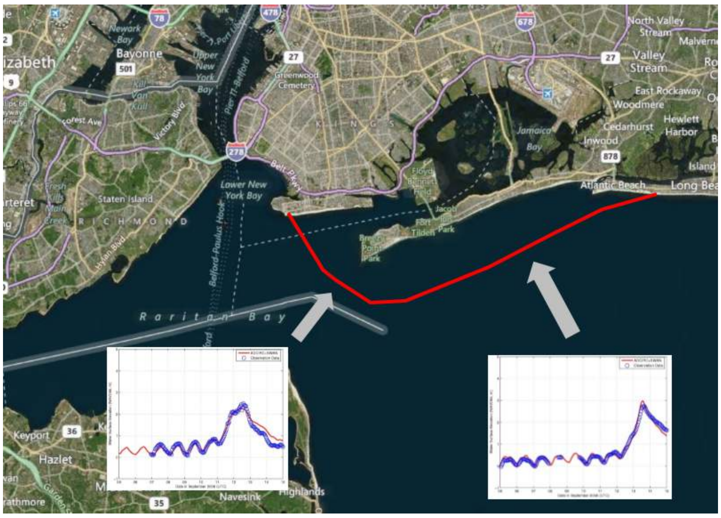


Figure 11.3: Water level and tidal constituents along the boundary)

11.5.2. GRID

Non-stationary hydrodynamic processes are solved on a staggered curvilinear model grid. The grid is chosen to be curvilinear to follow the coast of the Rockaway Peninsula. Flow can be adequately described in this manner. As said before the calculations will be run in a depth averaged, 2D sense. The number of layers in grid parameters is therefore 1.

It can be seen that the boundaries of the domain are defined in a different way than the pictures in section 11.5.1 show. There are three open boundaries now that will be forced with a water level time series of Sandy from ADCIRC. The reason is that it is necessary for the open boundaries in Delft3D to be straight along the grid cells en not staged like it would be when the digital elevation model would be used. And the grid cells follow the coast, thus three boundaries remain as can be seen in figure 11.4. Because the grid extends further into the sea than the original digital elevation model, the bathymetry is extended towards the seaward boundaries using the NGDC Coastal Relief Model data.

The resolution of the grid inside Jamaica Bay is finer than offshore. This is necessary because the scale of the tidal channels is smaller, the flow can be described more adequately. The finest resolution is about 70 x 70 meter inside Jamaica Bay. Offshore the biggest resolution is about 280 x 280 meter. This resolution inside

Jamaica Bay is expected to be good enough to give accurate results because the magnitude of the prescribed measures is not as small and mostly the effective, qualitative results are being treated in this study. The remaining quality parameters orthogonality, smoothness and aspect ratio are considered good as well. The orthogonality is 0 almost in all the domain. The smoothness, both in M and N direction are around 1 and maximum 1,2, which is good. Furthermore the aspect ratio has a maximum of 2 in the area of interest (inside Jamaica Bay).

11.5.3. BATHYMETRY

The DEM used for the model had a very high resolution. This data has been adjusted for calculation time purposes, resolution has been decreased by a factor 8. Which mean the new resolution of the DEM is 16 meter, which is still good enough for describing the processes in the Jamaica Bay properly. This reduced resolution bathymetric data will be used in Delft3D.

This bathymetry has been created in QUICKIN using the above defined grid. A picture of the bathymetry and the grid can be seen in figure 11.4.

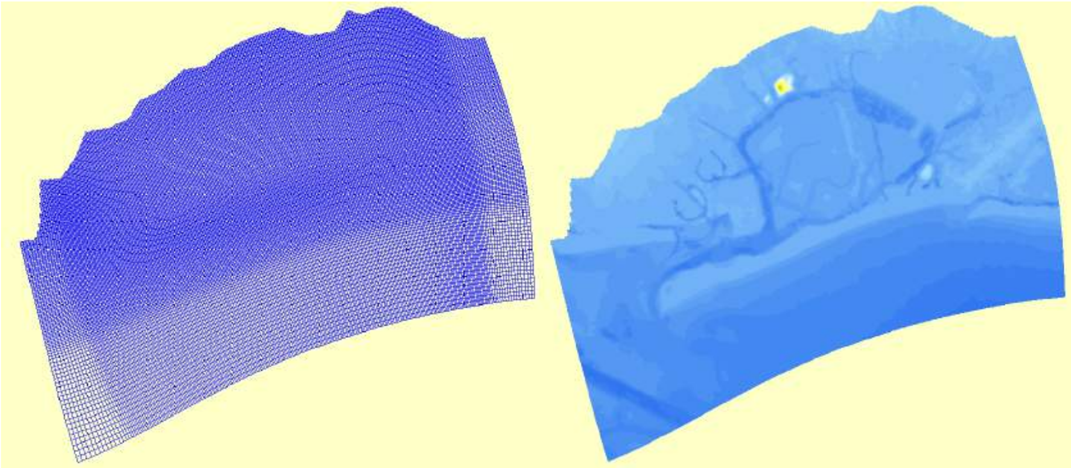


Figure 11.4: Plots of the computational grid and bathymetry)

11.5.4. BOUNDARY CONDITIONS

The setup of the boundary conditions is already discussed in section 11.5.1. Here the precise implementation of the boundary conditions will be treated.

TIDAL BOUNDARIES

The tidal boundaries follow from astronomical data from the TPXO7.2 data set. This is interpolated on the three open boundaries from data of nearby stations using DelftDashboard.

A reflection parameter alpha of 100 [s2] is used in the calculations.

SANDY BOUNDARIES

Since there are three open boundaries for the model, for simplicity it is chosen to define three forcing boundary conditions, one for each open boundary. At three locations a hydrograph from ADCIRC is extracted to simulate water levels forcing the boundaries during Sandy of the small scale model. These three water level time series are provided to the project team by ARCADIS US, and are imported in Delft3D as a bct file. Exact locations can be seen in figure 11.5 below.

Figure 11.5: Exact locations for three boundary conditions (Google Earth)

The hydrographs of the water level (visualization of the time series) during Sandy at the three locations along the boundary of the domain are shown in figure 11.3.

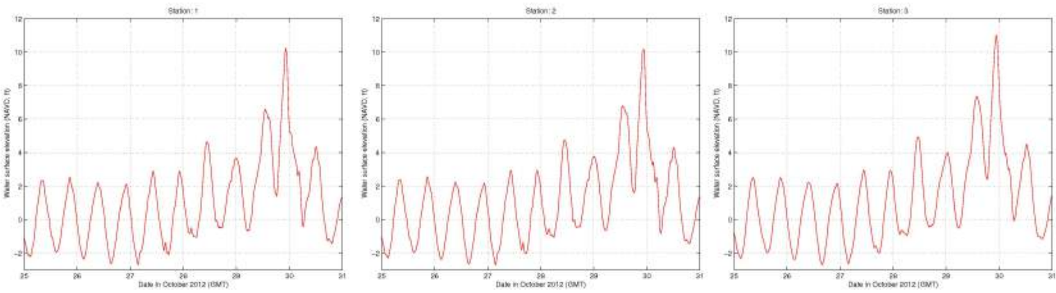


Figure 11.6: Hydrographs at the three boundaries of Superstorm Sandy forcing the boundaries of the small scale model

11.5.5. WIND

This local phenomenon can cause wind setup inside the domain. Therefore the water levels in Jamaica Bay can be different from the water levels due to only large scale processes.

It is assumed that the wind is uniform over the entire domain. But the wind is time varying during Sandy regarding speed and direction. Therefore the wind is imported into the Delft3D model using a time series, but uniform in space. The wind time series is extracted from NOAA data [26]. NOAA has several meteorological stations. The station Robbins Reef, New Jersey is chosen to be the reference stations, because it is closest to Jamaica Bay with a total wind measurement during Sandy. This has also been explained in chapter 3.
A plot of the wind speeds and direction during Sandy can be seen in figure 11.7.[26]
This wind will be translated into a time series (bct file) with a varying speed and direction and used as input in Delft3D. The winds are used instead of the wind gusts.

It can be noticed that the wind is most of the time during Sandy coming from the east. At the end of the storm the wind turned from the south. This means that the wind blows the surge out of the bay at the peak of the storm, therefore making the water level a little bit lower inside Jamaica Bay.

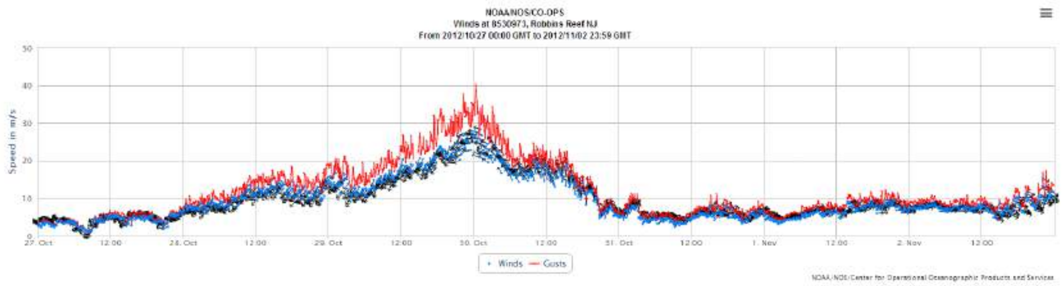


Figure 11.7: Governing wind speeds and direction during Sandy at Robbins Reef, NJ, close to Jamaica Bay [26]

11.5.6. MONITORING STATIONS

To process results of Delft3D calculations some monitoring stations have to be chosen. One offshore, one far into Jamaica Bay and 10 other stations have been chosen. The ten stations are at the same locations as the tide predictions of NOAA, used for the tidal calibrations. A .obs file is created and this file is used in every calculation of Delft3D.
A figure of the observation locations is plotted in figure 11.8.

Figure 11.8: Observations points in the domain

11.5.7. REMAINING FLOW INPUT PARAMETERS

The remaining parameters for the calculation which are non-zero will be treated.

TIME FRAME

The time frame is an important parameter in the calculation. Reference date is October 5 2012 for every calculation, an imposed value from the boundary conditions.

For the storm surge modeling of Hurricane Sandy the simulations runs from October 29, 2012 until October 31, 2012. A time step of 0.25 minutes is used, which gives accurate enough results.

Tidal modeling for the sustainability of the marsh islands needs a bigger time frame. A simulation period of about a month is chosen, the start of the simulation is October 5, 2012 and the end of the simulation is November 1, 2012. The time step is 1 min, to save computation time.

PROCESSES

During the storm surge modeling the physical process wind is used in the calculation. For the tidal modeling no extra processes have been used.

PHYSICAL PARAMETERS

The water density will be set to 1025 [kg/m3], since the water in Jamaica Bay is saline. Gravity constant is 9.81 as usual.

NUMERICAL PARAMETERS

The numerical parameters can be seen in the below figure 11.9, the left table shows the tidal model and the right table shows the parameters for the storm surge model.

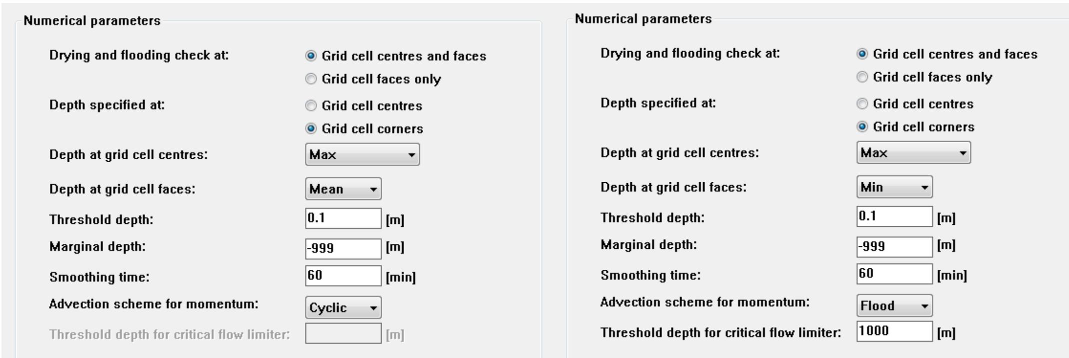


Figure 11.9: Numerical Parameters, left table tidal model, right table storm surge model

For the storm surge modeling the Flood Scheme is used, because this scheme gave better results. The next picture 11.10 shows the difference in velocity at the peak of the storm between the two schemes, the flood scheme in blue on the left and the cyclic (default) scheme in red on the right. It can clearly be seen that the flood scheme gives higher depth averaged velocities over the Rockaway Peninsula, which seems more accurate and reasonable. Therefore the Flood Scheme has been chosen for the storm surge modeling.

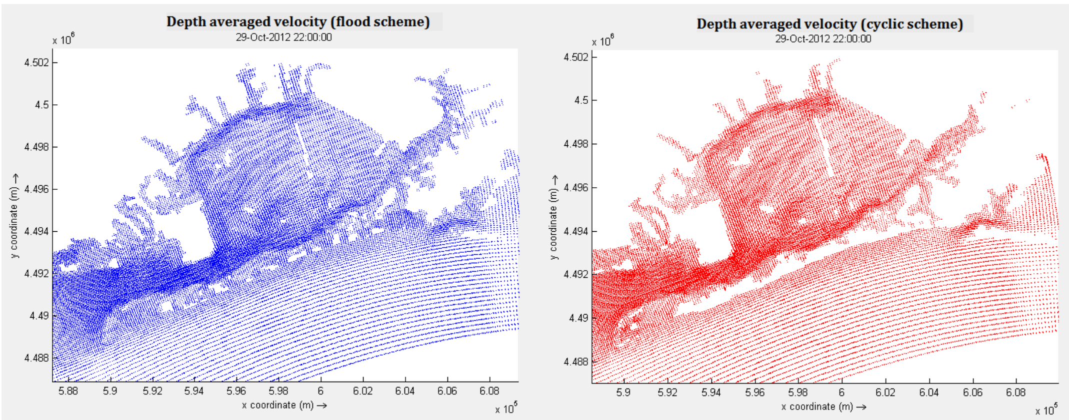


Figure 11.10: Comparison between Flood Scheme and Cyclic Scheme, for depth averaged velocity at peak of Sandy

11.5.8. ROUGHNESS

In most calculations the entire domain will get a Manning roughness value of 0.035. This value is based upon reports by FEMA, 2013 and Bunya et al, 2010 [69] [53]. According to Bunya et al, 2010 sand beaches have a

Manning value of 0.030 and rock has a Manning value of 0.040. Therefore a Manning value of 0.035 is chosen to be reasonable for the sandy bottom in the low depth Jamaica Bay.

For the calculations with submerged wetlands an increased roughness is important. Wetlands have a bigger roughness in comparison to the bottom of the bay or sea, because of the vegetation like cordgrass. According to Appendix A of FEMA 2012, marshes/wetlands have a Manning value of 0.05. Therefore this value of 0.05 has been chosen for the roughness on the marshes in Jamaica Bay, old as well as new marsh islands (to be created for the purpose of this study) will get this roughness value. The bottom of the bay and the sea will still have a Manning value of 0.035.

11.6. TIDE CALIBRATION OF THE MODEL

The storm surge model will not be calibrated. There are two important reason for this. One is that there are no measurements inside Jamaica Bay, only predictions in regards to the tidal movement. Reason two is that in the small-scale model like this one the water levels during a storm are mostly determined by the forcing on the boundaries. In this case this forcing is from hurricane Sandy from the ADCIRC model. It is assumed the water levels (Sandy water levels) from ADCIRC forcing this small-scale model are accurate.

Therefore a tidal calibration will be performed instead. Because of the absence of tide gauges inside Jamaica Bay the calibration of the model with respect to tides is a difficult task. NOAA has tidal predictions in the bay on the other hand. These predictions are subordinate predictions, and they will not be very accurate. Probably the interpolated data from the TPXO7.2 data set will be a better approximation of the real water levels. But it gives an idea of the behavior of the model.

A plot of the locations of the stations in and around Jamaica Bay can be seen in figure 11.11. According to NOAA subordinate predictions are "the high and low height values for subordinate predictions are obtained by means and differences and ratios applied to the full harmonic constant predictions at a specific referenced station. The line of these plots depicts a curve that is fit between the high and low predicted values and approximates the segments between" [70].

Figure 11.11: Locations for NOAA tide predictions in Jamaica Bay ([70]))

With two of the discussed locations the Delft3D model will be calibrated inside Jamaica Bay. Furthermore an offshore location will be compared to measurements, more on that later. The locations for calibration are 4 and 7. The most important reason for choosing these two locations is that they are wet all the time in the Delft3D model and they lie far inside the bay. On other locations the location may be at a point which is not in the water all the time, i.e. it lies above the lowest tidal level.

The water levels calculated by the model in Delft3D during almost a month period are plotted in blue against the predicted values in red in the next two figures 11.12 and 11.13, respectively for location 4 and 7.

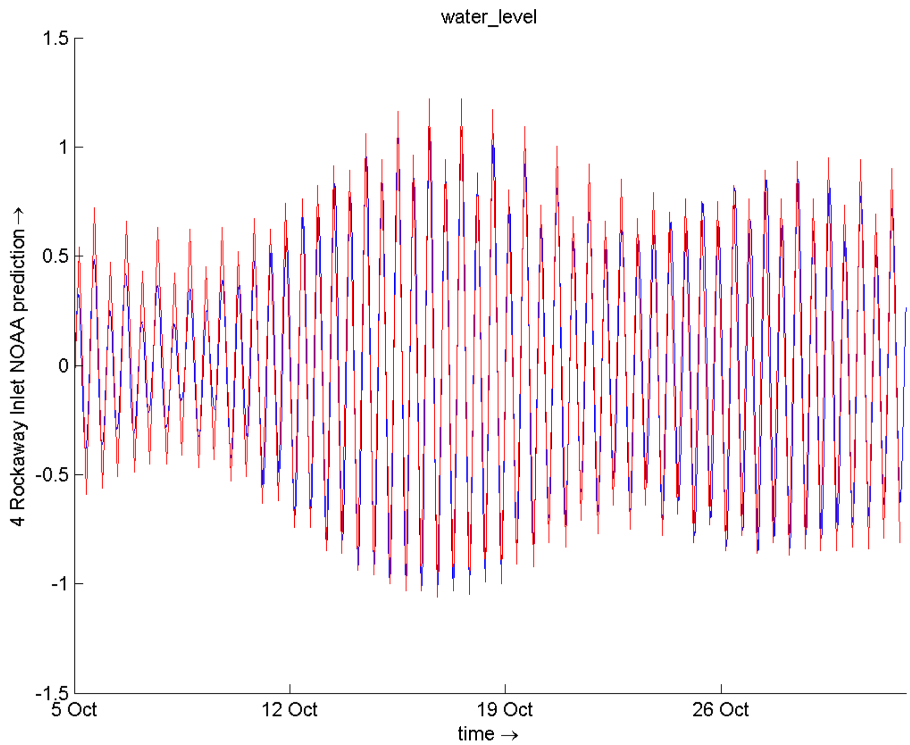


Figure 11.12: Tidal calibration for location 4 in Jamaica Bay. Blue = model result, Red = NOAA prediction

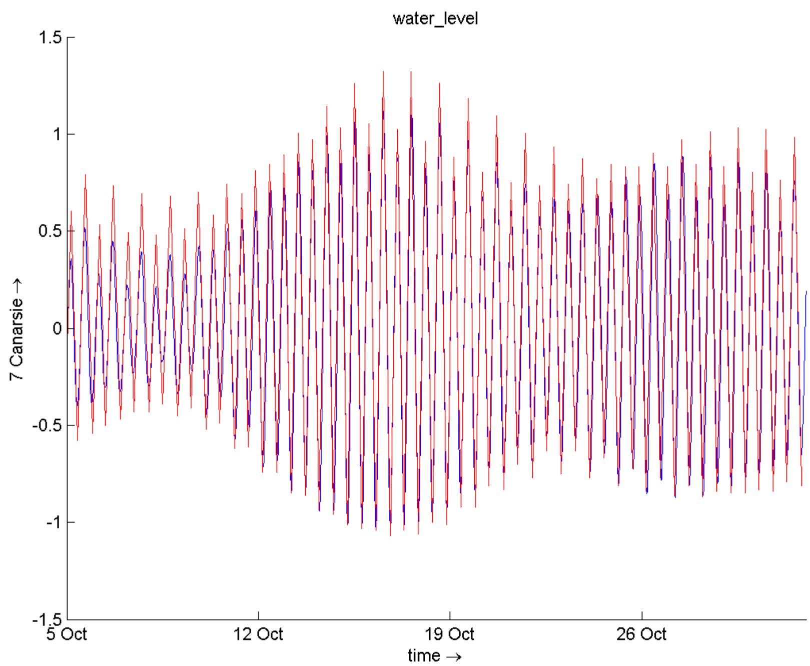


Figure 11.13: Tidal calibration for location 7 in Jamaica Bay. Blue = model result, Red = NOAA prediction

It can be seen that the model corresponds pretty good with the predictions. Only in the beginning the model gives lower values of water levels, but the reason for that could be that the spin-up time of the simulation has not been reached in the first few days.

An offshore location inside the domain of the model can be calibrated using tide stations (measurments in this case instead of inaccurate predictions) nearby in Sandy Hook, New Jersey. The results are presented in figure 11.14.

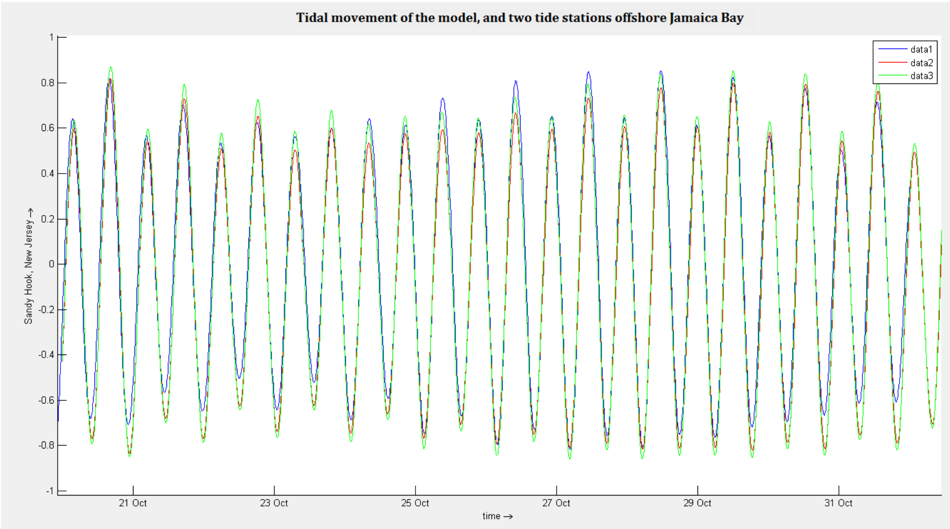


Figure 11.14: Tidal calibration for observation offshore compared to two tide stations in Sandy Hook, NJ. Blue = model result, Red and Green = Tide stations near Sandy Hook, NJ

The results are comparable, the biggest difference is about 0.1m at some points. This difference can be attributed to the fact that the location of the observation in the model and the tide stations is different.

It will be proceeded with the current model, because the model works good to get effective results for the purpose of the study (qualitative results of several proposed measures). Although the predictions were a bit different, still the results were good enough. And the offshore locations gave good results compared to two tide stations close. Also the storm surge model seems to be working good as well, compared to water level stations nearby.

11.7. STORM SURGE RESULTS

Now the input in the model is ready and the model is calibrated for tidal movement, the actual calculations can be done. See chapter 9 and chapter 10 for the precise interpretation of the measures. First it will be discussed how it was attempted to lower the storm surge inside Jamaica Bay. In the next chapter, the sustainability of the tidal system and the marsh islands will be discussed. All storm surge calculations have been executed with the parameters as discussed in section 11.5.

It is chosen to present two visualizations for the results. The first visualization is a plot of the peak water levels during Sandy for the reference situation (do nothing) in comparison to different measure taken, i.e. shallowing the inlet or shallowing the tidal channels in the bay. The second visualization is a plot of the graphs of water levels in time for both the reference situation and measurements taken into account. These water levels are taken for a couple of days around the peak of Sandy for a single observation point in the north of Jamaica Bay. Several different observation points are taken, but the general trend was the same for every point, and because the goal is to get a qualitative idea of the effectiveness of the measures it was chosen to represent only the results of one observation point.

The two reference visualizations are as follows. See figure 11.15 and 11.16 for respectively the plot of the water levels during the peak of Sandy and the graph of the water level plotted against time for an observation point in the north of Jamaica Bay.

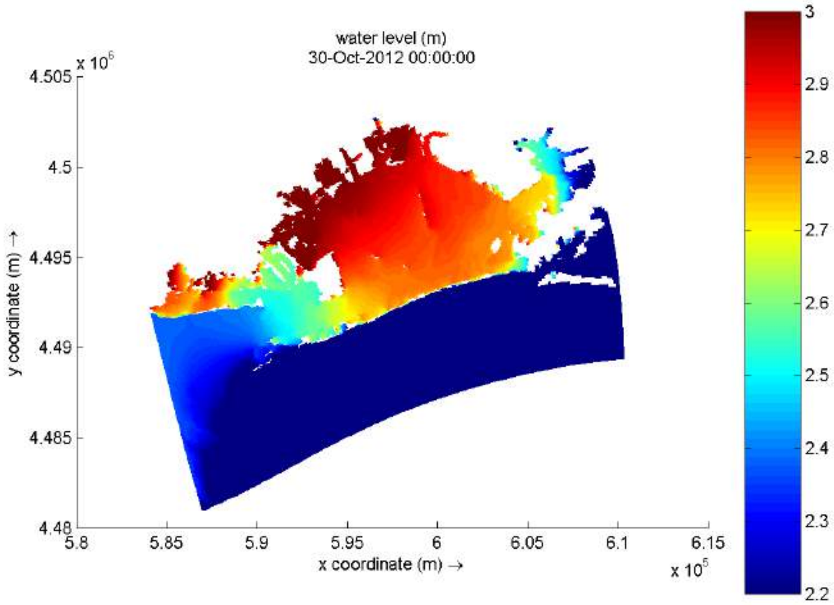


Figure 11.15: Reference plot for peak Sandy water levels inside Jamaica Bay

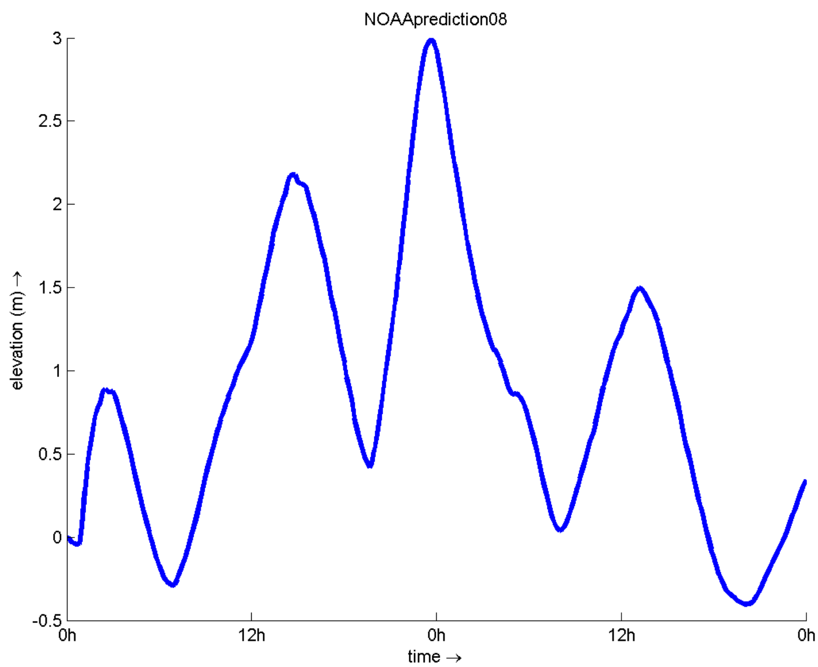


Figure 11.16: Reference graph for water levels in time of Sandy for location in the north of Jamaica Bay

11.7.1. SHALLOWING OF THE INLET

The inlet will be defined as the total channel in front of the Jamaica Bay itself between the mainland and the Rockaway Peninsula. In this manner the inlet is approximately 5 kilometer long.

The inlet of Jamaica Bay will be shallowed in two different ways, one way is to multiply the depth of the inlet by 0.5 and the other way is to multiply the depth by 0.25. These alterations will be done with the QUICKIN tool in the bathymetry of the domain. This idea looks like this, see figure 11.17.

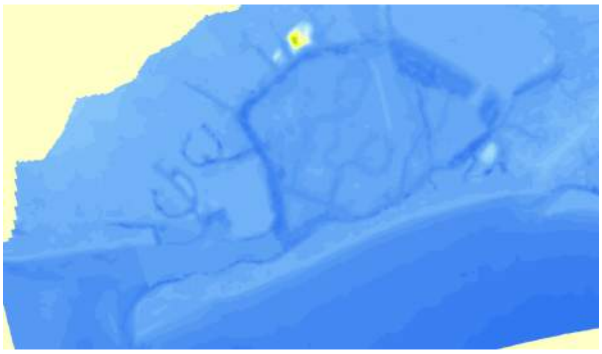


Figure 11.17: Top view idea of Jamaica Bay with shallower inlet (0.25 times original inlet)

The results for the surge in Jamaica Bay during Sandy are as follows, see figure 11.18 and figure 11.19.

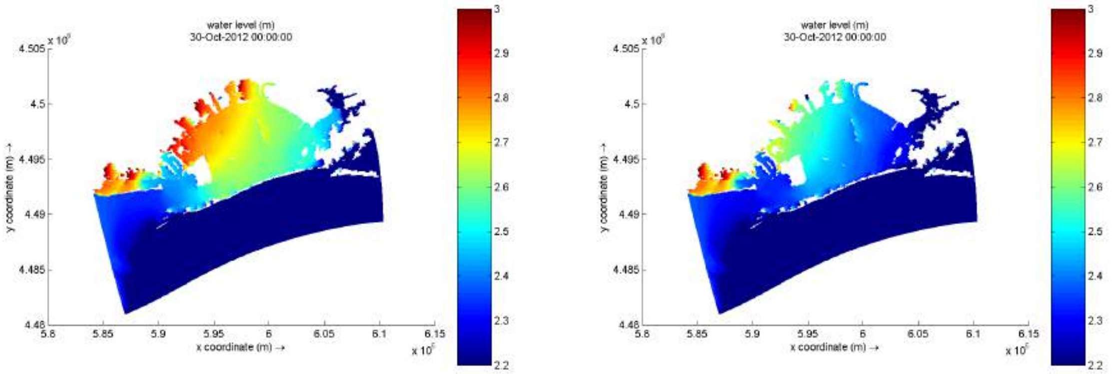


Figure 11.18: Plots for water levels inside Jamaica Bay at peak Sandy. Left = inlet shallowed by 0.5; Right = inlet shallowed by 0.25

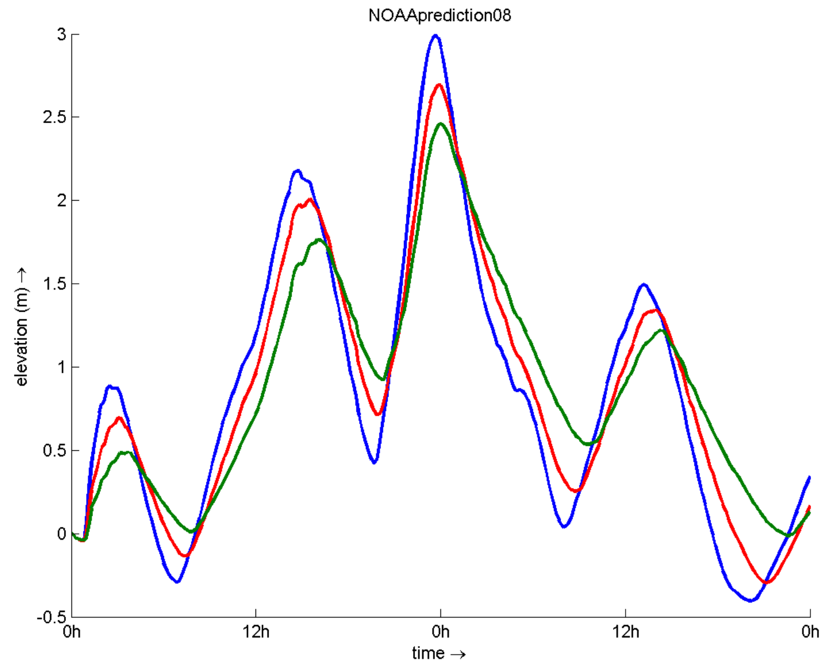


Figure 11.19: Plots of water levels during Sandy in the north of Jamaica Bay. Blue = reference situation. Red = shallower inlet by 0.5. Green = shallower inlet by 0.25

The results show that shallowing the inlet has a rather large effect on the storm surge water levels inside Jamaica Bay. Even a shallow inlet by a bigger, but more unrealistic factor, have been calculated. Results were obviously better, but not realistic and therefore the results are left out of this report. Peak Sandy water levels can be lowered by about a 0.5 meter (about 20%) according to the qualitative results when applying an extreme shallowing of the inlet, but of course it should be noted that ships should be able to enter Jamaica Bay.

11.7.2. Shallowing Tidal Channels

The tidal channels are defined as the channels within Jamaica Bay.

Also the tidal channels are shallowed in different ways to investigate effects. One realistic measure has been investigated, with one navigation channel and the rest of the channels of 2 meter. The other solution is an extreme solution with all channels of 1 meter. An example of a visual of Jamaica Bay with shallowed channels in Delft3D can be seen in figure 11.20.

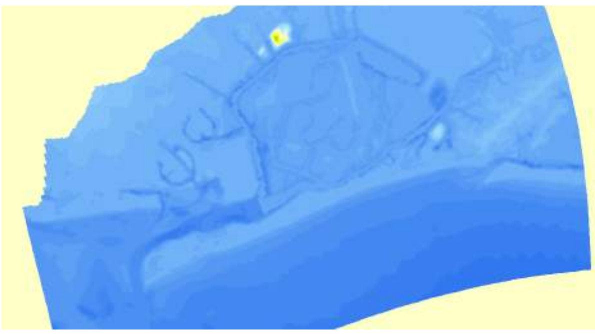


Figure 11.20: Top view idea of Jamaica Bay with shallower tidal channels (1m)

The results for running calculations with two different shallow channels configurations are:

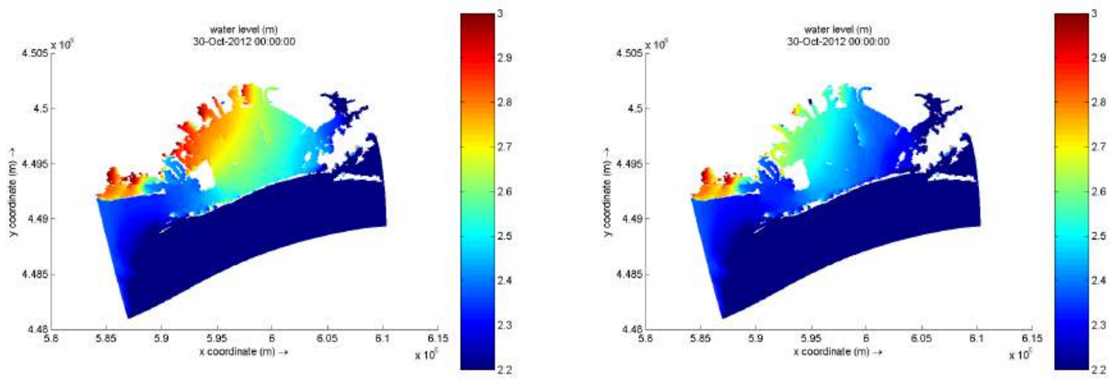


Figure 11.21: Plots for water levels inside Jamaica Bay at peak Sandy. Left = channels shallowed realistically (navigational channel 7m, rest 2m); Right = channels shallowed to 1m

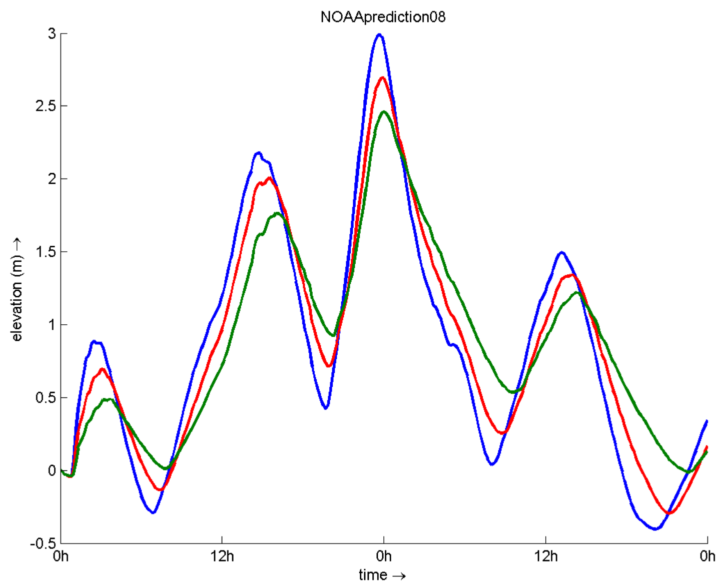


Figure 11.22: Plots of water levels during Sandy in the north of Jamaica Bay. Blue = reference situation. Red = shallower channels. Green = shallower channels to 1m

Also the shallowing of the tidal channels has a large effect on the storm surge in Jamaica Bay, with an unrealistic shallowing to 1m for every channel inside Jamaica Bay a water level reduction at the peak of Sandy of about 15% percent could be achieved according to our model calculations. Although the green line is an unrealistic solution because a lot of sediment is needed to fill all the channels. But resuls show that shallowing of the channels does have a big effect, and was not intended as a realistic solution but more as a qualitative investigation. At least dredging of the channels to make them deeper will have an negative impact on the storm surge mitigation. This fact that the channels are very deep should be realized. It should be noted also that this measure could have a bad effect on the refreshment rate in Jamaica Bay and thus on the water quality, which is already pretty bad. This should be investigated.

11.7.3. CREATE HIGH MARSH ISLANDS

The creation of high marshlands is based on the fact that the islands are always emerged, even when a storm surge hits. The idea is to cut the water surface and in this way lower the wind setup, waves and possibly even the surge. It's investigated in this subsection if the surge levels are been lowered according to the model. The wave height is not being couple with the FLOW calculation in this research, but it is recommended that this is still done in future research.

Two sets of high marsh islands are created in the model using QUICKIN. The method is that on every tidal flat where there is space an island will be built. In this way big amount of islands is built. Situation one is the creation of high marsh island on the tidal flats (shallow parts of the bay), and the second situation is the creation of high marsh island on the tidal flats and in the tidal channels. The purpose of the latter is to fill the channels partly to reduce prism and possibly lower the storm surge. An general idea of how the bathymetry looks in QUICKIN is presented in figure 11.23, where the islands are placed partly in the tidal channels. This visual is a maybe unrealistic representation of the islands, where the islands are very high. But the most important factor is that most of the islands will be emerged all the time.

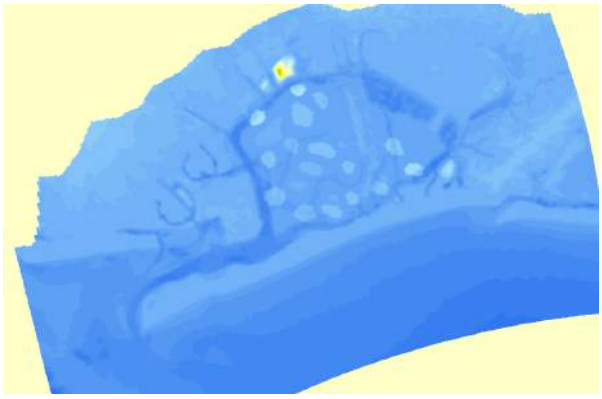


Figure 11.23: Top view idea of Jamaica Bay with created high islands

CREATE ISLANDS ON TIDAL FLATS

First the results for the creation of high islands on the tidal flats, see plots in figure 11.24.

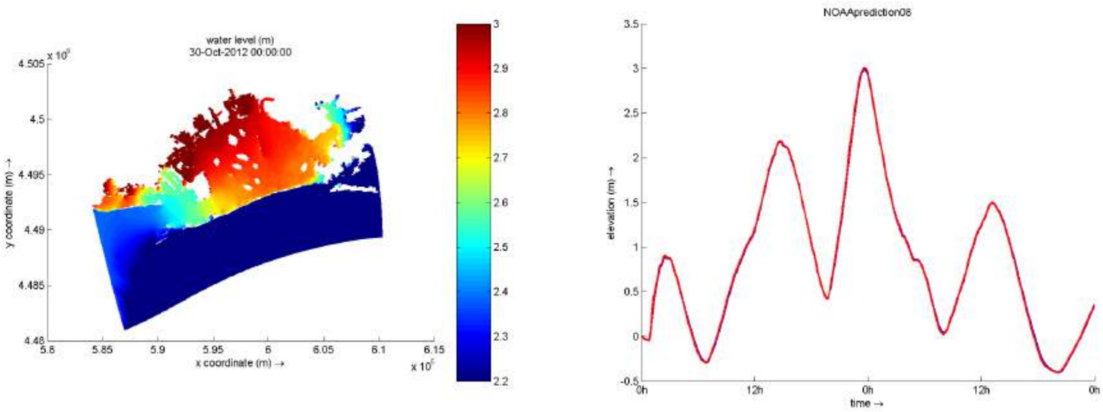


Figure 11.24: Results high marshes on flats. Peak water levels inside Jamaica Bay (left) and water levels in time during Sandy for an observation in the north of the bay. Blue = reference, Red = high marshes on flats (right)

The creation of high marsh islands does not change the surge water levels during Sandy at all, according to the model results. The red line (high marshes) lies on top of the blue line (reference). It can be seen that the islands are still emerged, even at the peak during Sandy conditions, in the left of the figure.

CREATE ISLANDS (PARTLY) IN TIDAL CHANNELS

Subsequently the results for the creation of high islands on the tidal flats and partly in the tidal channels will follow, see figure 11.25.

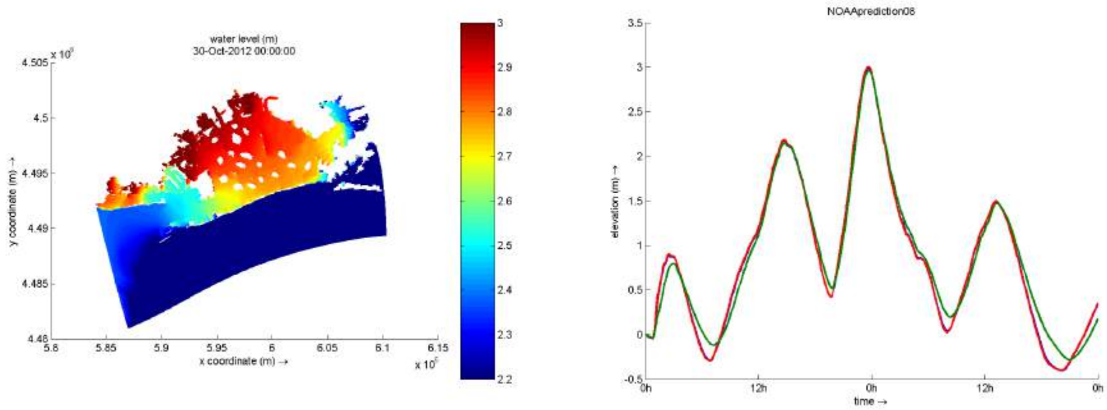


Figure 11.25: Results high marshes on flats and in tidal channels. Peak water levels inside Jamaica Bay (left) and water levels in time during Sandy for an observation in the north of the bay. Blue = reference, Red = high marshes on flats. Green = high marshes also in tidal channels (right)

The creation of high marsh island in the tidal channels as well as on the tidal flats has a little bit more effect, but still the reduction of the water level inside Jamaica Bay due to the islands is negligible. More whit dots can be seen in figure 11.25, so that means that the waterlevel is lower than in figure 11.24. It probably does have a positive effect on the wind setup and the wave height inside Jamaica Bay.

11.7.4. CREATE SUBMERGED WETLANDS

Last important subject of the storm surge results is the submerged marsh islands (wetlands). Submerged wetlands are more important islands because a lot of the marshes in Jamaica Bay are these kind of wetlands. The USACE is restoring wetlands as we speak. These wetlands are already submerged during flood. To construct these wetlands obviously requires much less sediment than for high marsh islands, which is interesting and cheaper. Therefore it is interesting to investigate whether the restoration of wetlands inside Jamaica Bay helps to mitigate storm surge. Which means possible advantages also to the restoration that is also being carried out.

Submerged islands are created on tidal flats where there is space available. In this way a lot of new islands are being created, an unrealistically amount of islands. But the goal is to find out whether even this extreme amount of wetlands can help slow the surge down. Extra roughness Manning value of 0.05 is added to the wetlands to simulate these islands more realistically, see 11.5.8.

The results can be seen in figure 11.26.

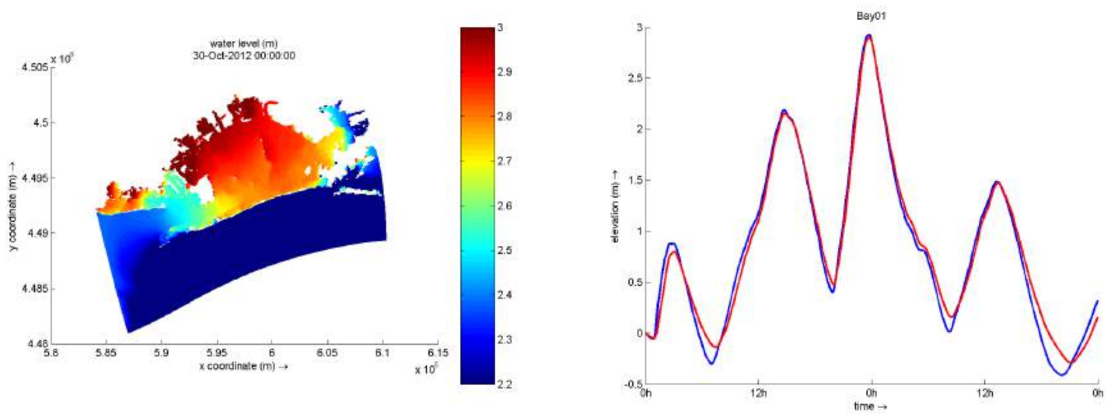


Figure 11.26: Results emerged islands with increased roughness. Peak water levels inside Jamaica Bay (left) and water levels in time during Sandy for an observation in the east of the bay. Blue = reference, Red = emerged wetlands (right)

As can be seen in the results, even an huge amount of extra wetlands (emerged) hardly has an effect on the storm surge level inside Jamaica Bay according to the model of Sandy conditions.

11.8. SUSTAINABILITY RESULTS

Now the focus shifts towards the sustainability of the tidal system and the marsh islands itself. See chapter 10 for the theory.

Every solution given in this section has already passed by in the previous section 11.7, so how these measures have been implemented into the model will not be explained again. Now the goal is to influence the tidal prism. It is chosen to present one visualization of the result, the cumulative discharge over the Rockaway Inlet. This has been done because the integral of the discharge is the tidal prism. From the discharge graphs the tidal prism can be related. The calculations

The reference situation is as follows. See figure 11.27 for the cumulative discharge over the inlet in time during normal tidal conditions in Jamaica Bay.

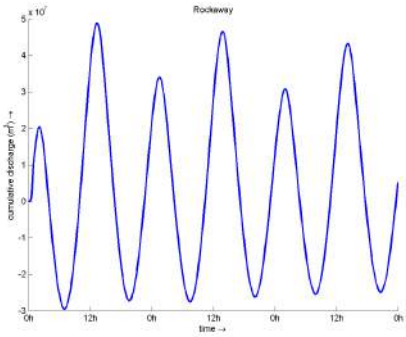


Figure 11.27: Reference plot for cumulative discharge over the Rockaway inlet in time

Only the results will be plotted and discussed from here.

11.8.1. SHALLOWING OF THE INLET

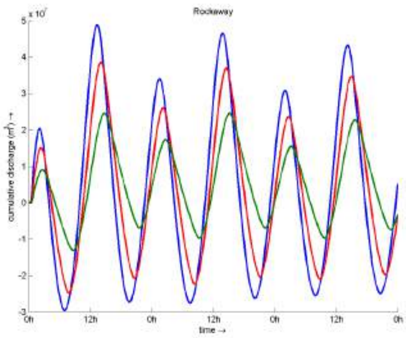


Figure 11.28: Discharge over inlet in time. Shallowing the inlet, 0.5 (left) and 0.25 (right)

The results show that by shallowing the inlet has a positive effect on the cumulative discharge and thus the tidal prism.

11.8.2. SHALLOWING TIDAL CHANNELS

Results show that shallowing the tidal channels has a positive effect on the tidal prism as well. The magnitude of the reduction calculating these two measures is about the same as the investigated shallow inlet scenarios, although it should be noted that shallowing the channels to 1m is a very rigorous and unrealistic measure.

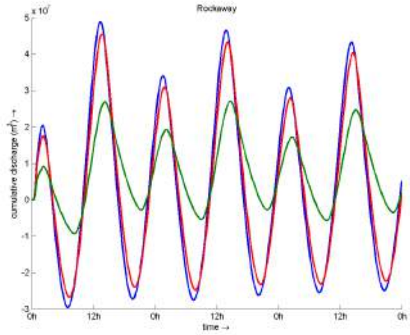


Figure 11.29: Discharge over inlet in time. Shallowing the channels, realistic/one navigational channel, rest 2m (left) & every channel 1m (right)

11.8.3. RESTORE AND EXPAND MARSH ISLANDS

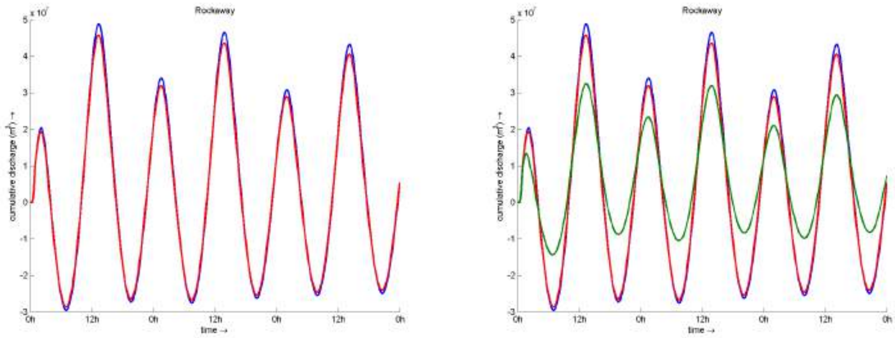


Figure 11.30: Discharge over inlet in time. Create high marsh islands on tidal flats (left). Create high marsh islands on flats and (partly) in tidal channels (right)

Results for creating high mars islands show that creating islands on the tidal flats (left plot in figure 11.30) only reduces the tidal prism by a little bit. When placing extra islands also in the tidal channels the channel volume is adjusted, and therefore the tidal prism gets a major reduction. This means that when islands will be built inside tidal channels as well, it can be beneficial to the sustainability of the tidal system. But it also means that the focus should lie on the tidal channels in particular.

11.9. EVALUATION

The creation of new marsh islands does not have a significant impact on the storm surge mitigation, but probably has a big effect on wind setup and wave height. If new islands are created on the tidal flats, because of the reduction in tidal prism some erosion could take place. Which is unintended of course because it costs more money. When creating islands partly inside the tidal channels it could be possible to do it in the right proportions to mitigate storm surge and improve the sustainability.

It is possible to reduce the storm surge levels inside Jamaica Bay with different measures. The measure which gives the best results is shallowing of the inlet, and also the shallowing of the channels could reduce the storm surge water levels significantly. With regard to the sustainability the solution of shallowing the tidal channels gives best results, because of the reduction of the tidal prism and also the reduction in channel volume. But to get good results huge amounts of sediment are needed. To shallow the inlet works as well for sustainability of the system and mostly for the storm surge mitigation, and probably less sediment is needed. But it should always be in mind that ships should be able to enter Jamaica Bay.

It is highly recommended to improve and expand the Delft3D model, sediment transport and water quality could be improved. Water quality aspects should be investigated, especially when the tidal prism and the refreshment are reduced.

12
Conclusions

In this chapter, for all of the four main subjects of the report the main conclusions can be found. Also answers on the research questions can be found here.

12.1. Perimeter Measures

It is shown that is is possible to protect the Jamaica Bay area against storm surges. However, the large dimension of these structures may seem harsh, but is realistic. To be able to retain water, the report states that measures need to be taken along the whole perimeter of the Jamaica Bay. Connecting these measures makes sure the surrounding neighborhoods do not flood during storm conditions. The research analyses the perimeters and combines similar areas. For these areas measures are proposed which can be used to retain storm surges. Because of the limited space the focus of these measures is on integrating infrastructure, nature and society.

12.2. Living Shorelines

This research shows that at the perimeter of the Jamaica Bay, vegetation can be used to help retaining storm surges. An analytical approach is used to calculate the way cordgrass (spartina alterniflora) has an affect on the energy of incoming waves. The analytical approach does implement wave energy dissipation because of drag, however it does not account for breaking of waves. The report shows that after dissipation, the wave height is approximately 25 centimeters. This is small enough for a soft revetment to be sufficient instead of implementing a hardened revetment.

12.3. Storm Surge Control for Jamaica Bay

Storm surges are investigated with a model with Sandy conditions. The influence of dimensions of the bay are researched, effectiveness was studied. Feasibility of the measures should be researched. Shallowing is preferred regarding flood risk mitigation. The results show that shallowing the inlet and/or the channels in the inner-bay can contribute significantly regarding the expected storm surge level in the bay. Shallowing the inlet results in the highest storm surge reduction, according to the model a maximum reduction for Sandy conditions of about 20%. Shallowing of the tidal channels results in a slightly lower reduction of about maximum 15%. It should be noted that this reduction is for a situation of tidal channels of 1 m, which is an extreme measure. Furthermore ships should be able to enter and leave the bay.

The restoration of marsh islands does not have a significant impact on the storm surge mitigation based on the results of this model, but probably has an effect on wind setup and wave height. Waves were not added to the model in this study but were calculated for idealized conditions with simple hand calculations. Both high and emerged wetlands were investigated, whereas emerged wetlands have an increased roughness because of vegetation, and both solutions hardly show influence in surge levels in Jamaica Bay. When required to expand marsh islands, a good way to do so with regard to flood risk mitigation is to place them partly in the tidal channels.

12.4. SUSTAINABILITY OF JAMAICA BAY

By shallowing Rockaway Inlet the cross-sectional area reduces and with that the tidal prism also reduces. This results in possible erosion of marshlands and/or adjacent coasts.

Shallowing the tidal channels within Jamaica Bay reduces the channel volume within the basin and with that also reduces the tidal prism. Accretion of marshlands and/or adjacent coasts is expected.

The restoration or expansion of marsh islands can be done in a few ways. The islands can be restored on the tidal flats without influencing the tidal channels or they can be restored (partly) within the tidal channels. If the islands are built on the tidal flats the tidal prism reduces. Some erosion of the (new) islands or adjacent coasts is expected. However, if the islands are (partly) placed within the tidal channels also the channel volume is decreased. If this is done in the right proportions accretion of the marsh islands or adjacent coasts is expected.

The best results regarding sustainability are expected for shallowing the tidal channels. However, also by creating islands a sustainable system can be reached.

12.5. ANSWERING THE RESEARCH QUESTIONS

In this section the research questions, formulated in the introduction on page 4, will be answered.

Which measures at the perimeter could be applied to improve flood protection of the Jamaica Bay area?

From chapters 4 to 8 can be seen that it seems to be possible to design a system of measures along the perimeter of Jamaica Bay to protect the hinterland from flooding during a 1/100 year storm. For the Atlantic side of Rockaway Peninsula and large parts of the bay perimeter (mainly the northeastern part) designing measures can be combined with creating ecological value vary well. For the other locations, like the perimeter near JFK International Airport and the bay side of Rockaway Peninsula, innovative solutions are required because of the limited amount of available space or due to strict requirements. Furthermore, some locations, e.g. the the inlets of the creeks, Floyd Bennett Field or Broad Channel, cannot be included within the set of proposed measures and are treated as exceptions. In order for the system to work properly, the different measures should be connected to each other.

What is the best way to improve the marsh islands in Jamaica bay and what are the effects on flood risk mitigation?

According to the theory used in this study, the marsh islands within Jamaica Bay are part of a tidal basin system. This tidal basin system consists of three areas; the bay, the inlet and the outer delta. The most important conclusion is that every alteration within one of the areas from this system affects the whole system. It is found that the best results are found when the tidal channels in the bay are shallowed. However, if it is required to build or expand islands in order to create ecological value, the best way to do this is to place them (partly) within the tidal channels.

A

CONVERSION TABLE

Table A.1 gives the conversion factors from the used metric system to the imperial system (commonly used in USA) and vice versa.

Length

known	multiplied by	wanted
millimeters (mm)	0.04	inches (in)
centimeters (cm)	0.39	inches (in)
meters (m)	3.28	feet (ft)
meters (m)	1.09	yards (yd)
kilometers (km)	0.62	miles (mi)
inches (in)	25.40	millimeters (mm)
inches (in)	2.54	centimeters (cm)
feet (ft)	30.48	centimeters (cm)
yards (yd)	0.91	meters (m)
miles (mi)	1.61	kilometers (km)

Volume

known	multiplied by	wanted
milliliters (ml)	0.03	fluid ounces (fl oz)
liters (l)	0.26	gallons (gal)
cubic meters (m^3)	35.31	cubic feet (ft^3)
cubic meters (m^3)	1.31	cubic yards (yd^3)
fluid ounces (fl oz)	29.57	milliliters (mm)
gallons (gal)	3.79	liters (l)
cubic feet (ft^3	0.03	cubic meters (m^3)
cubic yards (yd^3)	0.76	cubic meters (m^3)

Mass and Weight

known	multiplied by	wanted
grams (gr)	0.035	ounce (oz)
kilograms (kg)	2.20	pounds (lbs)
metric tons: 1,000 kg (t)	1.10	short tons (t)
ounces (oz)	28.35	grams (gr)
pounds (lbs)	0.45	kilograms (kg)
short tons: 2,000 lbs (t)	0.91	metrics tons (t)

Temperature

known	multiplied by	wanted
degrees Fahrenheit (°F)	(°F - 32) / 1.8	degrees Celsius (°C)
degrees Celsius (°c)	(°C * 1.8) + 32	degrees Fahrenheit (°F)

Table A.1: Conversion table from metric system to imperial system and vice versa

B

ABBREVIATIONS

Table B.1 gives some commonly used abbreviations with their meaning.

Abbreviation	Meaning
CEHA	Coastal Erosion Hazard Area
CSO	Combined Sewage Overflow
DEM	Digital Elevation Model
DOITT	Department of Information Technology and Telecommunications
DPR	Department of Parks and Recreation
ENSO	El Nino-Southern Oscillation
FAA	Federal Aviation Administration
FBF	Floyd Bennett Field
FEMA	Federal Emergency Management Agency
FIRMS	Flood Insurance Rate Maps
HUD	U.S. Department of Housing and Urban Development
IPCC	Intergovernmental Panel on Climate Change
JFK	John F. Kennedy International Airport
LULC	Land use/land cover
MTA	Metropolitan Transit Authority
MWA	Metropolitan Waterfront Allience
NED	National Elevation Data
NFIP	National Flood Insurance Program
NOAA	National Oceanic and Atmospheric Administration
NPCC	New York City Panel on Climate Change
NPS	National Park Service
NYC	New York City
NYCDEP	New York City Department of Environmental Protection
NYCDS	New York City Department of Sanitation
NYPD	New York City Police Department
NYH	New York Harbor
NYSDEP	New York State Department of Environmental Protection
OEM	Office of Emergency Management
PANYNJ	Port Authority of New York and New Jerser
PWM	Preliminary Work Maps
RBD	Rebuild by design

RWA	Rockaway Waterfront Allience
SDEC	State Department of Environmental Conservation
SIRR	Special Initiative for Rebuilding and Resiliency
SLR	Sea Level Rise
TU Delft	Delft University of Technology
USACE	United States Army Corps of Engineers
USGS	U.S. Geological Survey
USMC	U.S. Marine Corps
WPCP	Water Polution Control Plant
WWTP	Waste Water Treatment Plant

Table B.1: Commonly used abbreviations and their meaning

C

LITERATURE STUDY

C.1. INTRODUCTION

New York City is one of the largest cities of the world. The city includes a large National Park with a wide variety of wildlife, recreation and communities: the Jamaica Bay. The changing climate is a threat to the Jamaica Bay area and its inhabitants. Super storm Sandy was an example of how these changing conditions can impact the area.

Because the Jamaica Bay is located at a developed area, over the years a lot of research has been done regarding the area characteristics. Several different institutes are involved with projects in which the Jamaica Bay is concerned. This literature review helps understanding the area without doing a lot of on-sight research.

Before the designing stage, it is important to have a clear background of the area. The literature review is the foundation of the report and will enable validating the proposed designs.

The review gives a brief overview of Jamaica Bay's main characteristics, flood risk mitigation in the United States, considered coastal measures, climate change and super storm Sandy. Although a lot of topics have not been emphasized, this review covers most of the relevant information for understanding the troubles of the Jamaica Bay area regarding flood risk reduction.

C.2. TERMINOLOGY

This chapter will elaborate on the meaning of the terminology used in this report. For this chapter the report Language of risk: Project definition by Gouldby & Samuels (2005) [71] is used for a very important part. The use of this chapter is to make sure there is as little confusion about the terms used as possible, not only for people reading this report, but also for the team itself.

C.2.1. INTRODUCTION

Nowadays the term "risk" has multiple meanings in different contexts. Despite that this is one of the strengths of the term it may also lead to misunderstanding and confusion. In technical terminology, words that are treated as synonyms in common language can have distinct meanings. For instance the words "risk" and "hazard" can be used as synonyms, but in technical reports there is a difference in meaning.

In this study the definitions shown in section C.2.2 are the definitions that will be used throughout the entire report. The given definitions are established by the project consortium FLOODsite and are a suitable for this study. For other studies, other definitions may be better suitable.

C.2.2. DEFINITIONS

The definitions in this section, table C.1, are directly copied from Gouldby & Samuels (2005) [71]. They give multiple definitions per term in their report, the definitions shown here are the the ones they recommend. For the other definitions, see the report Language of risk: Project definitions.

Term	**Definition**
Hazard	*A physical event, phenomenon or human activity with the potential to result in harm. A hazard does not necessarily lead to harm*
Vulnerability	*Characteristic of a system that describes its potential to be harmed. This can be considered as a combination of susceptibility and value*
Risk	*Probability multiplied by consequence*
Exposure	*Quantification of the receptors that may be influenced by a flood (for example, number of people and their demographics, number and type of properties etc.)*
Consequence	*An impact such as economic, social or environmental damage/improvement that may result from a flood. May be expressed quantitatively (e.g. monetary value), by category (e.g. High, Medium, Low) or descriptively*
Flood	*A temporary covering of land by water outside its normal confines*
Flood Risk management	*Continuous and holistic societal analysis, assessment and mitigation of flood risk*
Risk Analysis	*A methodology to objectively determine risk by analysing and combining probabilities and consequences*
Risk Assesment	*Comprises understanding, evaluating and interpreting the perceptions of risk and societal tolerances of risk to inform decisions and actions in the flood risk management process*
Risk Management Measure	*An action that is taken to reduce either the probability of flooding or the consequences of flooding or some combination of the two*
Scenario	*A plausible description of a situation, based on a coherent and internally consistent set of assumptions. Scenarios are neither predictions nor forecasts. The results of scenarios (unlike forecasts) depend on the boundary conditions of the scenario*
Strategy	*A strategy is a combination of long-term goals, aims, specific targets, technical measures, policy instruments, and process which are continuously aligned with the societal context*
Sustainable Development	*Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs*
Sustainable Flood Risk Management	*Sustainable flood risk management involves:* • *ensuring quality of life by reducing flood damages but being prepared for floods* • *mitigating the impact of risk management measures on ecological systems at a variety of spatial* and temporal scales • *the wise use of resources in providing, maintaining and operating infrastructure and risk* management measures • *maintaining appropriate economic activity (agricultural, industrial, commercial, residential) on the flood plain*

Table C.1: Terms and their definitions. The used definitions are the recommended ones given by Gouldby & Samuels (2005).

C.3. BACKGROUND OF THE JAMAICA BAY AREA

C.3.1. DEVELOPMENTS OF JAMAICA BAY

Throughout time, the Jamaica Bay area has constantly been changing. This part of the report will give a brief overview of the development and future plans for the area.

PRE 1911 HISTORY

Cody & Auwaerter (2009) [72] state that roughly 50,000 years ago, the Jamaica Bay was situated at the edge of the Wisconsin glacier. The glacier created an accumulation of unconsolidated glacial debris which created a line of hills. As time passed, the glacier melted and deposited sand, silt, and clay at the south side of these hills. These materials created an outwash plain which extended into the Atlantic ocean and when the glacier melted further, due to sea level rise the delta flooded, forming Jamaica Bay.

In the next centuries storms, waves and westward running longshore currents changed the Jamaica Bay. They formed a spit that separated the bay from the Atlantic ocean, later known as the Rockaways. At the same time a barrier island was formed which later was named Barren Island and is now known as Floyd Bennett Field. According to Cody & Auwaerter (2009) [72], one of the most dramatic changes to the Jamaica Bay system was the elongation of the spit in the nineteenth century. Figures C.1, C.2 & C.3 entail maps in which the elongation is shown. Between 1866 and 1911, the spit lengthened by more than 1.6 kilometers. According to Cody & Auwaerter (2009) [72], also the construction of jetties, groin fields and other beach stabilization structures partially caused the accelerated lengthening of the Rockaways.

Figure C.1: Jamaica Bay ca. 1780, New York Public Library Digital Gallery, annotated by SUNY ESF

DEVELOPMENTS FROM 1911 TO PRESENT

Until 1911, the ecology of Jamaica Bay changed because of ongoing environmental processes. From 1911 up to now, changes were primarily caused by human interference.

Jamaica Bay to be Great World Harbor

In the late 19th century plans had been underway to transform the Jamaica Bay into a new commercial port for New York City (Cody & Auwaerter (2009) [72]), see figure C.4. The area would be a good option for industrialization because of its remote location and deep waters suitable for navigation. However, the plan was abandoned due to a lack of commercial activity. A couple of decades later, in 1906, the plan was again presented to Congress.

An article from the Department of Docks and Ferries from 1910 [73] states that the entrance channel needs to be dredged, widened and deepened to 5.5 meters during low tide, and 6.7 meters during high tide. Also bulkheads, sand dikes or riprap retainings needed to be constructed, to retain dredged material taken from the channel. The report refers to the future purpose of the bay and states that it should be the new harbor

Figure C.2: Jamaica Bay ca. 1840, New York Public Library Digital Gallery, annotated by SUNY ESF

Figure C.3: Jamaica Bay ca. 1898, New York Public Library Digital Gallery, annotated by SUNY ESF

entrance to New York City. It compares the Jamaica Bay to the harbors of Liverpool and Antwerp. The plan also projects that an additional 150 miles of harbor waterfront could be of incalculable value to the city of New York.

Building activities began in 1911, when the federal Secretary of War approved bulkheads and pierhead lines throughout Jamaica Bay. A year later, the New York City Department of Docks started dredging the main inlet. The extracted material was used as landfill for the marshes. According to Rhoads et al. (2001) [27] the deepening of shipping channels (see figure C.5) has greatly affected the appearance, hydrology, and ecology of the entire bay. The industrial development also transformed the landscape through stabilization of its shifting shorelines. Cody & Auwaerter (2009) [72] state that in 1918 the City of New York began implementing plans for fourteen piers. However, around 1922, mainly due to legal and financial limitations, the original plans for the port were largely abandoned. Still, the Department of Docks continued the dredging of the navigable channel through Jamaica Bay.

Filling

Because of the abandoning of the plans, Barren Island would not become part of a large port. In 1928 the City of New York decided to build an airport at Barren Island, which they named Floyd Bennett Field. Barren Island had been filled for a large part and was therefore an eligible area for the creation of runways. The filling had raised 387 acres of former estuary to a level terrace measuring 3,6 meters above sea level. According to Cody & Auwaerter (2009) [72], the largest area of land has been filled at the eastern side of Barren Island. Also

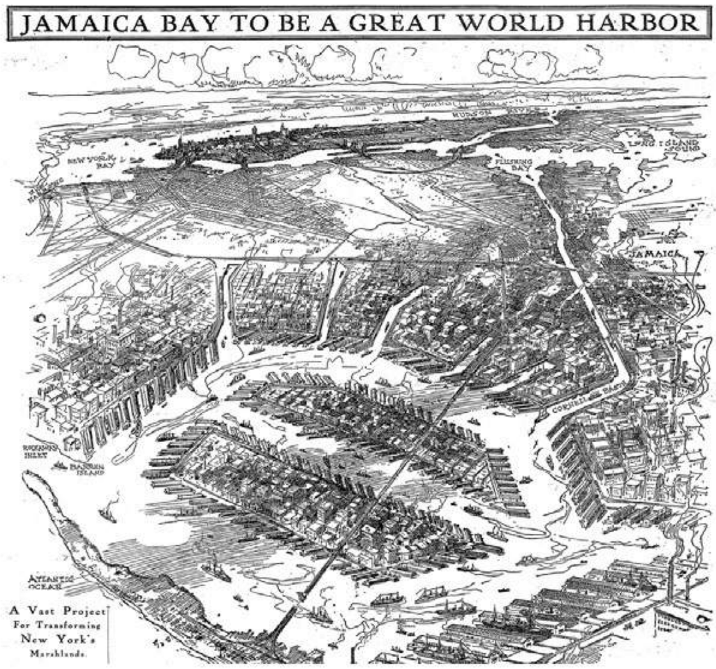


Figure C.4: Jamaica Bay to be Great World Harbor, Cody & Auwaerter (2009), Cultural Landscape Report for Floyd Bennett Field

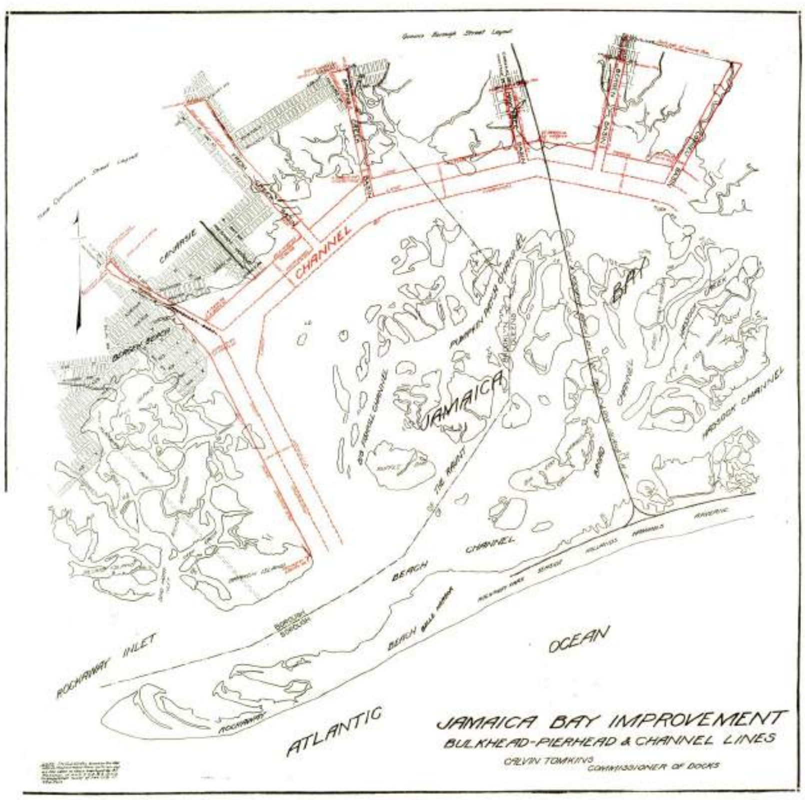


Figure C.5: Habor Plan Jamaica Bay 1910, Department of Docks and Ferries, 1910, Report on Jamaica Bay Improvement

parts of the north side of Barren Island and the 60 meter wide Flatbush Avenue (1923, see figure C.6) were filled, meaning that Deep Creek, that prior to the happening connected the Jamaica Bay to the ocean, was closed. According to Rhoads et al. (2001) [27], approximately 65 Million Cubic Meters (MCM) of sediment have been dredged from Jamaica Bay from 1921 until 2001. Most of it has been used to fill intertidal marshes around the perimeter of the Bay.

Figure C.6: Floyd Bennet Field 1928, Cody & Auwaerter, 2009, Cultural Landscape Report for Floyd Bennett Field

The report of Cody & Auwaerter also states that it is estimated that 70% of Jamaica Bay's volume has been added through dredging. Walsh (1991) [74] states that most of the landfills were located at the shoreline marshes. They enabled the creation of deep bulkhead lines that were important for marine commerce. Also, to remove barriers to overland travel, in some areas streams and swamps were filled.

1938 Impacts on Jamaica Bay

The year 1938 was a year of significant environmental impact to the Jamaica Bay. According to Rhoads et al. (2001) [27], in September of this year a hurricane hit the Jamaica Bay and caused widespread flooding and sewage flowing into the water.

Also in 1938, jurisdiction of the Jamaica Bay was transferred to the City Department of Parks. The reason for the transfer was to prevent further landfills and therefore the complete destruction of the marshlands. Rhoads et al. (2001) [27] also state that in 1948 the Jamaica Bay wildlife refuge was established. However, only the center islands of the Jamaica Bay became City Parks. The perimeter of the bay was left out of the park, allowing continued developments like filling of marsh habitats.

JFK Airport

Cody & Auwaerter (2009) [72] state that Floyd Bennett Field had never been a commercial success. Only in 1937 and in 1938 had there been commercial airlines flying at the airport. For this reason and because of the upcoming threats of World War II, all commercial aviation was moved to John F. Kennedy airport and the Navy took over Floyd Bennett Field, creating bulkhead walls at the southeastern side.

In 1941, plans arose to create an airport at the Idlewild Golf Course. One year later, the construction of, what is now known as, JFK airport began. After six years, with one runway still under construction, the airport was taken into use. Like Floyd Bennett Field, JFK airport is situated on what used to be intertidal marshes. Rhoads et al. (2001) [27] state that the largest single dredging in the history of Jamaica Bay took place at the JFK airport. 34 MCM of material was used as fill. The report also states that the construction of the airport had a large impact on the ecology of the Jamaica Bay system. According to Walsh (1991) [74], the land reclamation project to create room for JFK airport encompassed over 3,500 acres in southwestern Queens.

1951 to 2006

With imagery taken in 1951, 1974 and 2006, Boger et al. (2012) [75] analized the shoreline changes over the second part of the 20th century. In the report the changes in shorelines were quantified using a land use/land cover (LULC) classification scheme. In 1972, the Jamaica Bay became part of Gateway National Park which also include Sandy Hook and Staten Island. The report by Boger et al. (2012) [75] shows the difference in land use before and after it became a park. It states that despite of the trend for shoreline modification, the shoreline within the Jamaica Bay has maintained large parts of sandy beaches and undeveloped vegetation. The largest change within the Jamaica Bay occurred at the perimeter, where creeks flowed into the bay. These creeks have been dredged en modified for either residential or commercial use.

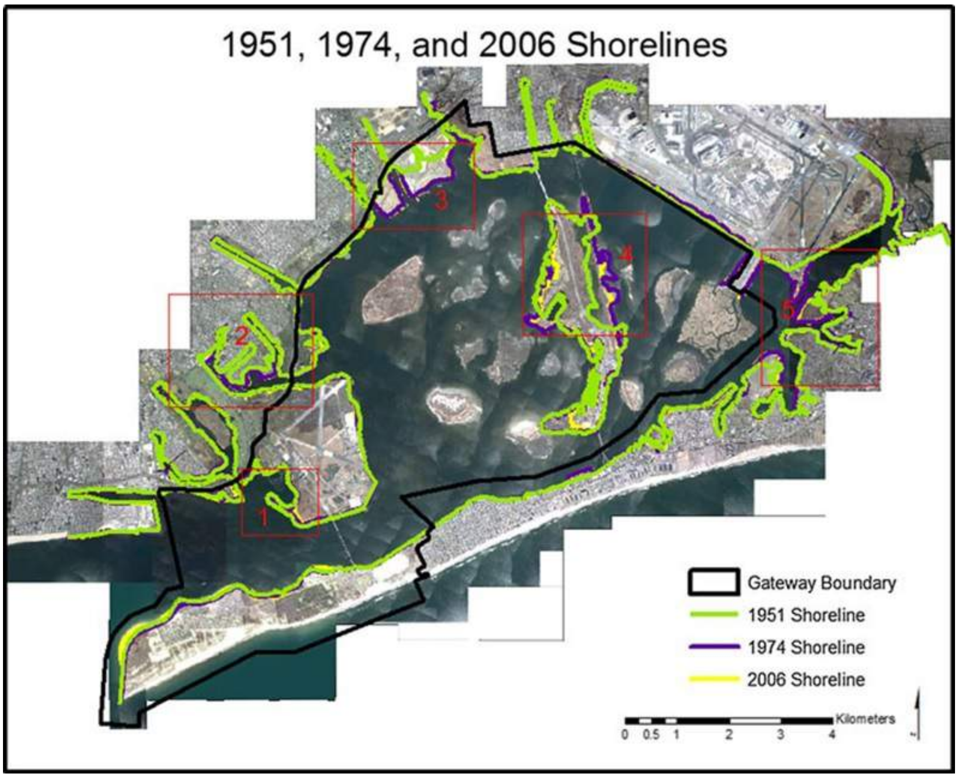


Figure C.7: Jamaica Bay in 1951, 1974 and 2006, Bogel et al., 2012, Estuarine Shoreline Changes in Jamaica Bay, New York City

Figure C.7 shows the shoreline changes throughout time. The years of 1951, 1974 and 2006 were chosen because of the availability of air photos and because they could compare it with the situation after the Jamaica Bay became a National Park. According to Boger et al. (2012) [75], in 1951 the shorelines of Jamaica Bay were undeveloped with 68%, in 1974 with 62% and in 2006 with 57%. They also state that there has been a general trend of increased commercial use in the second part of the 20th century.

C.3.2. WATER QUALITY IN JAMAICA BAY

Rhoads et al. (2001) [27] state that in 1931, the City of New York created a program to treat wastewater flowing into waters around the city. In the years before, millions of liters of raw wastewater were flowing into Jamaica Bay daily. According to Rhoads et al. (2001) [27], during the 19th century there were several occasions where raw sewage water was directly flowing into the Jamaica Bay even at the time when waste water treatment plants (WWTP's) were active.

According to Rhoads et al. (2001) [27], around the year 2000, the temperature in the Jamaica Bay ranged from 1°C to 26°C. The salinity in the bay ranges from 20.5 and 26 parts per thousand and pH from 6.8 to 9. These system characteristics are similar to that of a temperate, eutrophic estuary. Furthermore they state that for over 50 years, virtually all fresh water streaming into the bay has been from urban runoff or through four WWTP's. In 1990, these WWTP's annually contributed 110.000 cubic meters of treated sewage. Also by 1990, 66 percent of fresh water input are discharged from secondary sewage treatment plants. 90 percent of the secondary discharge got treated, and 10 percent came from confined sewer outfalls (CSOs) (Rhoads et al. (2001)

[27]). Boger et al. (2012) [75] state that the WWTP's, which releases a large amount of fresh water into the bay, are not equipped with a tertiary biological treatment and consequently, the effluent contains a high level of nutrients. The report also states that the rapid loss of marshes has been connected to the high concentration of nutrients in the bay.

When looking at the tidal movement within the Jamaica Bay, with each semidiurnal cycle, tidal currents are estimated to exchange one third of the volume of the bay (Rhoads et al. (2001) [27]). An effect of the deepening of Jamaica Bay through dredging, the residence time of fresh water streaming into the bay is approximately 30 days. The National Park Service notices a significant improvement of water quality in the Jamaica Bay over between 1972 and 2001.

C.3.3. GEOLOGY JAMAICA BAY AREA

Baskerville (1982)[76] states that the soil of New York City consists of nine different foundation rock types and dozens of soils. He states that the soil at the coastal plains consist of loosely consolidated materials. According to Rhoads et al. (2001) [27], the Jamaica Bay is a shallow bar-built estuary and represents a historic delta of the Hudson River. The Rockaway Peninsula is composed of tidal sediments and upper glacial sands. The marshes at the perimeter of the bay are characterized by dark gray clayey silt to silty clay sediments. According to the report, the Jamaica Bay is similar to a eutrophic estuary. The underlying glacial sands are Upper Pleistocene deposits.

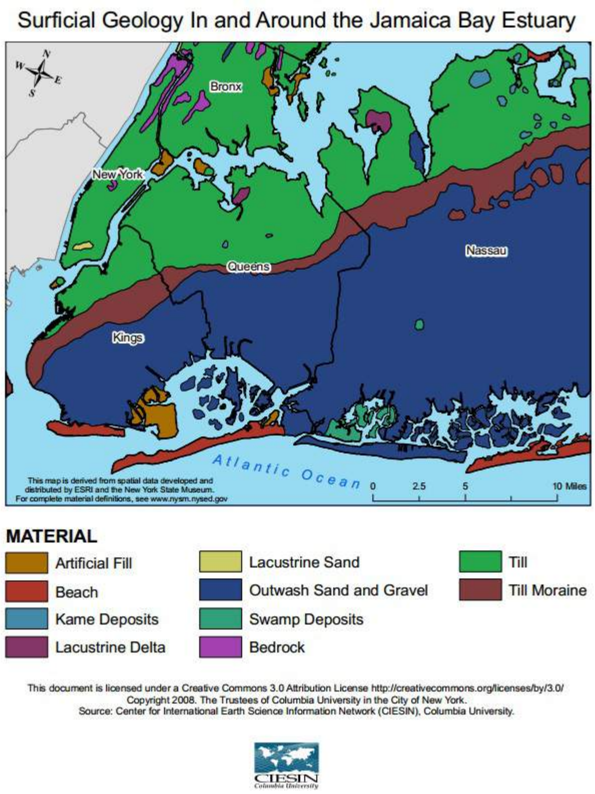


Figure C.8: Geology Map of New York City area, Center for International Earth Science Information Network, 2013

Figures C.8, C.9 & C.10 show the geology of the New York City area, created by the City University of New York [77]. They show that the sedimentary rocks are located deep into the ground. On top of the rock layer, relatively old sediment has created the outwash plains, consisting of sand and gravel [78].

C.3.4. ACTIVITIES BEFORE SANDY

There have been a great amount of studies regarding the Jamaica Bay area. These studies resulted in recommendations and proposed plans. In the next part the current activities at the Jamaica Bay are elaborated.

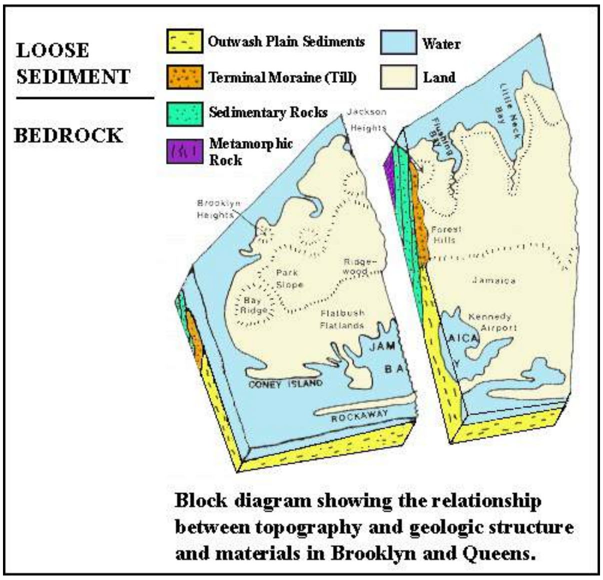


Figure C.9: Geology Block Diagram of New York City area, City University of New York, 2013, The Geology of the New York Metropolitan Area

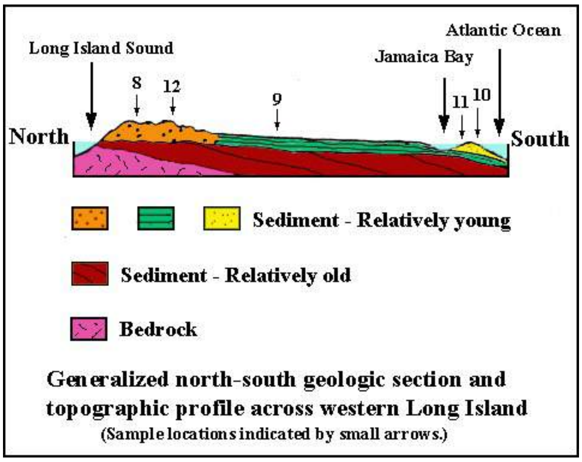


Figure C.10: Geology Section of New York City area, City University of New York, 2013, The Geology of the New York Metropolitan Area

JAMAICA BAY WATERSHED PROTECTION

In 2007, the New York City Department of Environmental Protection (DEP) researched watershed protection for the Jamaica Bay[79]. It proposed to establish the pathway to restoring and maintaining water quality and ecological integrity in the bay. According to the report this objective requires the DEP to develop a plan with an advisory committee. The plan should entail solutions for seasonal dissolved oxygen levels, degraded upland habitats, loss of wetlands and jurisdictional coordination. The current practices of the DEP are upgrading water pollution plants, a Combined Sewer Overflow (CSO) program and the Jamaica Bay Ecosystem Restoration Project.

PLANYC

In 2007, the City of New York released a long term sustainability plan which looks at the year 2030 [80]. This plan was called PlaNYC and consisted of 127 different initiatives addressing air quality, water quality, climate change and energy efficiency. In 2011, this plan was renewed and after Sandy a Special Initiative for Rebuilding and Resiliency (SIRR) was introduced. PlaNYC elaborates on reducing water pollution and improving water infrastructure.

COMPREHENSIVE RESTORATION PLAN

In 2009, the US Army Corps of Engineers (USACE) and the Port Authority (PA) of New York & New Jersey created a Comprehensive Restoration Plan (CRP)[81] as a master plan to guide ecological restoration efforts in the Hudson-Raritan Estuary (HRE), in which the Jamaica Bay lies. The report identified eleven Target Ecosystem Characteristics (TEC's). Also it identified fifty-five sites, most of which are for wetland restoration and maritime forests. There is potential for creation and restoration of several habitats. Also it states that the human influence can be reduced due to improving water and sediment quality.

MARSH RESTORATION

Currently the USACE is restoring marsh islands within Jamaica Bay. In 2006-2007 they restored about 40 acres at Elders Point East and in 2010 they restored about 40 acres at Elders Point West. They also planted vegetation in these areas to help prevent them from eroding. Subsequently the USACE restored another 87 acres of marsh island; in 2012 Yellow Bar Hassock, Black Wall and Rulers Bar were restored. In the list below the projects and restored acres are summarized. This information is publiced by the USACE [56].

- Elders East, approximately 40 acres
- Elders West, approximately 40 acres
- Yellow Bar Hassock, approximately 44 acres
- Black Wall, approximately 20 acres
- Rulers Bar, approximately 10 acres

C.4. CURRENT AND FUTURE THREATS TO JAMAICA BAY

C.4.1. INTRODUCTION

Like mentioned in the previous chapter, in 2007 the city of New York published *A Greener, Greater New York* with new initiatives that placed an even greater emphasis on climate resiliency in response to changes in weather. Some of the initiatives were reducing greenhouse gasses, updating its Building Code to make new buildings more flood-resistant and restoring plus enhancing wetlands. However, Sandy's magnitude showed that the efforts needed to be redoubled. Therefore Mayor Bloomberg convened the Special Initiative for Rebuilding and Resiliency (SIRR) and they started with analyzing the impacts of the storm on the city's building, infrastructure and people; assessing the risks the city faces from climate change in the medium term (2020s) and long term (2050s).

C.4.2. DENSELY POPULATED AREA

Questions about how to handle flood risk in densly populated areas are as old as many human settlements. Water supply has always been an important factor in the search for eligible settlement locations throughout history. Given the high spatial concentration of people and infrastructural assets in coastal cities, the damage of inundations in those cities is very high. Globally, approximately 400 million people live within 20 m of sea level and within 20 km of a coast. By the end of the century, increases in sea level rise of two to five times the present rates could lead to inundation of low-lying coastal regions, more frequent flooding episodes and worsening beach erosion declare Gornitz et al. (2001) [82]. It is stated that the greater New York metropolitan area covers 33,670 km^2 area, with 23.3 million inhabitants of which 8.3 million reside in NYC. Four out of five of the NYC boroughs are located on islands. More than 2000 bridges and tunnels connect these islands and the mainland.

However, New York City is and will always be a waterfront city. The majority of NYC's coastline is situated in the southern part of the city, like for example South Queens. South Queens is predominantly residential, home to 130000 people who form 15 different communities. On the eastern most end of the Rockaway Peninsula the neighborhoods of Bayswater and Far Rockaway are found, jointly reffered to 'Far Rockaway', like stated in PlaNYC (2013) [2]. This part is much denser than other communities on the Peninsula, Far Rockaway is home to 54000 residents - this is 42 percent of South Queens's total population. To the west of Far Rockaway there are five neighborhoods present, referred as 'Rockaway'. These communities are Arverne, Edgemere, Somerville, Rockaway Park and Rockaway Beach. The Rockaway is with 49100 residents, the second most densely populated part of South Queens. According to Aerts et al (2012) [13] socioeconomic developments, such as population and economic growth, will likely increase the potential consequences of flooding. The projections of the NYC's population is projected to continue to grow to 9.1 million in 2030. Currently 300.000 people live in the 1/100 flood zone. Furthermore 33000 buildings (assets which represent US$18.3 bn) are located in the same 1/100 flood zone of which 252 properties are considered to be critical infrastructure, i.e. schools, power plants, police stations and airports. More information about flood zones see section C.7.2.

C.4.3. EROSION

A short description of the erosion problems is given in subsection C.6.3.

C.4.4. DISAPPEARING SALT MARSHES

In the past, several studies have been done on the Jamaica Bay wetlands. According to Hartig et al. (2001) [19] a degradation of the salt marshes inside Jamaica Bay can be seen over the past decades. They state that between 1959 and 1998 the land area has decreased with 12%, or roughly 0.3% per year. In this study the ground field work has been compared with previous remote sensing observations for several marshes in the bay. The report points out that a process of erosion can be defined as slumping and inward retreat of peat along banks of creeks and island edges. It is noted that the process of marshland loss looks similar to loss of wetland in Louisiana and Chesapeake Bay, however, the causing mechanisms may differ. The most critical factor to be pointed out is the general sediment deficit, others would be dredging for navigation channels, wave action due to boat traffic and excessive waterfowl grazing.

This view is also shared by the New York State Department of Environmental Conservation (2001) [83]. Using aerial photography and geographic information system (GIS) technology they have documented of the bay in

Figure C.11: Erosion of low marsh along tidal channel, Yellow Bar Hassock, exposing underlying peat layers. This illustrates a transitional stage in the transformation of low marsh to mudflats.

1974 and 1999. NYSDEC shows that from 1974 to 1994, 526 acres of marsh islands were lost at an average rate of 26 acres per year. Almost half of this decrease happened between 1994 and 1999, stating 220 acres were lost at an average rate of 44 acres per year. Two notable examples are shown below: Elders point and Duck Point, see figure C.12. 76 acres were lost at Elders Point in a period of 15 years. For Duck Point it can be seen that 65 acres of marshland was lost in the same period of time. Using old maps of the bay from 1924, it is estimated that between 1924 and 1999 nearly half of the bay's vegetated marsh islands have disappeared. And if this alarming rate of wetland lose continues, the islands would completely vanish by 2024.

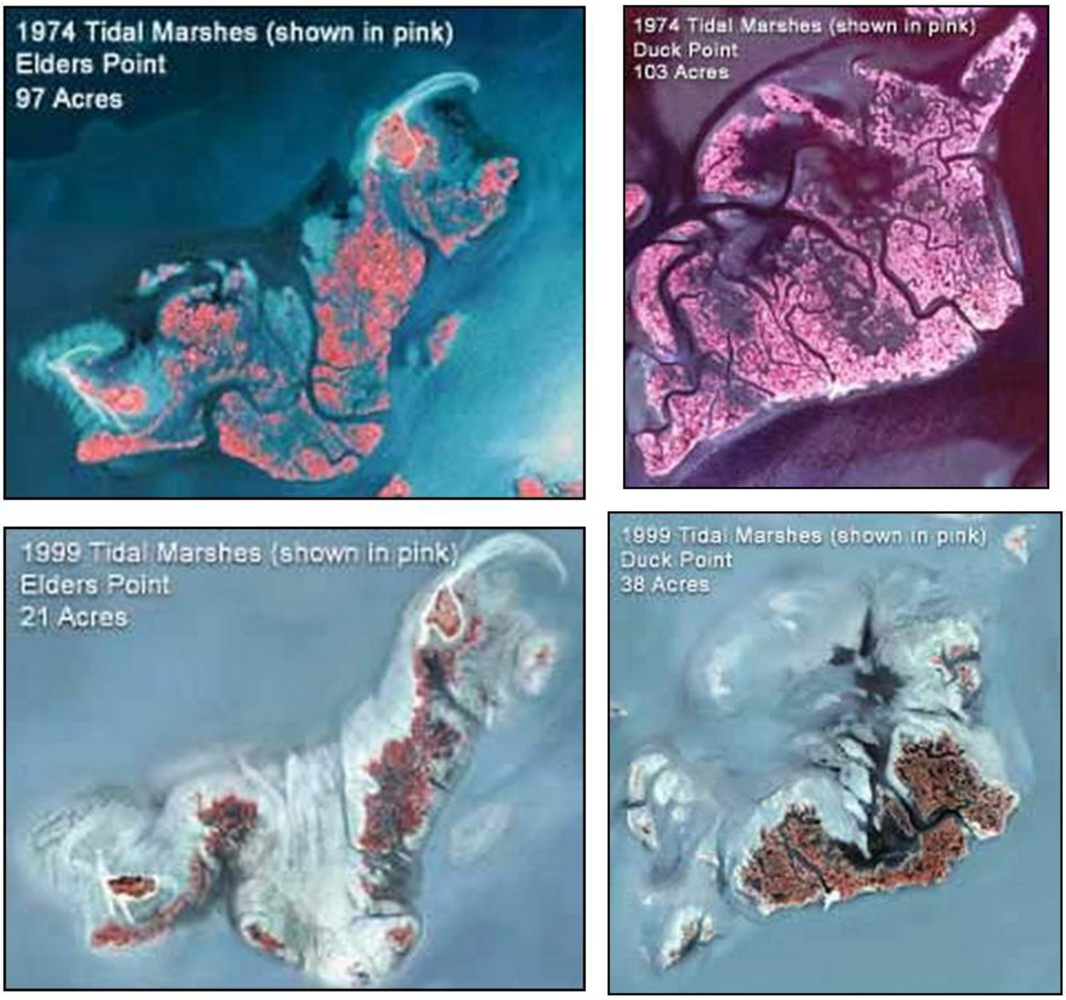


Figure C.12: left: Elders Point, right: Duck Point

A follow up study has been done on the previously discussed DEC study from 2001. This study was conducted by the Gateway National Area, National Park Service, U.S. Department of the Interior and the Jamaica Bay Watershed Protection Plan Advisory (2007) [61]. For this report, the conductors made use of field observations, satellite imagery and aerial photography 2003 obtained by GNRA, and aerial photography obtained from DEC for the years 1951, 1974, 1989, 2003, and (for selected marshes) 2005. Unlike previous studies conducted by the DEC which only mapped vegetated areas of marsh, the methodology used by GNRA GIS office mapped internal marsh structures, such as tidal creeks, mud flat, and areas of degrading vegetation at a fine scale. Together with field work the effort resulted in a comprehensive view on the disappearing wetlands.

From observation it can be deducted that tidal pools or tidal creeks will expand, if vegetation consisting of largely salt marsh cordgrass becomes waterlogged and will subsequently drown. Because of the loss of the root structure what keeps the soil in place, the marsh will get fragmented and transforms into a unvegetated mud flat. Without its root structure the marshes are heavily subject to further erosion.

The research has pointed out that a decrease of 63 percent of vegetated salt marsh islands can be noted between 1951 and 2003, see table C.2. To put this figures into perspective, the rate of marsh island loss has been computed in the next table, table C.3. In the periods 1951-1974 and 1974-1989 the rate of loss was 17 acres/year and 18 acres/year respectively. For the last period 1989-2003 this was 33 acres/year. What can be concluded is an acceleration of marsh island loss in the past 60 years, especially in the period 1989-2003. This infers that this rate is not nearing an equilibrium, and might however result in total loss of marsh islands. Even sooner then the previously projected 2024.

	Time Period			
	1951	1974	1989	2003
Vegetated Marsh (Acres)	2347	1610	1333	876

Table C.2: Jamaica Bay Marsh Islands: Total vegetated Marsh

	Time Period		
	1951-1974	1974-1989	1989-2003
Average Rate of Loss (Acres/Year)	17	18	33

Table C.3: Jamaica Bay Marsh Islands: Rate of Marsh Loss

A definite cause to sediment deposition, resulting in disappearing salt marsh islands, remains unknown. However, several developments have been addressed as processes which could have influence in the overall state of the Jamaica Bay. When compared to the earliest data of the bay some differences in activities and usage of the bay can be pointed out. Landfilling, dredging, hardening of the bay's perimeter, residential and commercial development, channeling of overland flow through storm sewers and combined sewer overflows (CSO's), little to know freshwater supply and water pollution are all loads the bay has coped with in the past, or is still subject to. A redistribution of sediment is therefore more then likely.

A link has been made between the increasing development around the Jamaica Bay and the disappearing salt marsh island. In figure C.13 this progression of urbanization is visualized for the area surrounding the bay. What can be clearly seen is that due to expansion of the city almost no ground has been left out without an urban function. New parts from Brooklyn and Queens now reach to the boarders of the Bay. One might think that this ecosystem was stable in the past, and that due to human interference alteration are happening in the bay.

As shown in chapter C.3.1 on page 207, a lot of alterations have been taken into effect in and around the bay, primarily in the 20th century. John F. Kennedy International Airport being most notable. However, the reclamation of Barren Island for Floyd Bennett Field was also a large project at the time, a reclamation which subsequently alters the dynamics in the Jamaica Bay system. Many creeks which used to reach out to the bay have been filled or hardened.
Navigation channels have also been dredged continuously in the passing decades to ensure sufficient draft for ships and boats. Stabilization of the Rockaway Inlet can have consequences for the eb-tidal delta. Although people like to think Jamaica Bay as an natural environment, this is hardly the case. Let alone self sustaining.

The bay used to have plenty of freshwater input from the surrounding area, however, this is not the case anymore. The only freshwater conveyed is that from the sewerage plants around the bay. Each day, 250 million gallons (946 million liters) of treated wastewater containing thirty to forty thousand pounds of nitrogen are discharged by the the four city water pollution control plant (WPCP). This amount of nitrogen is far to much for the marshes to assimilate. The four WPCP's are highlighted in figure C.14 (26th Ward, Coney Island, Jamaica, and Rockaway plants).

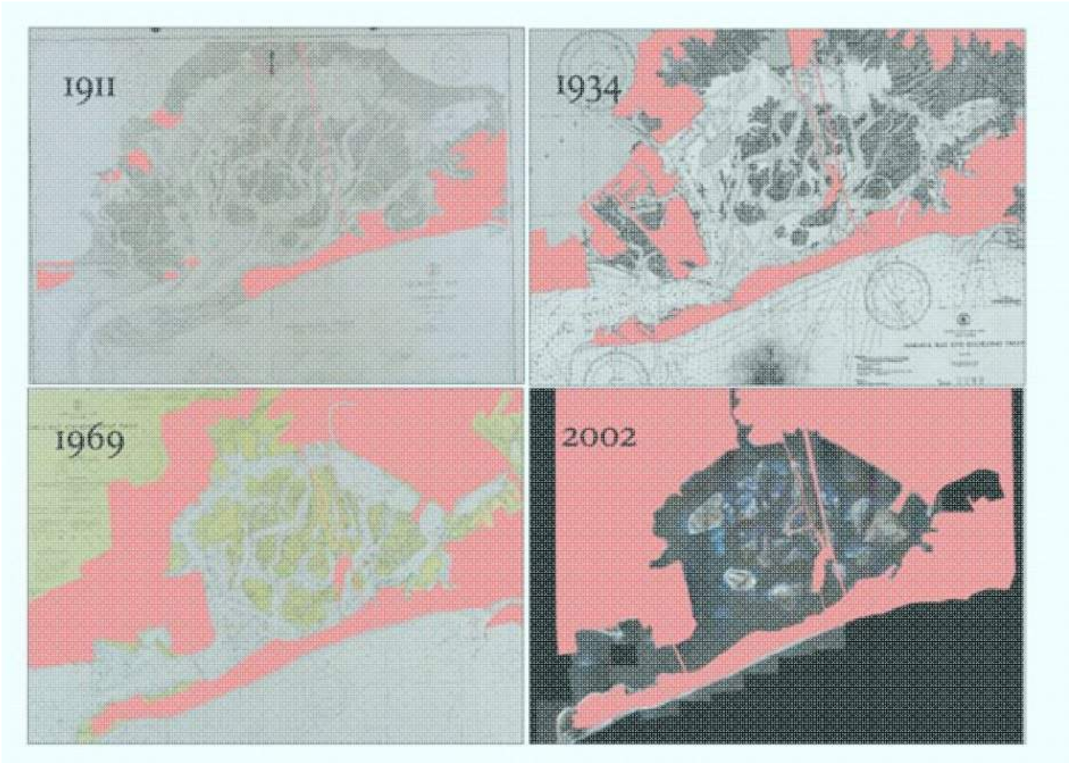


Figure C.13: Pink shading shows increased development around Jamaica Bay

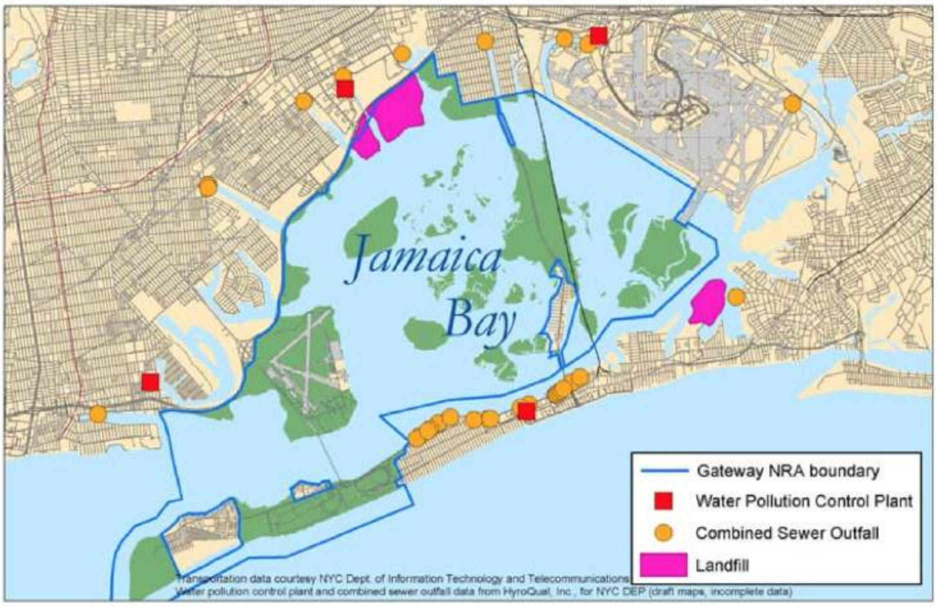


Figure C.14: Sewerage activity around Jamaica Bay

In case of consistent rainfall or a high demand in wastewater treatment discharge, the WPCP's capacity is vastly met, resulting of overflow of untreated sewage (CSO). A rainfall with an intensity of 0.15 centimeters an hour for 6.7 hours will exceed the city's limit. This CSO is high in organic pollutants combined. Currently, only 32 percent of the bay's CSO is being captured, the remaining 68 percent flows directly into the bay. The Jamaica bay is believed to be in violation with the water quality standards set by the DEC in 1998, relating to pathogens, nitrogen, and oxygen demand. In addition, the DEP states that the WPCP's are the major contributors to the phosphorus, nitrogen, silica and carbon loadings to Jamaica Bay. Also, it is indicated that high concentrations of sulfide are to be found in the bay due to the CSO. This high concentration can subsequently lead to the build up of hydrogen sulfide in sediments. Due the longer periods of flooding the marsh grass has limited ability to oxygenate its roots and detoxify sulfide. When this happens, the roots of the marsh grass degrade, hence the loss of grass and marsh.

Another threat to the salt marsh islands is sea level rise. Historically, the bay's sediment capacity has been in balance with relative sea level rise. For further predictions of sea level rise, see chapter C.4.5, would exceed the historical sediment accretion rate of the bay. This leads to more frequent inundation of the marshes, which has been noted as a serious threat to the well being of its vegetation, hence marsh erosion. Analysis, done by the U.S. Global Climate Change Research Program, suggest that with sufficient mineral sediment supply, the wetland could survive. The sediment such be rich in minerals so plant growth can be stimulated. With increasing water level due to sea level rise, marshland elevation is needed, to prevent inundation.

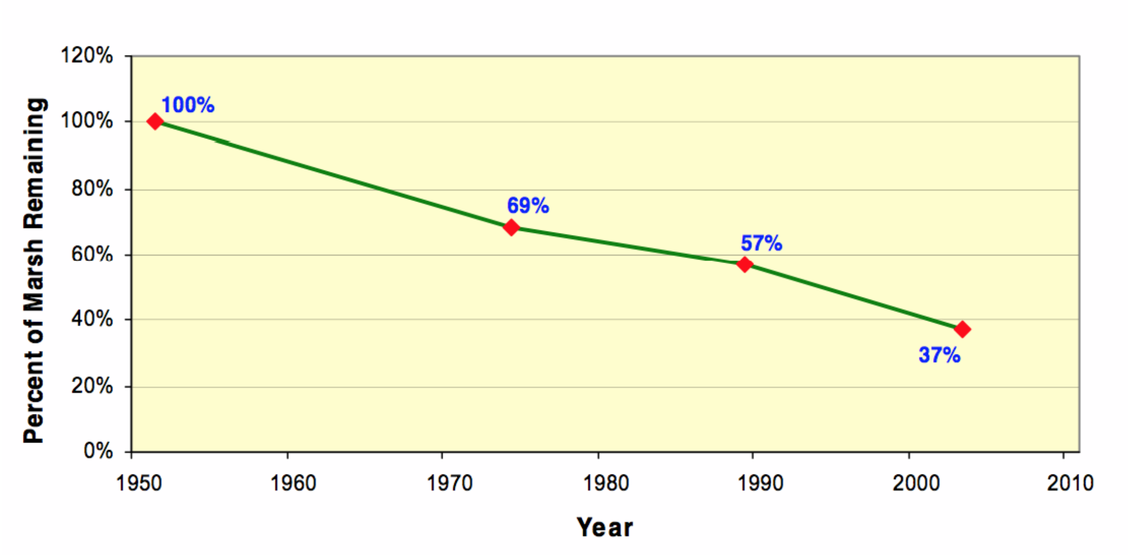


Figure C.15: Jamaica Bay Marsh Islands: Vegetated Marsh as estimated percentage of 1951 marsh extent

In conclusion, the report states that, although a definite culprit is unknown to the marsh land disappearance, immediate action is needed to preserve these wetlands with their ecological value. The results have been compared with DEC's ongoing salt marsh mapping project study, and a general agreement in rates of loss and overall marsh status is established. An visual impression is given in figure C.15 and figure C.16.

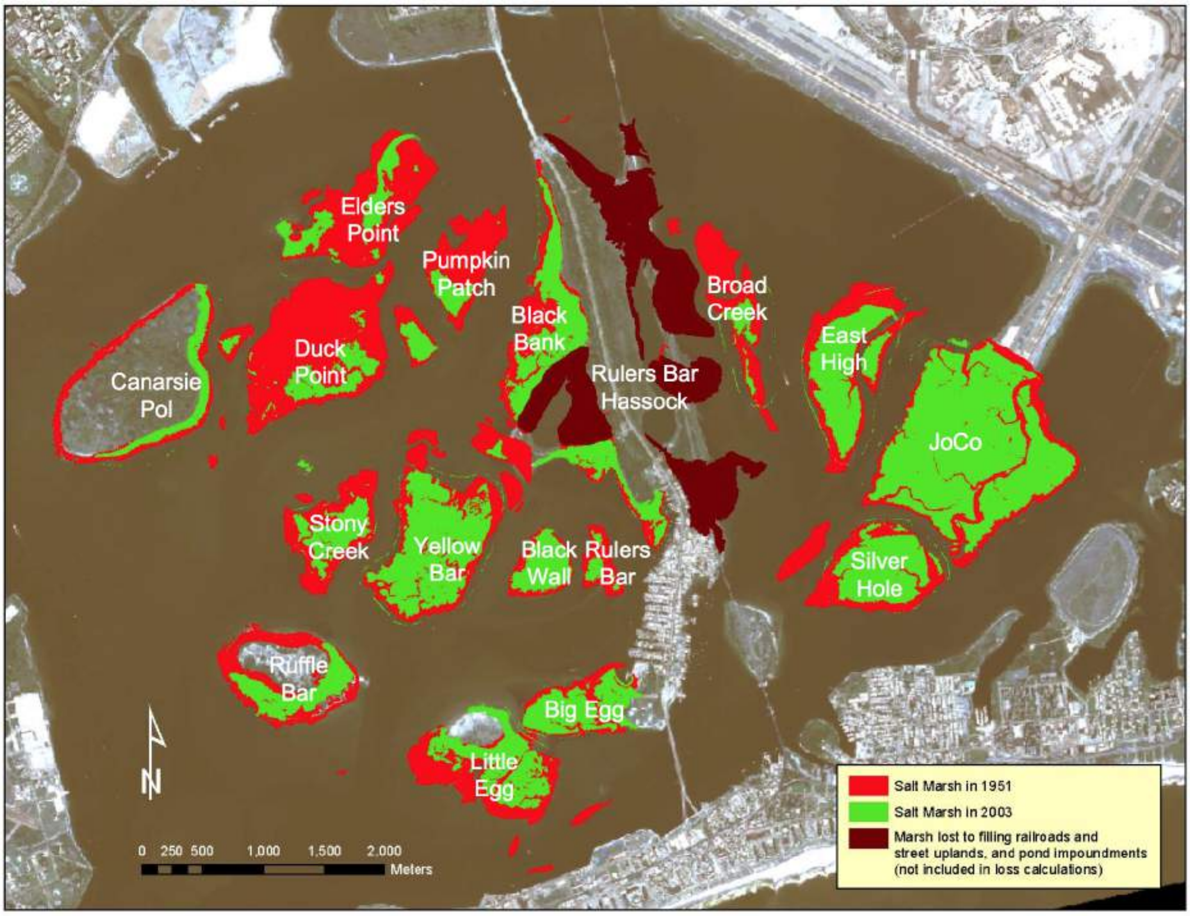


Figure C.16: Overview of salt marsh island loss between 1951 and 2003

In response to the alarming rate of sediment loss in Jamaica Bay, shown by numerous studies and which had been accelerating for certain marsh islands to 54 acres in 2007, an intent plan is signed by Mayor Bloomberg to asses the technical, legal, environmental and economical feasibility of variety of protection measures as part of the Jamaica Bay Watershed Protection Plan (2007) [79]. The objective is to establish the pathway towards restoring and maintaining water quality and the ecological integrity of Jamaica Bay. The NYCDEP highlights once again the importance of the bay, pointing out the providence of local marine research, flood control, natural pollutant attenuation and support for 214 species. An array of focusses were defined:

- Water quality
  - Reduce nitrogen loadings
  - Reduce CSO and other discharges into the tributaries to reduce pathogens and improve dissolved oxygen
  - Increase dissolved oxygen levels in tributary basin areas to improve ecological productivity
  - Develop a robust scientific monitoring program
- Ecological Restoration
  - Restore the salt marsh island in Jamaica Bay
  - Protect natural areas along the periphery of the bay

Subsequently, as of 2006, nourishment operations have been done by the U.S. Army Corps of Engineers to four marsh islands: Elder Point East, Elders Point West and Yellow Bar Hassock Rulers Bar Marsh Island. A total of 232 acres are recovered up to 2012. Further notice has been taken care of storm water BMPs, public education and outreach and public use/enjoyment.
PlaNYC - A Stronger, more resilient New York (2013) [2] made by SIRR believes the declining of salt marshes is due to pollution, alteration due to dredging, sediment deprivation, tidal changes, and the loss of freshwater tributaries. It has given a post-Sandy overview of the bay. Although, the main concerns regarding the state of the bay did not change, now an extra point of attention has been added, namely, flood risk reduction of the Jamaica Bay area.

Like stated in chapter C.3.1 on page 209, a study was conducted on the land use/land cover (LULC) of the estuarine shoreline in Jamaica Bay by Boger, et al (2012) [75]. At three time periods 1951, 1974, and 2006, satellite imagery was used for this study on Jamaica Bay. These years were chosen because of the availability of air photos and the comparable time periods they represent before and after the park was created in 1972. ArcGIS was used to determine the high water line for each year. What can be concluded from this study is that despite the heavy development of New York City and the trend for shoreline modification, the overall shoreline of Jamaica Bay has maintained large percentages of undeveloped vegetation and sandy beaches. Therefore the bay has been successful to retain a fair amount of natural based shoreline, see figure C.17.

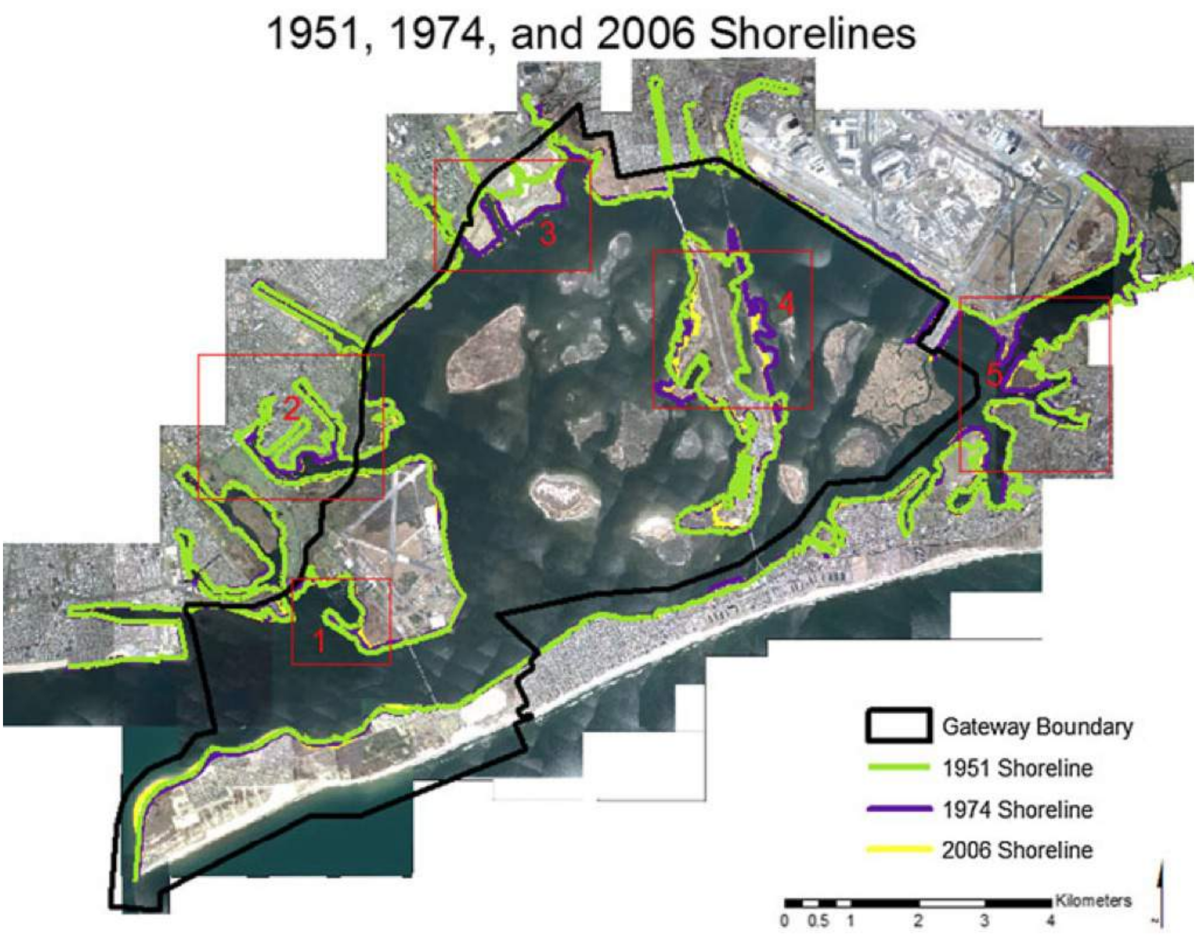


Figure C.17: Comparison of 1951, 1974, and 2006 shorelines

Research done by the New York - New Jersey Harbor (2012) [84] showed that surprisingly the estuary's health is much better than it was 30 years ago, but many problems remain. The fact sheet they made summarizes a few aspects, including pollution, wildlife, and natural areas. Loss and degradation of habitat have generally slowed in recent decades. A couple of graphs show that the several populations of fauna have relatively stabilized. For example the harbor heron's and fish's, see figure C.18. Nutrient pollution in the estuary has decreased, thanks to investments in better wastewater treatment. Excessive nutrients in the waters enable microorganisms to grow and consume dissolve oxygen, stressing or even killing valuable aquatic wild life. Therefore, an increase is to be found in dissolved oxygen in bottom waters. Pathogens relating to bacteria to found has decreased, and PCB's as well. Improvements in WWT infrastructure have generally resulted in cleaner waters. In overall, it can be said that the water quality has vastly improved over the last couple of decades.

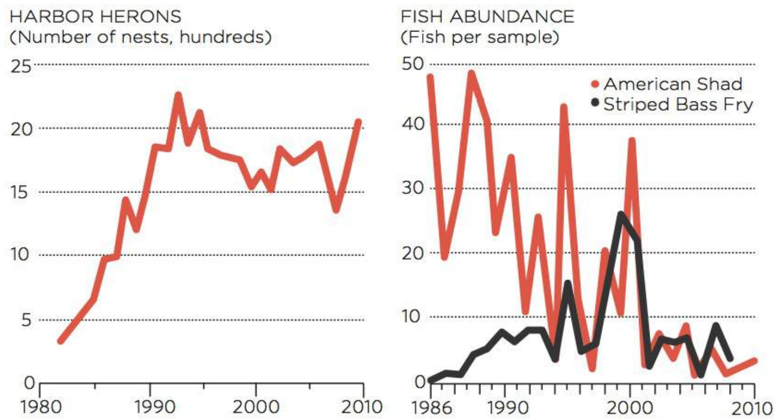


Figure C.18: Left: Harbor Heron, Right: Fish

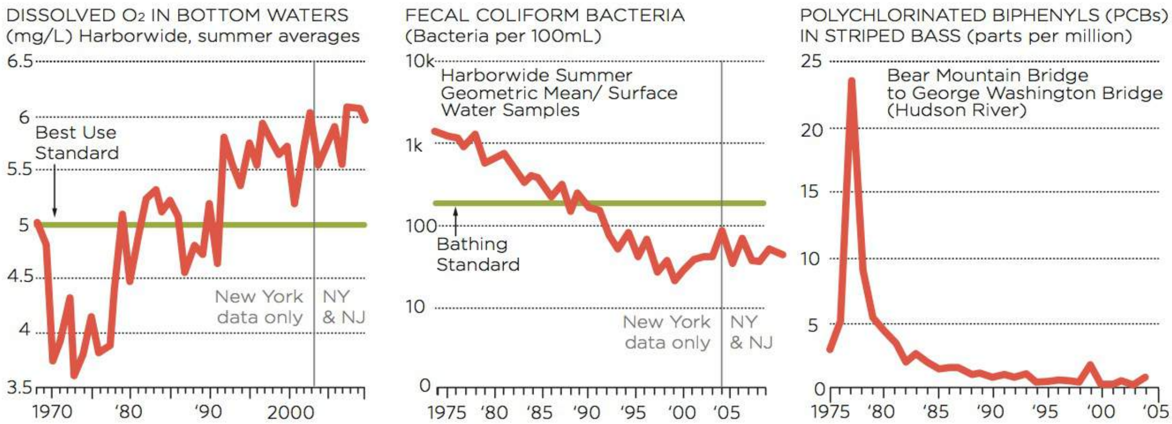


Figure C.19: Pollution monitoring in past 35 years

C.4.5. CLIMATE CHANGE

Sandy has brought public attention to the climate hazards of the New York area. But did climate change cause the storm? In a report written by New York City Panel on Climate Change [85], it is pointed out that the first panel was assembled in 2008 (NPCC1) to study the climate changes projected on NYC and accomplish the goals outlined in PlaNYC 2008, the City's long-term sustainability plan. After hurricane Sandy, as a part of PlaNYC, the Bloomberg Administration founded the second New York City Panel on Climate Change (NPCC2). This body of leading climate, social scientists and risk management experts, was convened to analyse the current climate risks for use in the Special Initiative for Rebuilding and Resiliency (SIRR). According this panel, the climate is changing in many ways. Recent obervations reported in the National Climate Assessment Public Review Version is revealing that the temperature and the downpours of the Northeast of the

United States are increasing. Moreover, it is found that there has been very likely an overall decrease in the number of cold nights and days and on the other hand, an overall increase of warm nights and days globally. The NPCC revealed that trends in temperature and precipitation have increased overall throughout the century. From 1900 to 2011 the mean temperature in NYC has increased 2.4 degrees Celsius. Furthermore, the mean precipitation has increased, during these 111 years, with 18.6 centimeters. This panel concluded, by using global climate models, that the mean annual precipitation will increase. While the middle range projection by 2020s is 0 to 10 percent, the projection by 2050 will be 5 to 15 percent. Besides the expected increase of precipitation also heat waves are very likely to become more frequent, more intense en longer in duration. Similarly, heavy downpours are very likely to increase in frequency, intensity and duration. An overview of their research is shown in figure C.20.

Quantitative Changes in Extreme Events

			2020s			2050s		
		Baseline (1971 - 2000)	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
Heat waves and cold weather events	Number of days/year with maximum temperature at or above 90°F	18	24	26 to 31	33	32	39 to 52	57
	Number of heat waves/year	2	3	3 to 4	4	4	5 to 7	7
	Average heat wave duration (in days)	4	5	5 to 5	5	5	5 to 6	6
	Number of days/year with minimum temperature at or below 32°F	72	50	52 to 58	60	37	42 to 48	52
Intense Precipitation	Number of days/year with rainfall at or above 2 inches	3	3	3 to 4	5	3	4 to 4	5
Coastal Floods at the Battery*	Annual chance of today's 100-year-flood	1.0 percent	1.1 percent	1.2 to 1.5 percent	1.7 percent	1.4 percent	1.7 to 3.2 percent	5.0 percent
	Flood heights associated with 100-year-flood (stillwater + wave heights)	15.0 feet	15.2 feet	15.3 to 15.7 feet	15.8 feet	15.6 feet	15.9 to 17 feet	17.6 feet

*Baseline period for sea level rise is 2000-2004. Based on 35 GCMs and two Representative Concentration Pathways. Data are from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) United States Historical Climatology Network (USHCN), Version 2 (Menne et al., 2009). The 10th percentile, 25th percentile, 75th percentile, and 90th percentile values from model-based outcomes across the GCMs and Representative Concentration Pathways are shown. Decimal places are shown for values less than 1, although this does not indicate higher precision/certainty. Heat waves are defined as three more consecutive days with maximum temperatures at or above 90 °F. The flood heights include the effects of waves.

Figure C.20: Quantitative Changes in Extreme Events NPCC

TROPICAL STORMS

According to Aerts et al. (2012) [7] the Atlantic hurricanes are affected by climate variations including the El Nino-Southern Oscilliation (ENSO). ENSO is the warming of the ocean surface that occurs every 4-12 years at the western coast of South America. During the El Nino phase, tropical vertical shear increases due to stronger upper-atmosphere westerly winds, suppressing the development and growth of Atlantic hurricanes. Although hurricane doesn't occur often in the NYC area, their impact can be huge, i.e. high storm surges and rain damage. In general, hurricanes occur between July and October in this area. A direct hit, like Sandy last October, may cause economic damage, hence Aerts et al. The Hurricane Evacuation Zones provided by the NYC Office of Emergency Management show that large parts of the city are potentially vulnerable to surge flooding. Another recent study, from Aerts and Bozen [8], to estimate the direct flood damage in NYC, revealed that for a category 1-3 hurricane, the total value of exposed assets varies between US$ 18 bn and 34 bn. The maximum potential damage to these assets varies between US$ 6 bn and 11 bn.
Hurricane Sandy gained additional strength from unusually warm upper ocean temperatures in the North Atlantic. NPCC expects that the temperatures in the upper layers of the ocean will increase which could allow storms to reach a greater strength. According to Urban Waterfront Adaptive Strategies (2013) [39] coastals are exposed and shaped by coastal hazards and processes. Due to climate changes, extreme events are likely to become more frequent and the damage will exacerbate over time. These hazards vary from sudden and extreme events to gradual and slow changes in time. Extreme events can be associated with sudden events like earthquakes, tornadoes, coastal storms and hurricanes. These hazards causes a rise in water level which are defined as storm surges. The storm surges occuring in NYC are mostly caused by two types of events, i.e. Nor'easters (Northeasters) and hurricanes. Nor'easters occur more frequently but are smaller in size. Especially low-lying areas of NYC are prone to flooding due to storm surges. Furthermore, storm surge can be

responsible to waves which can lead to (sudden) erosion of shorelines and banks. On the other hand, stated in this report, gradual hazards are those hazards that slowly develop in time in contrast to the previous mentioned hazards. Coastlines are shaped and modified over time by winds, waves, tides and currents. These processes gradually erode soft shorelines and move sediment from one place to another, reshaping the landscape. One of the main gradual hazards is the rise of the global sea levels. This increase can cause flooding to low-lying areas on a daily basis and therefore the risks that NYC faces will only intensify. NYPCC concludes that Hurricane Sandy has focused attention on the significant effects that extreme climate events have on NYC. Also other events in the United States, like the drought in 2012, have raised awareness of the impacts of weather and climate extremes. In figure C.21 the observed temperature and precipiation at Central Park are illustrated.

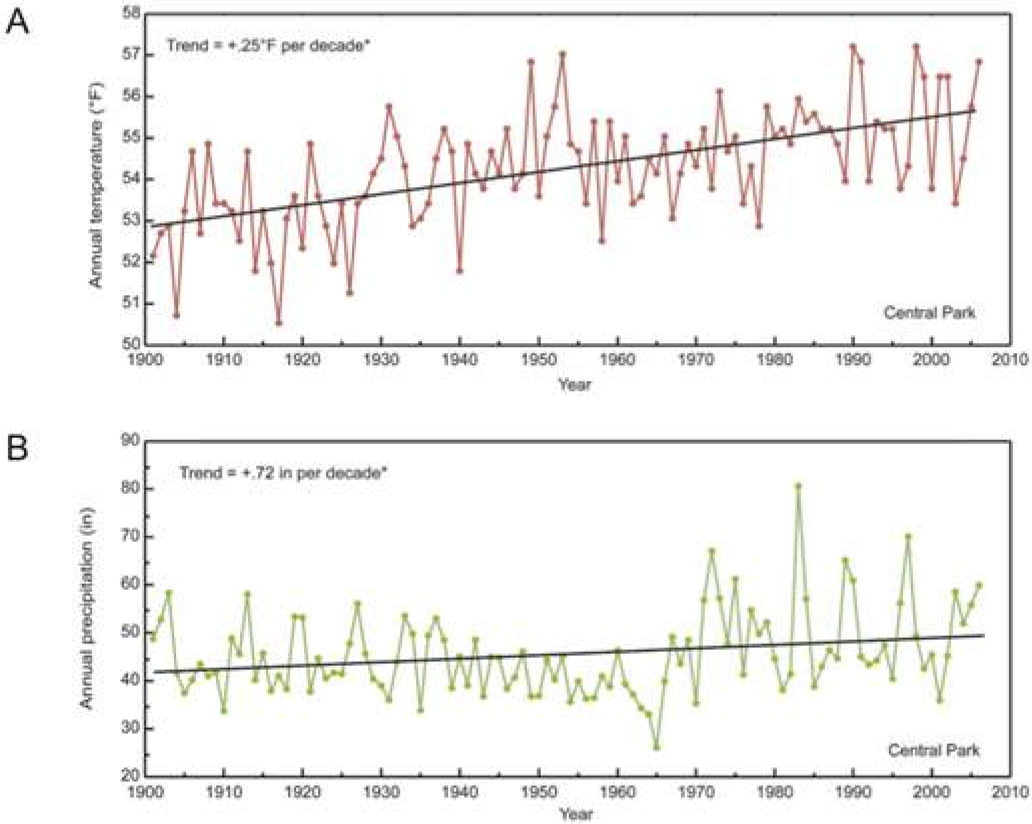


Figure C.21: Top figure shows the temperature at Central Park from 1900-2010, the figure below shows the precipitation at Central Park from 1900-2010

PROJECTED SEA LEVEL RISE

According to National Geographic (2013) [86] there is 21 million km^3 ice present on our planet and no one knows exactly how long it will take when this ice is melted. Several scientists suggests it will take over 5000 years. However, when one will burn all coal, gas and oil and therefore produce 5 billion tons of CO_2 emissions, the ice capacity will be reduced to almost nothing. As a consequence the average earth temperature will rise from 14.4 to 26.6 degrees and additional deserts will be created. If all the ice will melt and is added up to the water present at earth, the sea level will rise with 66 meter. Figure C.22 show the world as it is now, with only one difference: all the ice on land has melted and drained into the sea, raising it 66 meters, creating new shorelines and reshaping our continents and seas.

A completely different planet will be the result of our extreme use of fossil fuels, is stated by National Geographic (2013) [87]. A planet where Sandy-scale flooding will become more common and cause more damage to cities situated at coast lines. Last century the global temperature increased with 0.5 degrees by releasing carbon dioxide and other heat-trapping gases into the atmosphere. This has caused an increase of sea level with approximately 20 centimeters, according this article. Even if our fossil-fuel-driven civilization would stop with burning the fossil fuels, the greenhouse gases already present would continue to warm this planet

Figure C.22: If all the ice melted

for centuries. It is explained that in May 2013 the concentration of carbon dioxide reached 400 parts per million, this is the highest concentration since three million years ago. During that time the sea level was about 20 meters higher than the the current levels. However, it would take centuries to reach such enormous heights but one can certainly influence this process by limiting the greenhouse gas emissions. Estimates have repeatedly been too conservative regarding the speed and the amount of global sea level rise. Global warming is affecting the Earth in two ways, hence National Geographic (2013) [86]. Approximately a third of the current rise is a consequence of thermal expansion. Water expands in volume as it warms. The rest of the sea level rise is caused by the melting of ice on land. The majority of the ice is melting at mountain glaciers, however, the big concern for the future is the melting process of the ice sheets in Greenland and Antartica. This article declares that Radyley Horton, researcher at the Earth Institute of Columbia University in NYC, observed accelerated melting of the ice sheets in West Antartica and Greenland. He states that if this acceleration continues, we could see a rise of 1.85 meter of our sea levels by the time we get to the end of the 21st century. One of the biggest concerns in the sea level rise-scenarios is the enormous Thwaites Glacier in West Antartica. Four years ago, National Geographic explained, NASA made a series of flights over this area to discover the seafloor topography. The flights showed that the 610 meter high undersea ridge holds the Thwaites Glacier in position, slowing its slide into the sea. Rising sea level could cause more water to seep between the ridge and the glacier and eventually unmoor it. However, no one knows whether it will happen or if it will happen.

In general, coastal cities face two kind of risks: rising oceans will gradually inundate low-lying areas and higher seas will exacerbate the damage causes by surges. In figure C.23. it is shown that if sea level rises an average of around three feet by 2100, winds, currents, and melting ice sheets will distribute the rise unevenly. Certain coastal cities will be especially vulnerable. Sea level did not change much for nearly 2000 years, judging from sediment cores. While the Earth started to warm, the sea level began to rise in the late 19th century. Moreover, if sea levels are continuing to grow with this rate, it could rise to 1 meter or more by 2100, states National Geographic. Like mentioned earlier, the great unknown is the future of the ice sheets. The National Oceanic and Atmospheric Administration (NOAA), which is a federal agency focused on the condition of the oceans and the atmosphere, made four scenaros, shown in C.24, which span the range of possibilities for 2100. The sea will keep rising after that.

Already in 2001 Gornitz et al [82] put forward that the NYC region, with over 2400 km of shoreline, will be vulnerable to accelerated sea level rise (SLR) due to anticipated climate warming. This article presents the findings of the Coastal Zone Sector of the Metropolitan East Coast (MEC) region, prepared for the US National Assessment of Potential Climate Change Impacts. Gornitz et al. suggest that the mean global sea level has been increasing by 1-2.5 mm per year, for the last 150 years, with 1.8 mm/yr considered the best estimate.

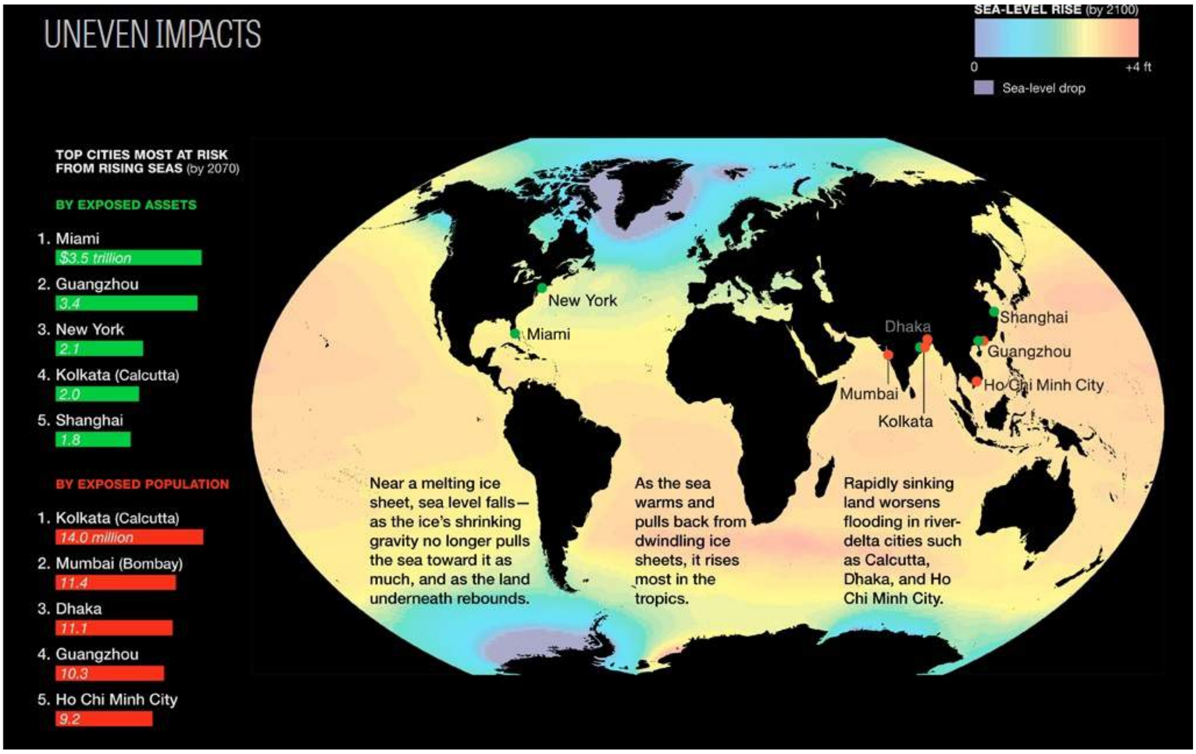


Figure C.23: Uneven Impacts Sea Level Rise

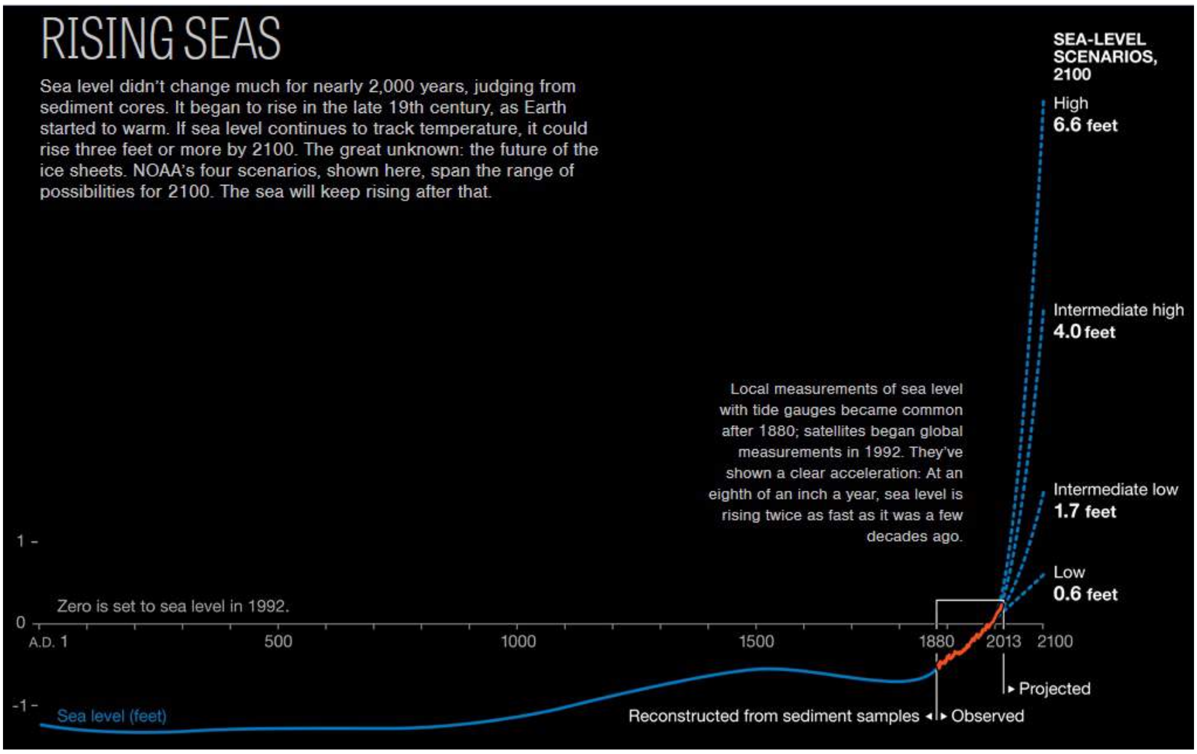


Figure C.24: Rising Seas

This is the most rapid rate within the last few thousand years and is probably linked to the 20th century global warming of nearly 0.5° Celcius. Since the end of the last glaciation the sea levels have increased along the US East Coast. Although deglaciation ended over 6000 years ago, Gornitz et al. noted, sea level has continued to change due to the earth's delayed viscoelastic response to the redistribution of mass on its surface following removal of the ice (i.e. glacial isostatic changes). An important consequence of the sea level rise is the erosion caused by it. The Bruun Rule is often used to the shoreline's response to sea level rise, which states that a typical concave-upward beach profile erodes sand from the beachfront and deposits it offshore, with the goal to maintain constant water depth [81].

SEA LEVEL RISE PROJECTIONS FOR NYC

An interesting discussion is going on about the magnitude of the sea level increase. PlaNYC (2013)[2] states that the higher sea levels certainly did increase the extent and magnitude of coastal flooding caused by the storm. This report declares that since 1900 the sea levels have risen more than a foot in NYC, especially due to the change of the climate. Several climate and social scientist studied the climate projections for the city within NPCC. This panel noted in their report [85] that the sea level rise does increase the extent and the magnitude of coastal flooding during storms. The NPCC projects that sea levels in NYC will rise between 0.1 and 0.2 meter by the 2020s and 0.28 to 0.78 meter by 2050s, based upon their global climate models. As a result of increased sea level, coastal floodings are very likely to increase in frequency, extent and height. The projections found by NPCC are listed in figure C.25. Different multiple processes are noted that contribute to sea level rise, including: changes in ocean height, expansion of ocean water as it warms (thermal expansion), vertical land movements, loss of ice from glacers, ice caps, and land-based ice sheets, gravitational, isostatic and rotational effects resulting from ice mass loss and land water storage. Most of the observed climate-related rise in global mean sea level over the past century can be attributed to thermal expansion, like stated by National Geographic. However, loss of land-based ice has become more important than thermal expansion and is expected to be the largest component of global sea level rise during the 21st century (Aerts et al., 2012 [13]).

Quantitative Changes in Extreme Events

			2020s			2050s		
		Baseline (1971 - 2000)	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
Heat waves and cold weather events	Number of days/year with maximum temperature at or above 90°F	18	24	26 to 31	33	32	39 to 52	57
	Number of heat waves/year	2	3	3 to 4	4	4	5 to 7	7
	Average heat wave duration (in days)	4	5	5 to 5	5	5	5 to 6	6
	Number of days/year with minimum temperature at or below 32°F	72	50	52 to 58	60	37	42 to 48	52
Intense Precipitation	Number of days/year with rainfall at or above 2 inches	3	3	3 to 4	5	3	4 to 4	5
Coastal Floods at the Battery*	Annual chance of today's 100-year-flood	1.0 percent	1.1 percent	1.2 to 1.5 percent	1.7 percent	1.4 percent	1.7 to 3.2 percent	5.0 percent
	Flood heights associated with 100-year-flood (stillwater + wave heights)	15.0 feet	15.2 feet	15.3 to 15.7 feet	15.8 feet	15.6 feet	15.9 to 17 feet	17.6 feet

*Baseline period for sea level rise is 2000-2004. Based on 35 GCMs and two Representative Concentration Pathways. Data are from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) United States Historical Climatology Network (USHCN), Version 2 (Menne et al., 2009). The 10th percentile, 25th percentile, 75th percentile, and 90th percentile values from model-based outcomes across the GCMs and Representative Concentration Pathways are shown. Decimal places are shown for values less than 1, although this does not indicate higher precision/certainty. Heat waves are defined as three more consecutive days with maximum temperatures at or above 90 °F. The flood heights include the effects of waves.

Figure C.25: Extreme Projections Sea Level Rise NPCC

With the above mentioned projections, the NPCC has created two Flood Zone Maps, i.e. a 100-year and a 500-year map. These Flood Zone Maps (not to be confused with the FEMA flood maps, see section C.7.2) illustrate the potential impact of sea level rise regarding the high projections. However, other changes in climate, e.g. change in storm intensity and freguency, that could affect storm surge occurences are not taken into account. The 100- and 500-year maps are respectively shown in figure C.26 and C.27.

While current rates of sea level rise and associated coastal flooding in the region appear to be manageable, the projections for sea level rise and associated floodings in the future, especially those associated with rapid ice melt of the Greenland and West Antactic icesheets, may be beyond the range of current capacity because extreme events might cause flooding and inundation beyond today's planning and preparedness regimes, hence Rosenzweig et al. (2010) [15]. Sea level has been rising along the East Coast of the United States, prior to the industrial revolution, at rates of 0.86 to 1.1 cm per decade. However, within the past 100 to 150 years, as

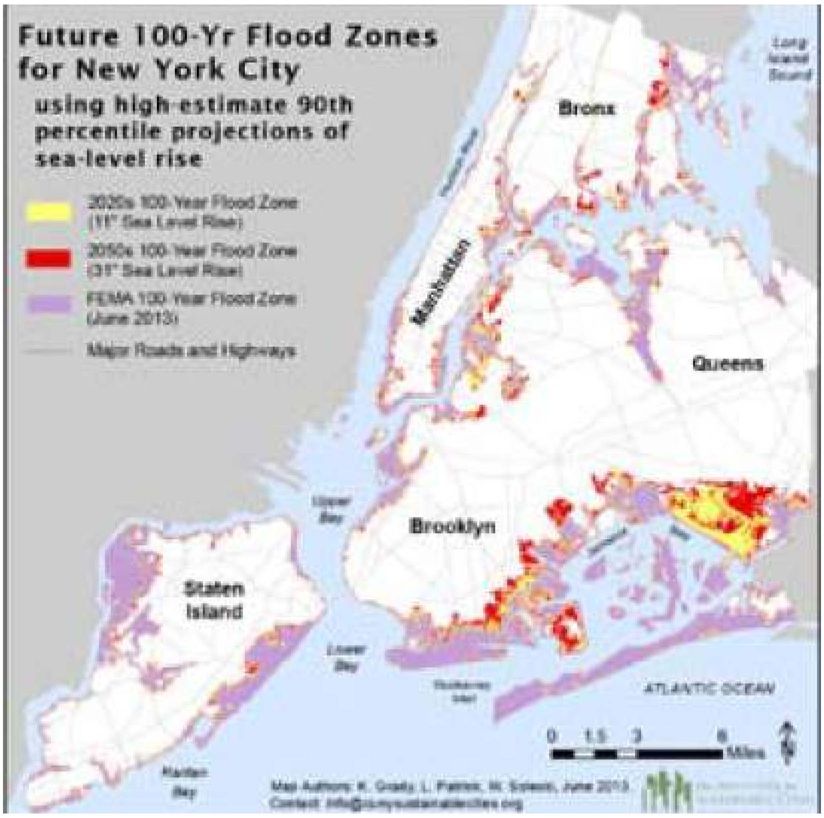


Figure C.26: The potential areas that could be impacted by the 100-year flood in the 2020s and the 2050s based on projections of the high-estimate 90th percentile sea level rise scenario

global temperatures have increased, the sea level have risen more rapidly than over the last thousand years. Also these researchers declare that the most of the observed climate-related rise over the past century can be attributed to expansion of the oceans as they warm. However, the dominant contributor in the 21^{st} to sea level rise is the melting process of land-based ice. In figure C.28 the observed sea levels are illustrated. Within the scientific community there has been a comprehensive discussion of the possibility that the IPCC (2007) approach to sea level rise may underestimate the range of possible increases in large part, because it does not fully consider the potential for land-based ice sheets to melt de to dynamical processes [15]. However, in the end of September 2013 the IPCC has released their new report.

The Intergovernmental Panel on Climate Change (IPCC) is the leading body for the assessment of climate change. It was established by the United Nations Environmental Programme (UNEP) to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and social-economic impacts. In their latest report, IPCC is even more outspoken about the human influences on climate change. The last 130 years the average temperature has increased globally with 0.9 degrees Celcius and between 1901 till 2010 the sea level is risen with 0.19 meter. In constrast with their former report, released in 2007, their knowledge about the the behaviour of ice sheets is increased significantly therefore their previous projections are raised. According IPCC WGI Fifth Assessment Report(2013) [24] the ocean thermal expansion and glacier melting have been the dominant contributors to 20th century global mean sea level rise. Since 1971 observations have been done which indicate that thermal expansion and glaciers (excluding the glaciers in Antartica) explain 75 percent of the observed rise (high confidence). IPCC states that the contribution of the Greenland and Antarctic ice sheets has increased since the early 1990s, partly from increased outflow induced by warming of the immediately adjacent ocean. It is very likely that the rate of global mean sea level rise during the 21st century will exceed the rate observed during 1971-2010 due to increased ocean warming and loss of mass from glaciers and ice sheets. The projections done by IPCC are depending of the type of RCP. RCPs (Representative Concentration Pathways) are four greenhouse gas concentration (not emissions) trajectories adopted by IPCC for its fifth Assessment Report (AR5). The pathways are used for their climate modeling and resarch. They describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four

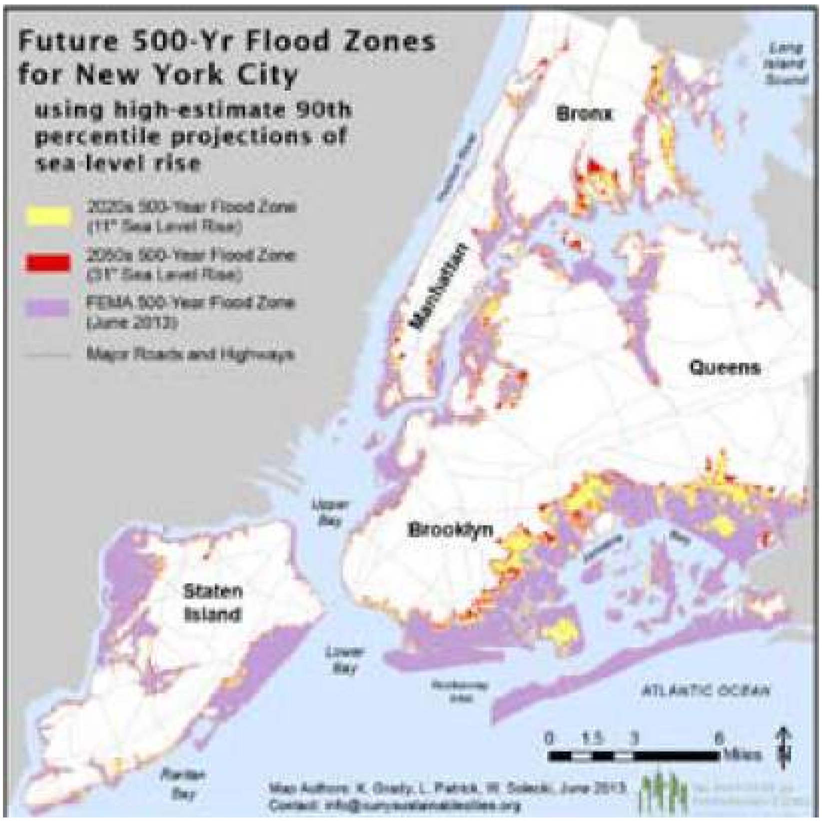


Figure C.27: The potential areas that could be impacted by the 500-year flood in the 2020s and the 2050s based on projections of the high-estimate 90th percentile sea level rise scenario

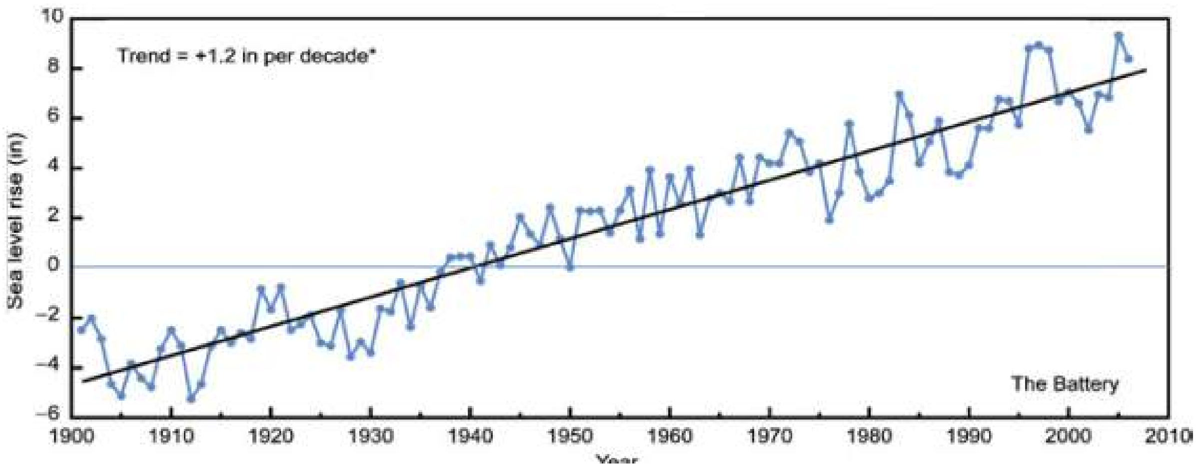


Figure C.28: Observed sea level rise at the Battery, NYC (Rosenzweig et al. (2010))

RCPs, namely RCP2.6, RCP4.5, RCP6 and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 (respectively 2.6,4.5,6.0 and 8.5 W/m^2. In climate science, radiative forcing is defined as the difference of radiant energy by the earth and energy radiated back to space. IPCC revealed that for the period 2081-2100 (long-term vision), compared to 1986-2005, global mean sea level rise is likely to be 0.26-0.55m for RCP2.6, 0.32-0.63m for RCP4.5, 0.33-0.63m for RCP6.0 and 0.45-0.82m for RCP8.5. Therefore, IPCC concludes that the global mean sea level rise will be between 0.26 and 0.81m. However, due to the shifting surface winds, the expansion of warming ocean water and the addition of melting ice can alter ocean current which lead to changes in sea level that can vary from place to place. Past and present variations in the distribution of land ice affect the shape and gravitational field of the Earth, which also cause regional fluctuations in sea level. Additional variations in sea level are caused by the influence of more localised processes such as sediment compaction and tectonics, hence IPCC. Futhermore also Sallenger et al. (2012) [88] declare that climate warming does not force sea level rise at the same rate everywhere. These fluctuations are caused by different natural processes, i.e. circulation, variation in temperature, salinity and static equilibrium processes. As an example of those local variations in SLR, they study the unique 1000-km-long hotspot in the highly populated coast north of Cape Hatteras. Between 1950-1979 and 1980-2009 the sea level rise rate increases in this northeast hotspot 3-4 times higher than the global average. This article refers als to the IPCC report [24] that by 2100 at NYC the modelled dynamic plus steric SLR by 2100 ranges from 36 to 51 cm, lower emission scenarios project 24-36 cm. Extrapolations from data herin range from 20 to 29 cm. SLR in combination with storm surge, wave run up and set up will increase the the vulnerability of coastal cities to inundations. The spatial variations of SLR on the North American East coast are shown in figure C.29.

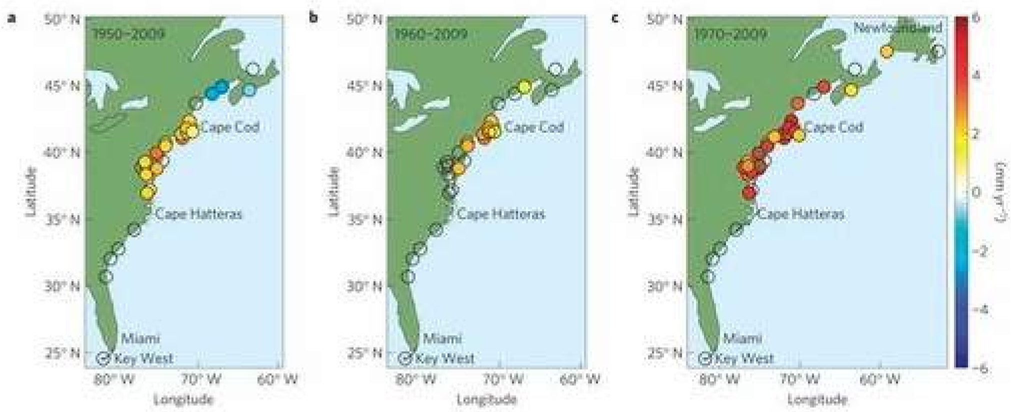


Figure C.29: Each circle represents a gauge location and is coloured to reflect the local SLR

C.4.6. DAMAGE ASSESSMENT

Aerts et al. (2013) [7] state that NYC is one of the most vulnerable cities to coastal flooding around the globe, in terms of probability of hit by a major storm surge and the potential consequences. In this report the flood risk is quantified by the probability of flood events and their potential consequences and is usually expressed in a monetary term such as US $/year. First, low-probability surge events for NYC are selected form the synthetic data set by Lin et al.[14] However, available historical data about hurricanes making landfall is very scarce. Therefore, hurricane surge events for NYC are often modelled with a Monte Carlo simulation. The hurricane surge events for NYC generated by Lin et al -a Monte Carlo set of 5000 events- are modelled by coupling a statistical/deterministic hurricane model with the hydrodynamic model SLOSH (sea, lake and overland surges form hurricanes) and ADCIRC (advanced circulation model). Slosh is a 2D tropical storm surge model, developed by the Techniques Development Laboratory of the National Weather Service, for real-time forecasting of hurricane storm surge. The accuracy of the surge predicted by the models is approximately 20% when the hurricane is adequately described. Furthermore is ADCIRC a finite element model for the purpose of simulating hydrodynamic circulations along shelves, coasts and within estuaries. The resolution of the applied mesh varies from 70 km to several hundred kilometers offshore to as high as 10m around NYC, hence Lin et al.[14] A few results of this modeling is shown in figure C.30. Climate change projections indicate that the zone that is currently expected to flood, on average, each 100 year (the 1/100 year flood zone) may flood approximately four times as frequently by 2080 (Aerts et al. (2012) [13])

The second step [7] for each event is the projection of the simulated coastal surge heights on a digital elevation model (DEM) to create inundation maps. The elevation data are available via the database of the National Elevation Data (NED) with a resolution of approximately 10 x 10 m^2. However, this modeling does not include levees or dunes that protect areas from inundation. Third, Aerts et al. combined the created inundation maps with information of the exposed assets to generate a set of flood damage maps using different stage damage functions, which produce high, medium and low estimates of damage. Subsequently, each grid cell (10 x 10m) describes the relation between flood depth and potential damage. In this modeling other physical characteristics, such as flow velocity or duration of the inundation, are neglected. Another risk-management

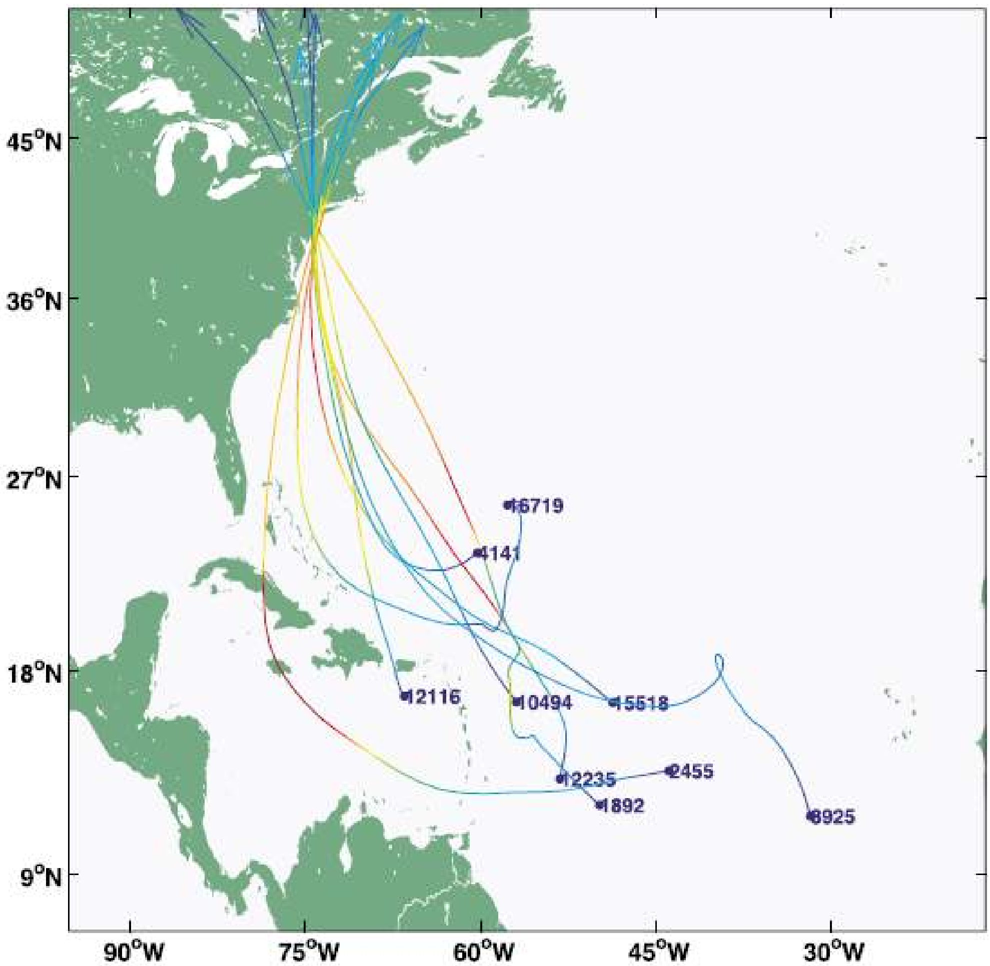


Figure C.30: The 9 (of the 7555) synthetic storms that generate the highest surges at the Battery in the SLOSH simulations

approach developed by NPCC is called Flexible Adaptation Pathways (figure C.31) which is partly based for the update of the Thames Barrier in London on climate change, hence Rosenzweig et al. [15]. The goal of this approach is to enhance climate change responses as understanding of climate change and that reflect local, regional, national and global economic and social conditions.

RESULTS

Aerts et al. [7] conclude that for the most extreme storms (probability<1/5000) the total damage varies roughly between US$ 14bn and 26 bn. The total damage caused by a 1/100 year storm (the design frequency applied for engineering features in the US), is US$2 bn to US$5 bn. Furthermore for a 1/500 year storm, the estimaties lie within US$5 bn to US$11 bn. According this research, Brooklyn and Queens are the most vulnerable areas. When analyzing the damage in the FEMA 1/100 and 1/500 surges, the damage increases relatively quickly in Brooklyn and Queens. This implies that quite a few buildings in these boroughs, which are currently in the 1/500 year flood zone, are located in the potential future 1/100 year flood zones due to for instance sea level rise. Flood-risk management policies could be first prioritized to these areas. The Jamaica Bay is one of these areas, hence Aerts et al. The expected annual damage for New York City lies between US$59 to US$129 million per year. Although climate change will exacerbate existing urban challenges and environmental stressors, it also provides an opportunity for cities like NYC by encouraging infrastructure investments and improving urban planning and regulation.

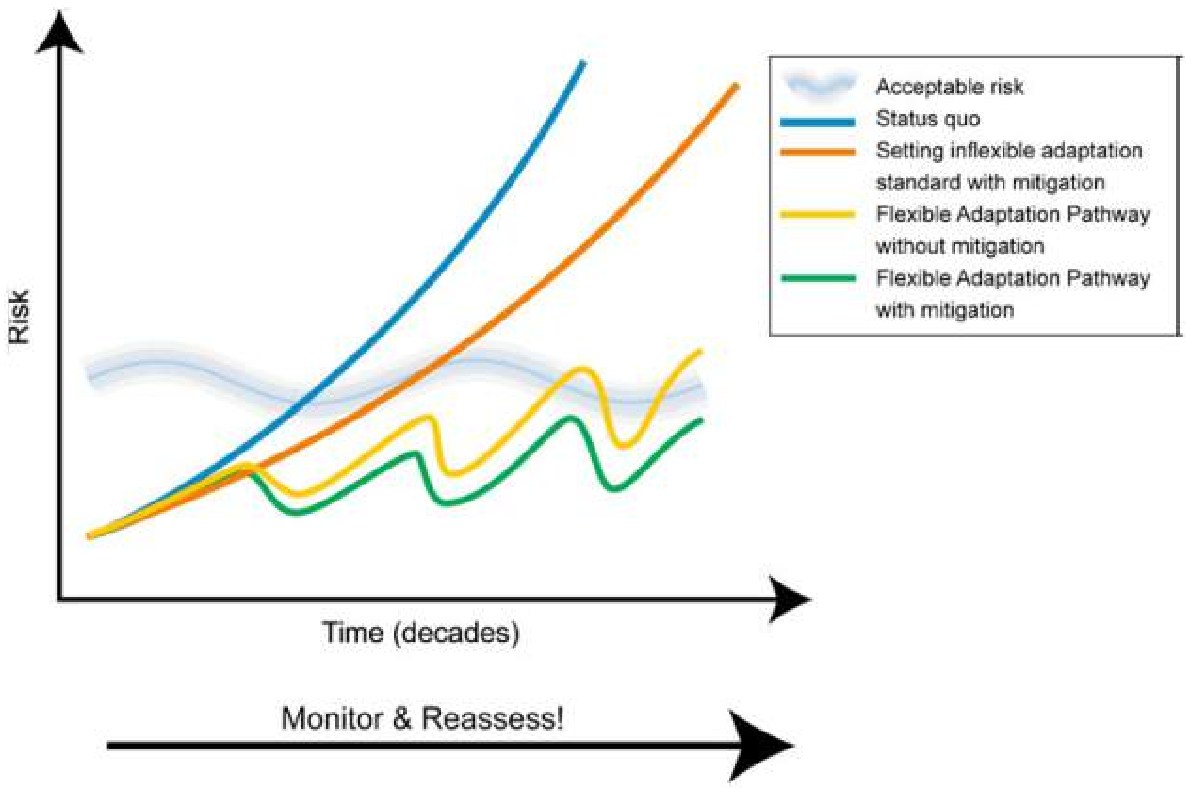


Figure C.31: The Flexible Adaptation Pathways Approach

C.5. HURRICANE SANDY

C.5.1. OCTOBER 29, 2012

Sandy made landfall in New Jersey in the evening of October 29, 2012. The consequences were devestating: 43 deaths, 90000 buildings in the inundation zone, 2 million people without power, 11 million travelers affected and $19 billion in damage. Based on measures done, Sandy was an event for NYC which was never recorded in its history. Until the arrival of Sandy, Hurricane Katrina was the most recent hurricane that struck NYC. Sandy was in many ways distinct from Hurricane Katrina in 2005. In figure C.32 the size and windspeed are compared. The timing of the storm was an important factor regarding the size of the storm. This implies that

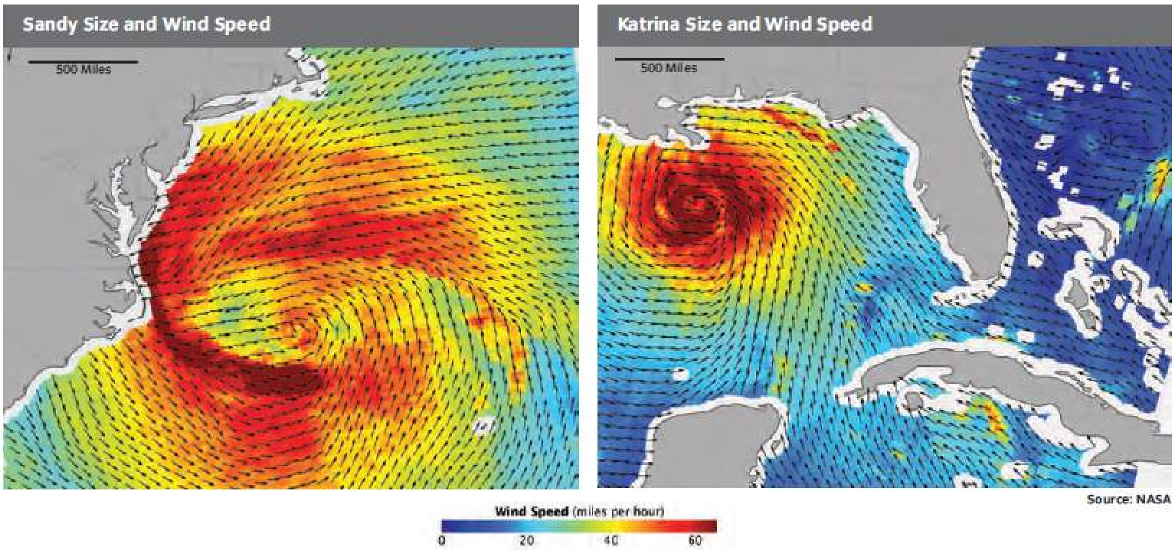


Figure C.32: Comparison between wind speed and size during Sandy and Katrina

the hurricane hit the shore almost exactly at high tide during full moon, when the tide was the highest of its monthly cycle (spring tide). Besides the timing, the storm's size was enormous. Like stated in PlaNYC (2013) [2], when Sandy made landfall, its tropical-storm-force winds extended 1000 miles from end to end, making it more than three times the size of Hurricane Katrina. The storm size, defined as the area over which strong winds blow, is closely related to the height of the storm surge. Storm surge is defined as an abnormal rise in sea level accompanying a hurricane or other intense storm wand whose height is the difference between the observed level of the sea surface and the level that would have occured in the absence of the strom (US Department of Commerce (20120) [89].The resulting rise in water level are caused by the storm's low pressure and the force of the wind pushing against the water. The winds cause the water to pile up and become trapped along the coast, bays and harbors. Sandy created a massive surge of 14 feet (4.27 m) above MLLW (see figure C.33), furthermore, a very high wind set up was created due to Sandy's path. Sandy's path was very unusual. In general the wind had been blowing in a southward direction in NYC. However, as Sandy made landfall, the wind direction shifted to a northwesterly direction. This shift increased the storm surge. Furthermore, some areas of the coast were hit by waves, reported to be 12 feet high or more, and experienced flooding, while other areas only experienced flooding (PlaNYC (2013) [2]). After landfall, Sandy weakenend while moving over the US. After hitting respectively southern New Jersey, northern Delaware and southern Pennsylvania it finally lost its defined center while passing over northeastern Ohio late on October 31.

C.5.2. DAMAGE

Some coastal features in the NYC area did offer some protection. However, many of those feature were not purpose-build but did offer protection coincidentally, hence PlaNYC (2013). Many features have been engineered with recreational goals in minds, for example recreational beaches which are nourished over time, though they also provided important protection for adjacent neighborhoods. Never had a storm causes so much damage to NYC. In general, Sandy's coastal inundation took one of three forms. First, floodwaters came directly from the ocean which deluged beaches, bulkheads and other critical infrastructure. The second way Sandy's surge impacted the city was via less direct routes. This means that many bays, inlets and creeks functioned as 'backdoor' channels, funneling ocean waters inland. The third way was by overtopping

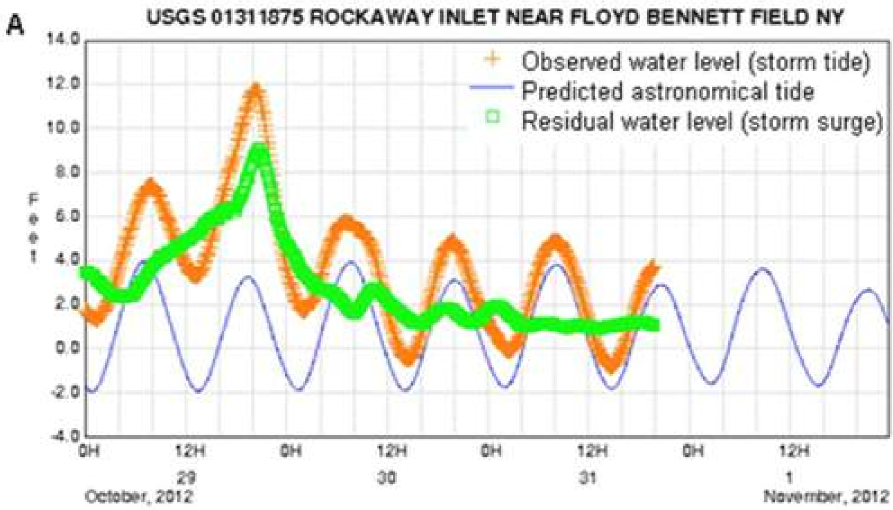


Figure C.33: Water levels at Rockaway Inlet near Floyd Bennett Field during Hurricane Sandy (Simonson (2013))

the city's extensive shoreline drainage infrastructure, especially in low-lying areas.
Although Sandy affected neighborhoods all across NYC, the ocean-facing areas situated in the southern part of the city were particularly struck hard by Sandy. One of these areas is South-Queens. The area that inundated during in South Queens is illustrated in figure C.34. The above described (three) forms of inundation

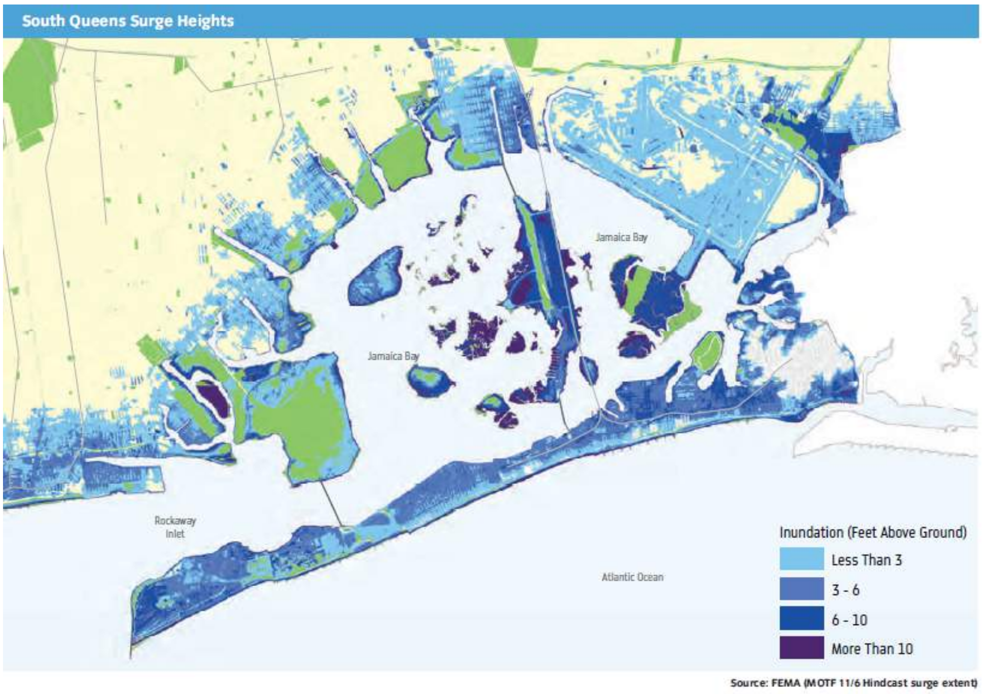


Figure C.34: Surge levels at South Queens

can also be applied to the Jamaica Bay/South Queens area. First, areas flooded when huge waves struck the sea side of the Rockaway Peninsula. Those waves broke behind the neighborhoods behind the beaches. Second, floodwaters were pushed through the Rockaway Inlet into the Jamaica Bay, subsequently followed by the tributaries and channels around the circumference of the Bay. During the last phase, inundation entered areas through low-lying drainage infrastructure that never was designed to face flooding of this magnitude (PlaNYC (2013) [2]). The inundation is shown in figure C.35. The result was a lot of devastation, i.e. build-

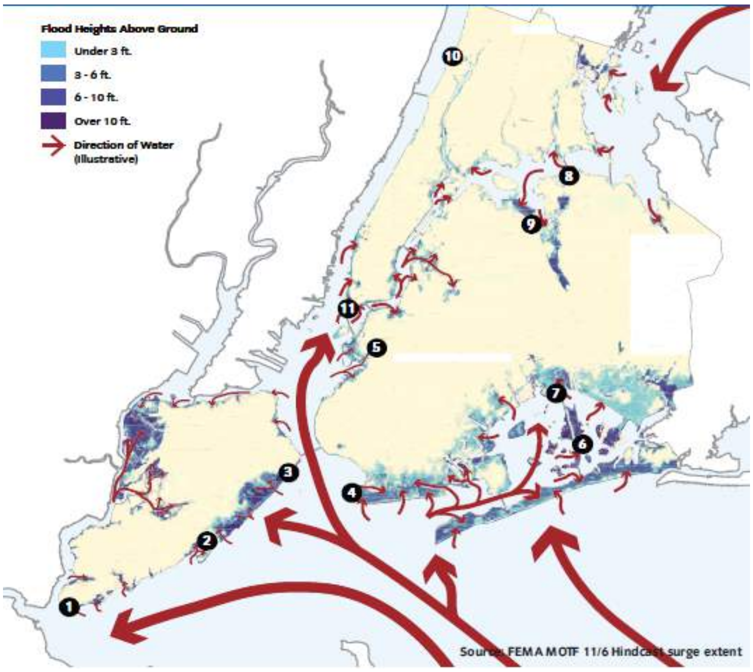


Figure C.35: Sandy Inundation

ing damage, power and transportation outages, disruptions in other services, financial hardship for many residents, businesses and nonprofits. For example, the storm damaged a large part of the board walk situated at the Peninsula. Furthermore, retreating water and waves resulted in coastal erosion. Some houses were pushed right off their foundations, basements were filled with floodwater and electrical systems were ruined. The inundation was about 3 to 10 feet. Fires, due to the storm, destroyed more than 100 of the lost homes and businesses. The neighborhoods on the Rockaway Peninsula experienced a difference in damage caused by the storm. In general, compared to other neighborhoods, Far Rockaway flooded minimally due to its higher elevation and the fact that a part of the coastline is protected by Long Beach. Furthermore damage was mitigated in large sections of Arverne By The Sea, where the dune system on the beach in front of the neighborhood reduced the wave energy, while the elevated site and special drainage features in the development kept most housing units free of water. On the other hand, in Rockaway Park and Rockaway Beach the surge waters spread throughout the area, resulting in significant damage. Furthermore Broad Channel, situated at low-lying area in the middle of the bay, suffered from Sandy's surge. After a year one can still notice the damage caused by the hurricane, see figure C.36. PlaNYC declares that after the storm, the New York City Department of Buildings (DOB) sent out inspectors to assess damages in South Queens and other inundated areas of the City. These inspectors tried to categorize the damage. Green tags indicated less serious damage or no damage, yellow tags indicated that portions of buildings might be unsafe or might have non-structural damage and red tags illustrated structural damage. The results are shown in figure C.37.

C.5.3. RESPONSE TO THE STORM

In response to the forecasted landfall of hurricane Sandy, personnel from the U.S. Geological Survey (USGS) installed storm-tide sensors along the eastern seaboard from Virginia to Maine. The New York Water Science Centre places 38 storm-tide sensors, 4 wave-height sensors, 11 barometric-pressure sensors and 4 rapid-deployments gages throughout Long Island, New York City and Westchester County (Simonson (2013) [90]). The Federal Emergency Management Agency (FEMA) responded with 1500 personnel on the ground along the East Coast to monitore the storm. According to PlaNYC (2013) [2] taught Sandy's magnitude, its effects on so many parts of the city and the threat of ever greater risks from climate change in the future, an important lesson: the city needed to redouble their efforts.

Figure C.36: Sandy damage at Broad Channel; houses were pushed right off their foundations

Figure C.37: Location and level of building damage

C.6. CONSIDERED COASTAL MEASURES

This chapter will discuss the considered measures in a general way, section C.6.2 will discuss the measures for the inner Bay and section C.6.3 will do the same for the Atlantic side of the Rockaway Peninsula. Also cost estimates will be given. A more detailed elaboration can be found in another section of this report.

C.6.1. GENERAL

One can say that New York City's coastline does not have coastal protection measures and that the features that are there, are coincidentally and not designed for that matter (PlaNYC (2013) [2]).

According to Waterway et al. (2011) [32], shoreline protection can be divided into two main categories: "hard" and "soft" measures. Soft measures consist mainly of beach renourishment, dune construction and living shoreline and hard measures include mainly of vertical bulkheads, seawalls, rock revetments and gabion structures. Another difference can be made: the difference between shoreline defense mechanisms and process altering structures. Process altering structures are designed to change the nature coastal processes, consisting mainly of groynes, jetties and breakwaters.

C.6.2. INNER BAY

In this section the considered measures for the inner bay will be discussed. The inner bay is defined here as the inlet, the banks of the bay and the marsh islands. Most of the land within Jamaica Bay is low lying. This results from the end of the last Ice Age when there were glacial outwash plains. Within the Bay there are shorelines that have been filled in and hardened with bulkheads and revetments (PlaNYC (2013) [2]).

IMPROVING/DESIGNING LEVEES

Aerts et al. (2013) [12] distinguish three different types of dikes in relation to costs:

Earth Filled and Armored Levees in High-Density Urban Areas

They define a dike as "an earth-filled levee body with a seal of stone or asphalt". The difference with between an earthen and a reinforced dike is that the reinforced dike consists of horizontal earth layers wrapped with steel sheet piles or woven geotextile for extra support. The costs for a complete new, 30 ft. hurricane levee in water for New Orleans are approximately $ 40 to $ 85 mln/km. Furthermore annual maintenance costs are about $ 0.14 mln/km[1] in the Netherlands.

Filled Levees in Low-Density Urban Areas

Low density urban areas can be protected with a combination of relatively cheap earth filled levees. The costs for this type of dike is estimated to be $ 10 mln/km.

Mix of Levees and Landfill in Medium to Highly-Urbanized Areas

For a medium to high urban density area the costs are estimated to be relatively high with $ 50 mln/km, because of high land prices.

ELEVATED HOMES

Increasing resilience of buildings and infrastructure by implementing stricter building codes could lower the flood damage, while areas of the city are still flooded. This could be applied in the 1/100 flood zones, classified by FEMA, and maybe also in the 1/500 flood zone to anticipate climate change. Furthermore, these investments would add value to the city (Aerts et al. (2013) [12]). Another possibility might be to build residential buildings that function as a coastal protection system. This could be a solution for the reduction of flood risk in highly urbanized areas (Van Rooijen (2013) [91]). Elevated homes could not only mitigate future flood risks, but could also make flood insurance premiums more affordable for homeowners (Hurricane Sandy Rebuilding Task Force (2013) [92]).

BULKHEADS AND SEAWALLS

The main difference between bulkheads and seawalls is that bulkheads are mainly designed to retain upland soil and seawalls are also designed to protect uplands from direct impact of waves (Waterway et al. (2011) [32]). Aerts et al. (2013) [12] distinguish three different types of bulkhead structures: 1) Floodwalls ranging from 7,874 €/m[1] (7 ft. L-wall) to 41,339 €/m[1] (30 ft. L-wall), 2) Retrofitting bulkheads in high density urban areas with a unit cost ranging between $ 10 and $ 41 mln/km[1], depending on the urban density of the area and 3) Mixed highway and floodwall in high-density urban areas with a unit cost price of $ 70 to $80 mln/km[1]. The last measure creates a road on top of a levee, this road is on stilts so the is space underneath the road for with can be used for other purposes, e.g. parking. Waterway et al. (2011) [32] estimate the costs for vinyl and timber bulkheads to be $ 115 to $ 285 per foot and for local commercial reinforced concrete or steel sheetpile bulkheads to be $ 2,500 to $ 4,000 per foot. See figure C.38 for an impression of a bulkhead

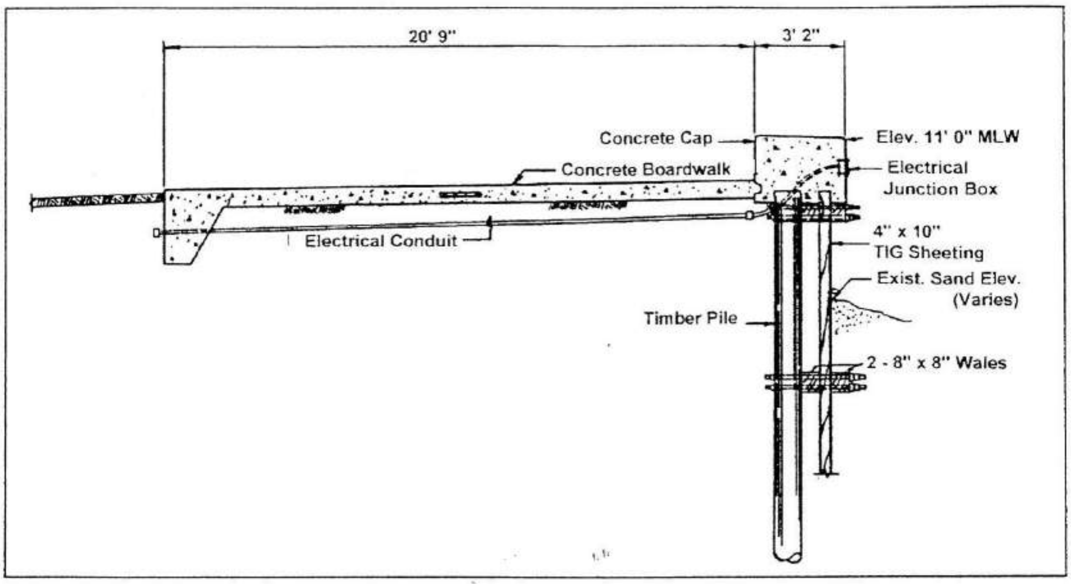


Figure C.38: Impression of a bulkhead (Waterway et al. (2011))

LIVING SHORELINES

Living shorelines can be seen as a composite strategy. On one hand they can provide protection and on the other hand it is possible to maintain or create natural habitats in the shore zone. Usually this system consists of natural vegetation, sand and rock. Vegetation functions as a habitat, has water quality benefits and helps preventing erosion. Normally also beaches and dunes are created and some sort of rock breakwater or sill is needed to maintain the system (Waterway et al. (2011) [32]). Figure C.39 shows what a living shoreline could look like.

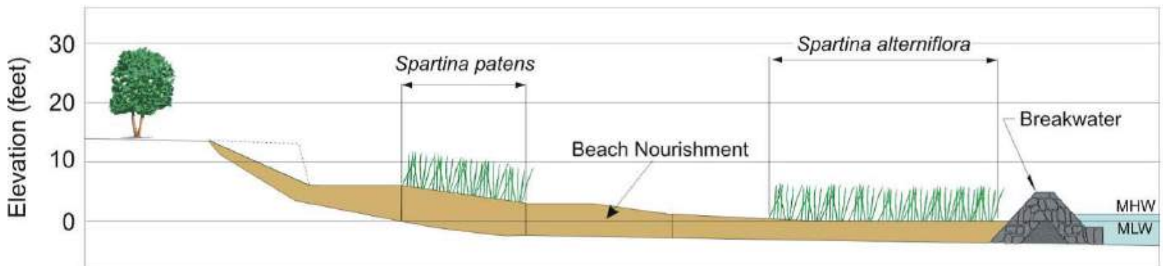


Figure C.39: Impression of a living shoreline (Waterway et al. (2011))

RESTORATION OF THE BAY

With "restoration of the bay" we mean the restoration of the ecological state of the bay. The bay is an important ecological area within the City of New York and was the US's first national urban park (U.S. Army Corps of Engineers (2009) [81]). They state that research shows that the marshes have degraded 44 acres/year between 1994 and 1999 and 33 acres/year between 1989 and 2003. About 50% of the surface area of the salt marshes have disappeared since 1900 (Aerts et al. (2013) [12], Gornitz et al. (2001) [82]). Restoration of the marsh islands and banks has an enormous potential for restoration and creation of habitats (U.S. Army Corps of Engineers (2009) [81]). According to U.S. Environmental Protection Agency (2006) [93] wetland restoration has been done for several reasons within the United States. It states that wetlands can help lowering flood heights and reduce the water's destructive potential. But it also says that the effectiveness may vary for different locations, depending on a number of things like size of the area, vegetation and location of the wetlands. See figure C.40 for restoration opportunities defined by the USACE. The two most effective features for mitigating floodrisk in this way would probably be the smaller prism because of restored marshes and the shortening of the fetch length. A smaller prism means that less volume of water will flow into the bay (Bosboom & Stive (2013) [33]). A shortened fetch length will decrease wave height and set up within the bay (Holthuijsen (2009) [57]). Furthermore the increased roughness of the bay could play a role.

For current projects on marsh island and bank restoration see subsection C.3.4.

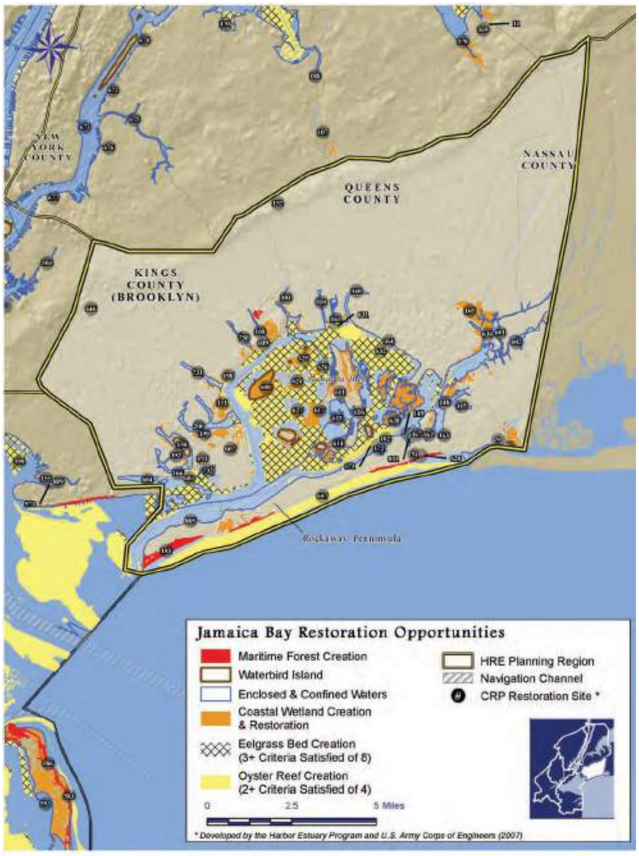


Figure C.40: Jamaica Bay restoration opportunities (U.S. Army Corps of Engineering (2009))

GEOSYNTHETIC TUBES

Geosynthetic tubes are usually filled with either sand, silt or jetted concrete. The tubes have multiple uses like groynes, retaining walls or as a stable core for dune or wetlands and beaches. A big advantage is that the use of geosynthetic tubes lowers contruction cost in comparison with similar structures that use a quarry stone and they are also often easier to place and fill. Some disadvantages are that they do not work in high energy areas and that they are sensitive to ultraviolet degradation, tearing and vandalism. Without repairs the tubes do not function anymore. Geosynthetic tubes have been used as base for dunes along the Salt Ponds public beach in the summer of 1998. The dunes were stabilizes with the use of American beach grass. During Hurricane Isabel these tubes performed very well, and since the placement of the tubes there have not been wave damages along the Salt Ponds Beach (Waterway et al. (2011) [32]). Figure C.41 shows what a dune with a geosynthetic tube base could look like.

Cost estimates for the use of geosynthetic tubes are about $ 250 to $350 per foot (Waterway et al. (2011) [32]).

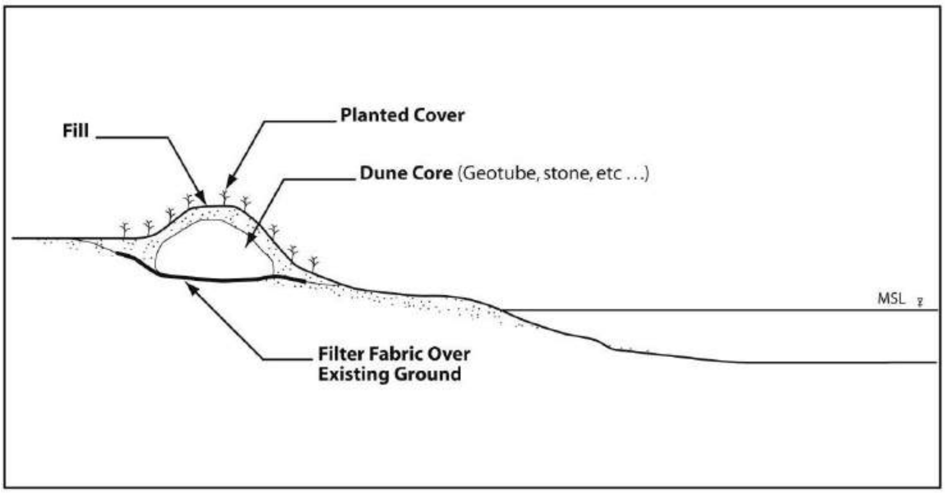


Figure C.41: Impression of a dune with a geosynthetic tube base (Waterway et al. (2011))

C.6.3. OUTER BAY

According to PlaNYC (2013) [2] the ocean side of the Rockaways consist of gently sloping sandy beaches and some built and natural dunes.

BEACH NOURISHMENT

The City of New York (2009) [8] has defined several Coastal Erosion Hazard Areas (CEHAs) within New York. Figures C.42 and C.43 show the CEHAs in respectively Brooklyn and Queens. As can bee seen from this pictures the whole Atlantic side of the Rockaway peninsula is subjected to erosion as well as parts of the Jamaica Bay inlet. They state that about 0.7 % of New York City's land area is situated withing a CEHA, this is approximately 1,427 acres. The total value of buildings located in a CEHA is about $ 24 million for the Brooklyn area and about $ 49 million for Queens. Aerts et al. (2013) [12] state that most of the Long Island south shore has been subject to erosion and restoration of this coast is estimated to cost $ 42.4 million for 5.8 km shoreline.

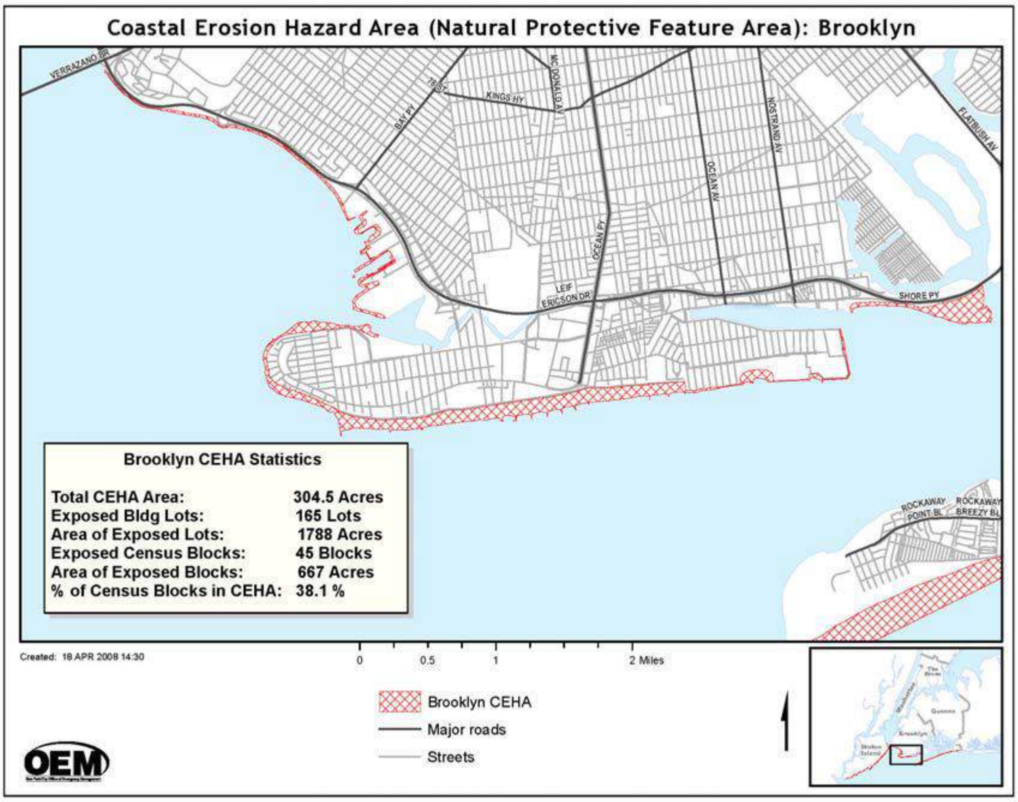


Figure C.42: Coastal Erosion Hazard Areas within Brooklyn (The City of New York (2009))

One of the ways to cope with this problem is the use of beach (re)nourishment. By adding sand to the area the shoreline is restored and the beach increases in height and width (Waterway et al. (2011) [32]). Effects to other, adjacent areas are negligible and environmental impacts are also minimal. The costs for beach nourishment vary and are dependent on several aspects, e.g. material and location. The costs for beach fill in the Hamptons varied from 7.50 $/cy to over 10 $/cy. An impression of a typical beach nourishment can be seen in figure C.44.

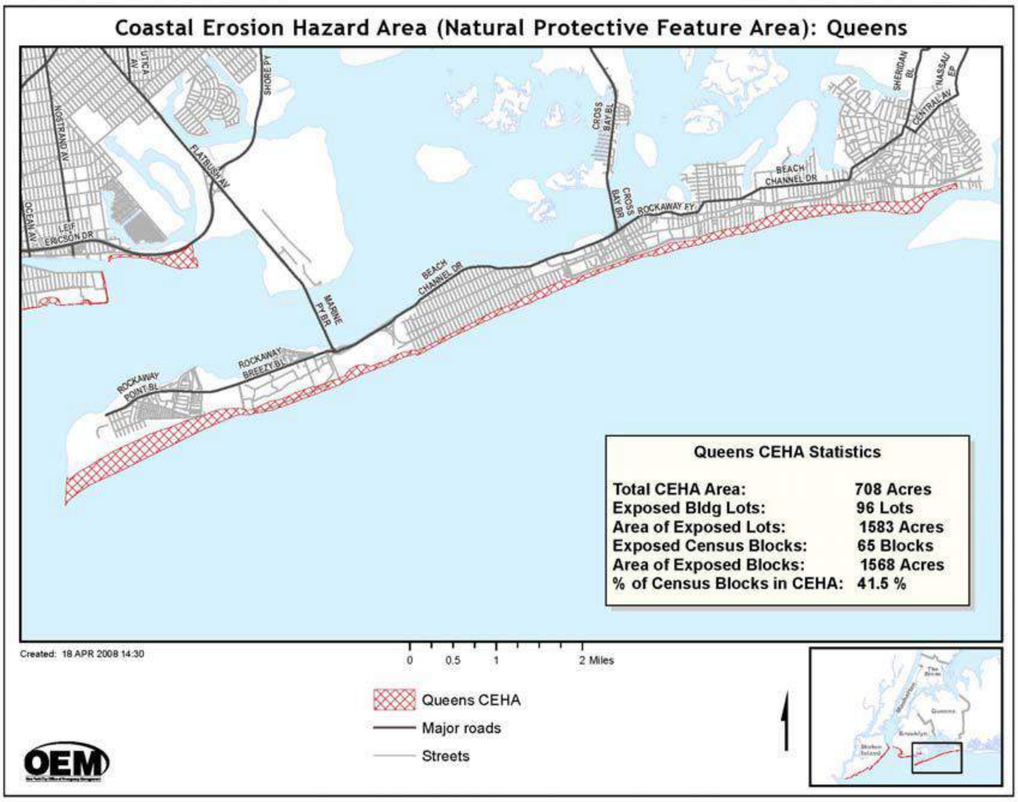


Figure C.43: Coastal Erosion Hazard Areas within Queens (The City of New York (2009))

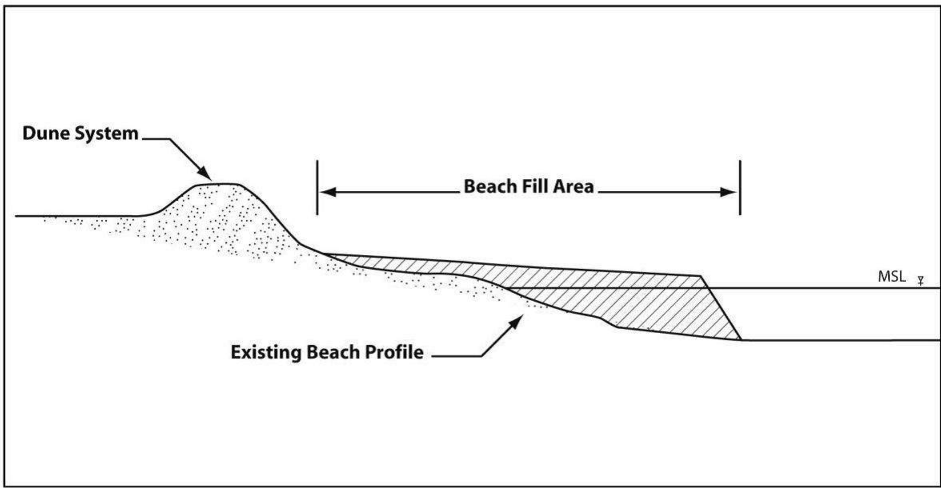


Figure C.44: Impression of a beach nourishment (Waterway et al. (2011)

GROYNES

In addition to beach nourishment, structures like groynes, can help stabilize the beach and prevent the beach from eroding. A typical disadvantage of groynes is that they directly impact sediment flows and with that have a big influence on the downstream situation. Usually there is erosion due to lack of sediment just behind the last groyne. A groyne like structure stops the longshore sediment transport, this means that accretion will take place at the updrift side of a groyne because of additional sediment. At the downdrift side of a groyne there will be less sediment and erosion will take place. See figure C.45 for an illustration of groynes. Groynes are only useful if there is enough longshore sediment transport, if there is nog longshore sediment transport the groynes will not capture sand (Bosboom & Stive (2013) [33]).

According to Waterway et al. (2011) [32] the costs for timber groynes are between 350 and 450 $/foot[1]. This means that a single 300-foot timber groyne will cost about $ 105,000 to $ 135,000. They also state that the costs for a rock jetty with a sectional height of 8 ft. and a crest that is 20 ft wide is about 2000 to 2500 $/foot[1]. Jetties are groyne like structures used to stabilize inlets.

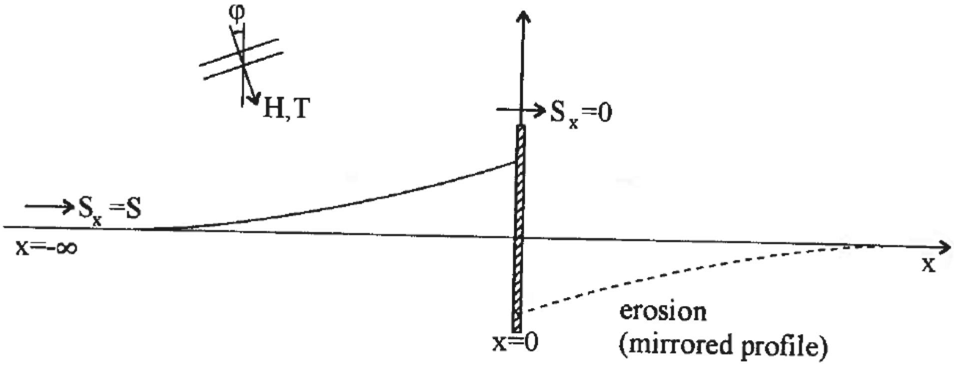


Figure C.45: Illustration of the working of groynes (Bosboom & Stive (2013))

OFFSHORE BREAKWATERS

Another name for offshore breakwater is detached breakwater. An offshore breakwater will reduce the wave activity in the wave shadow zone, behind the breakwater and at the shore. This reduction in wave energy results in a reduction of sediment transport capacity and material brought to this location will be deposited over here. In very specific circumstances a tombolo can be created in this way. In the early stage, when the sand does nog reach the offshore breakwater (yet), it is called a salient. This tombolo then completely blocks the longshore sediment transport. One of the uses of this shadow effect of an offshore breakwater is the preservation of recreational beaches (Bosboom & Stive (2013) [33]). An impression of a tombolo and a salient behind an offshore breakwater can be seen in figure C.46.

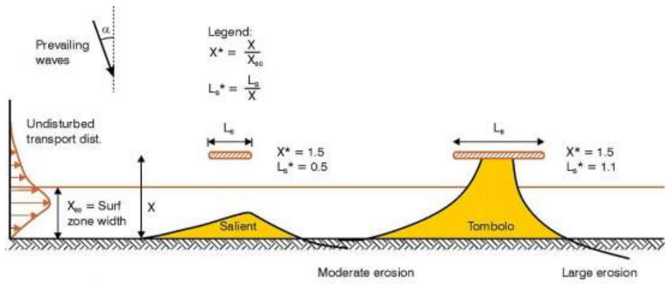


Figure C.46: Illustration of the working of offshore breakwaters (Bosboom & Stive (2013))

DUNES

Sand dunes can be natural or handmade and consist of mounds of sand separating the active beach and the hinterland. They can work as a barrier protecting the hinterland during high waters and they nourish the beach when they are eroding. Sand dunes are considered to be soft shoreline stabilization. Dunes can be of just sand but can also be constructed with the help of a hardened core such as geosynthetic tubes and rock. A hardened core can provide an increased storm surge protection and still give a natural look. Dunes with a geosynthetic base were constructed in 1998 at Salt Ponds. The tubes were covered with sand and vegetation (Waterway et al. (2011) [32]).

During a storm dune erosion will take place if the water level increases and the waves can hit the dunes. Due to a strong undertow, sand from the dunes is transported offshore. Offshore the transport capacity of the water goes down and the sand settles ending up with a new coastal profile that is better suitable for storm conditions. Because this new coastal profile is much more effective in dissipating wave energy, dune erosion rates will decrease during the storm. Using Bruun's rule, a first-order magnitude estimate of dune retreat can be found. When the storm is gone the beach is much wider and is not in equilibrium anymore with the post-storm conditions. If there is no or little longshore sediment transport, waves, tide and wind will reshape the foreshore and dunes. This growing of the dunes and foreshore takes a lot more time then the erosion does. A submerged offshore breakwater can help save the sand for the beach and not letting it get to far offshore (Bosboom & Stive (2013) [33]. An impression of this dune erosion can be found in figure C.47.

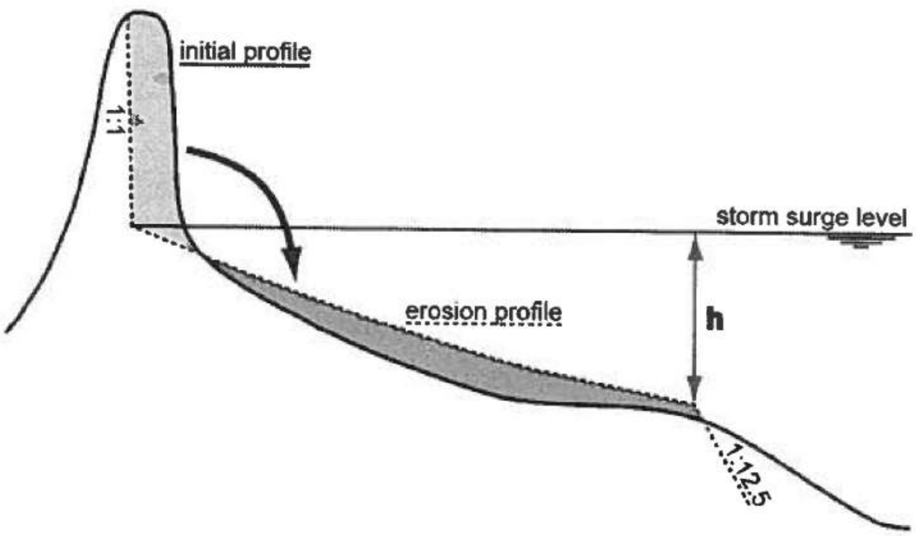


Figure C.47: Impression of dune erosion and (Bosboom & Stive (2013))

C.7. FLOOD RISK MITIGATION IN THE US

C.7.1. DIFFERENT WAYS OF FLOOD RISK REDUCTION

When living in areas close to the sea, flood risk mitigation is an essential part of communities. Inundation is an unwanted happening, however it can not be excluded.

LAYERS OF SAFETY

According to an article [94] of Rijkswaterstaat (Executive Body of the Dutch Ministry of Infrastructure and the Environment), in general there are three layers of safety: prevention, robust urban planning & disaster management.

Prevention

The first layer comprises the prevention of inundation. In some countries this includes laws about design direction to keep water away. In other countries local communities surround their village with levees and in some neighborhoods houses are individually elevated.

At the Jamaica Bay area, both individual and public efforts are used as a way to prevent inundation. At Broad Channel homes are elevated by their owners, where at the Atlantic side of the Rockaway Peninsula the United States Army Corps of Engineers (USACE) use beach nourishments.

Robust Urban Planning

Not only the ocean can be a threat. Also inland water issues can cause or enhance inundation. Robust urban planning consist of water control systems that consider issues like water storage in urban environments and rainwater runoff.

In New York City, the Department of Environmental Protection (DEP) is in charge of ensuring water quality and in charge of water management within New York City. At the Rockaway Peninsula, the DEP is currently constructing storm drains to drain heavy rainfalls.

Disaster Management

The third level of safety involve the mechanisms and coordination of hazard programs. It focuses on the scenario where the flooding is already ongoing. Evacuation is an important measure.

The New York City Office of Emergency Management provide the Hurricane Evacuation Zones (Aerts et al., 2012)[7]. These zones show that large parts of the city are potentially vulnerable to surge flooding. However, according to PlaNYC (2013)[2], in some cases the efforts of the over a dozen City, State and Federal agencies involved were not completely aligned.

DISASTER RELIEF APPROPRIATION ACT

Although in different areas different types of flood risk mitigation is preferred, most communities are involved in all of the three layers. In the Jamaica Bay area the DEP, the USACE and the Port Authority (PA) are the primary actors regarding preventing inundation. When looking at robust urban planning, the DEP and the PA take care of managing the infrastructure and several different agencies coordinate evacuation and disaster management.

In 2013 President Obama signed a Disaster Relief Appropriation Act that established guidelines for the investment of federal funding (Hurricane Sandy Rebuilding Task Force, 2013[92]). The act involved 50 billion dollars in funding and most important is to align funding with local rebuilding visions. It supports the local governments in identifying opportunities to work with potential partners. Also rebuilding the region in a way that makes it more resilient is important. This means that the area would be better able to withstand future storms and other risks posed by a changing climate. The report also states that infrastructure investment should be done on a regionally coordinated, resilient approach. Homeowners should be encouraged to take steps to mitigate future flood risk, such as elevating their homes, which will both protect their homes against future storms and make their insurance more affordable.

C.7.2. FLOOD MAPS

Since 1983, in order to reflect the New York City vulnerability to coastal storms, the Federal Emergency Management Agency (FEMA) produces flood maps (PlaNYC, 2013[2]). These FEMA maps are also used as a guideline of the New York City building codes, and describe the Federal Government's assessment of flood risk. An area that has a 1 percent or greater chance of flooding in any given year is called a 100-year floodplain. Similarly, an an area that has a 0.2 percent or greater chance of flooding in any given year is called a 500-year floodplain. So there is a 1% chance per year of flooding in the 100-year floodplain. The following calculation reveals the problem. The average life expectancy of a New Yorker is 80.9 years, the probability of facing a 100-year flood is therefore:

$$P_f = 1 - (1 - P_f/year)^{lifetime} = 1 - (1 - 0.01)^{80.9} = 0.5565 = 55.65\% \quad (C.1)$$

In other words, a child born today has a probability of 56% to face a 100-year flood within her lifetime (without the current sea level rise projections).

SIZE OF FLOODPLAINS

A floodplain is an area susceptible to being inundated by water from any source. The FEMA maps mark the two floodplains, and within the 100-year floodplain, different zones of vulnerability are defined. These different zones of vulnerability include areas that generally require flood-protective construction standards. PlaNYC (2013)[2] states that the oldest FIRMS, created in 1983, show that a full 33 square miles of NYC, almost half of Brooklyn are within the equivalent of the 100-year floodplain. In 2010, there were about 218.000 inhabitants of New York living in those areas. Moreover, the entire wastewater treatment infrastructure is situated in the 100-year floodplain and almost half of all the power plants (12 out of 27). These power plants represents 37 percent of the city's generation capacity.

Although the maps are a good way of assessing flood zones, according to Aerts et al.(2011)[95], climate change and other future developments are not addressed in the FEMA maps. Also according to PlaNYC (2013)[2], the City and FEMA knew that flood maps did not adequately represent New York City's risk. Although the New York City shorelines were changed significantly, since their introduction in 1983, all changes to the maps were minor. In addition, sea levels continued to rise and more accurate mapping techniques were developed. Also, an addition 30 years of storm surge data were available.

INSURANCE

The FEMA maps are called Flood Insurance Rate Maps (FIRMS), and they are used by the National Flood Insurance Program (NFIP) to require buildings within the flood zone to incorporate different measures, like obliging flood insurance when applying for a mortgage. The NFIP creates national building design and construction standards for new construction and improvements of the buildings in these hazard areas. NFIP monitors those standards and only provides flood insurance coverage to those who adopt and enforce floodplain regulations that meet the NFIP criteria.

Pre Sandy Insurance

In October 2012 when Sandy struck the city of New York, according do PlaNYC (2013)[2], most of the property owners who suffered damage did not have adequate flood insurance. The report states that the owners were probably unaware of the risk that faced and were not obliged by law to have insurance. Even many people living in the 100-year floodplain were not insured for flood damage. Less than 50 percent of houses situated in the 100-year floodplain were insured. In most cases, the law that required the owners to have insurance was not enforced or the owners did not have mortgages at all.

UPDATING FLOOD MAPS

In 2007, to adequately reflect New York's risks the City requested FEMA to update its flood maps. This process was started in 2009. Hurricane Sandy showed the importance of updating the FEMA maps. The timeline of all the different processes regarding flood maps are illustrated in figure C.48.

PlaNYC (2013) revealed that the area that flooded during super storm Sandy was more than one and a half times larger than the 100-year floodplain defined at FEMA's 1983 FIRMs. The areas outlined on the maps were much smaller than the areas that inundated during Sandy. In figure C.49 the area that inundated during Sandy and the area outlined in the 1983 FIRMs are compared.

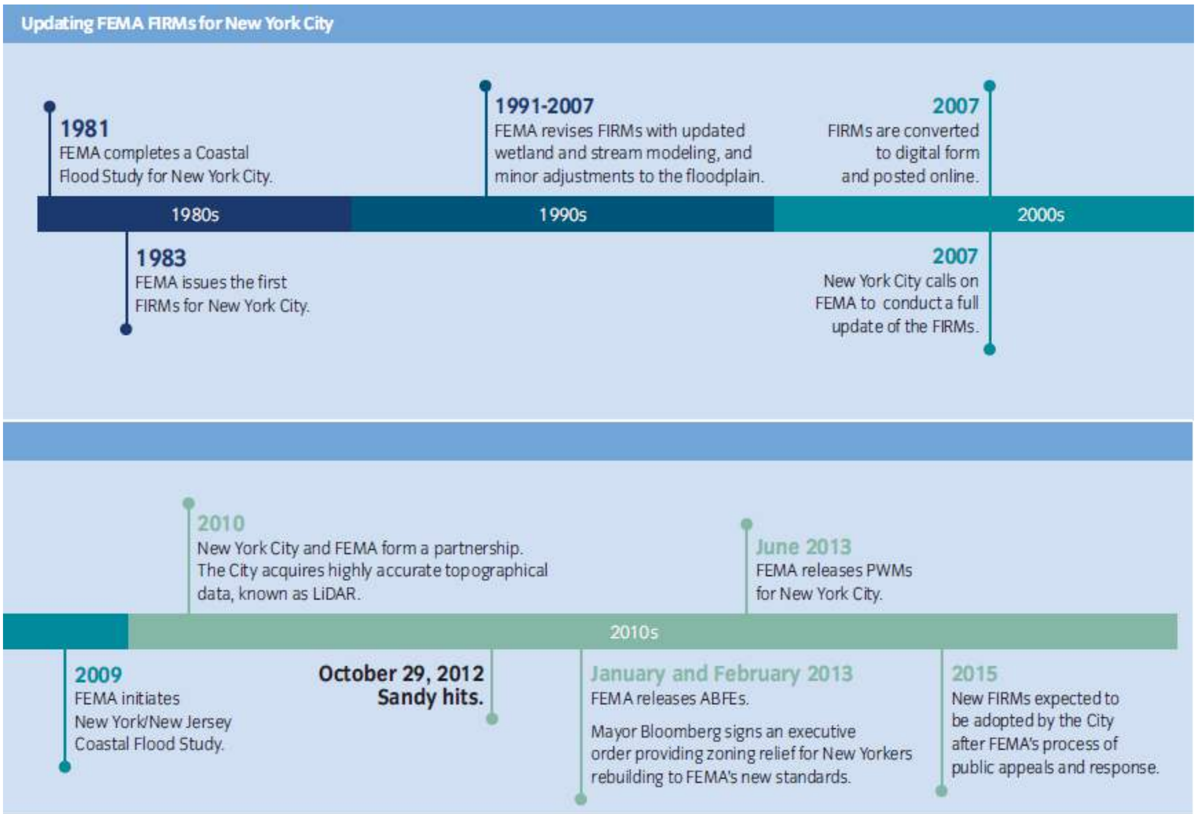


Figure C.48: Timeline flood maps

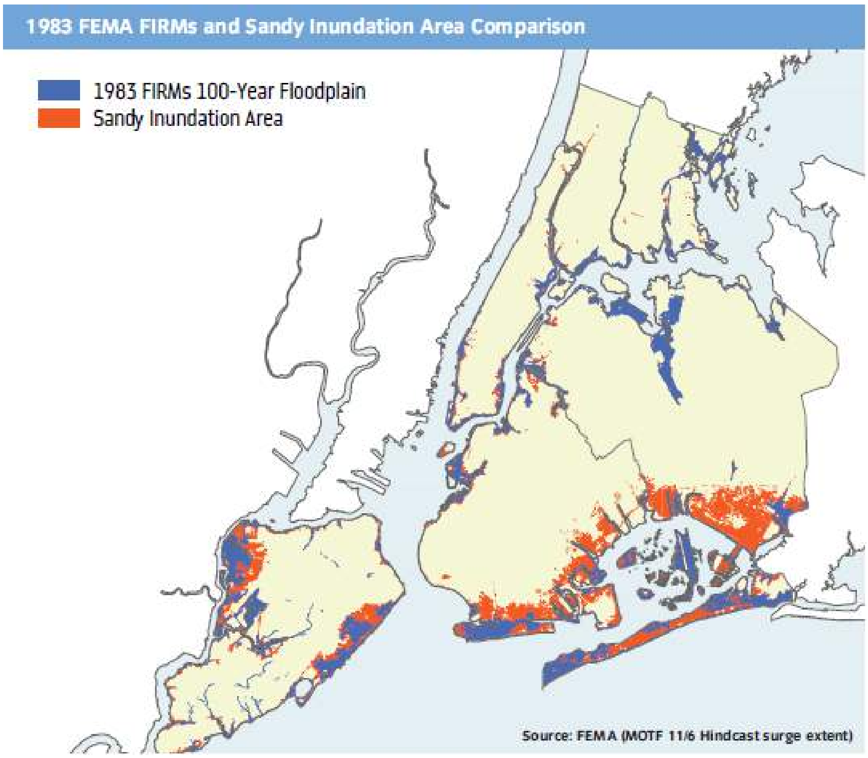


Figure C.49: Compared: 1983 FIRMs and the Sandy flooded areas, PlaNYC, 2013

Until recently the 1983 FIRMs were the best flood maps available, however, in June 2013 FEMA released projections reflecting on the 100-year floodplain for both 2020 and 2050, see figure C.50. These projections expand the city's 100-year floodplain by 18.8 square kilometers or 45 percent over the 1983 maps. By 2050 the maps are projected to cover 186.5 square kilometers or 24 percent of New York City's land area. These two projections include sea level rise. However, this is not an official FIRM.

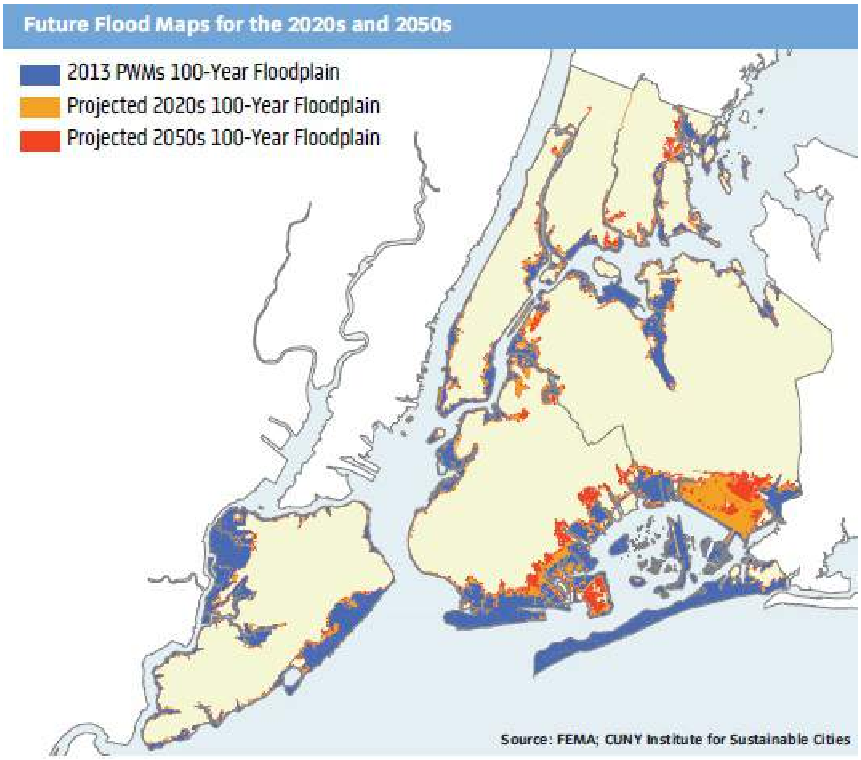


Figure C.50: 2020 & 2050 FEMA projections, PlaNYC, 2013

FEMA also issued the Preliminary Work Maps (PMWs) for NYC that incorporated more accurate wave modeling. The PWMs are intended to help communites and property owners understand current flood risk and likely flood insurance requirements in the future. Communities have to use the preliminary work maps as the best available flood hazard data when making decisions related to floodplain management and post-Sandy recovery efforts, hence FEMA. The PWMs are an interim step in the process of the development of preliminary FIRMs (releases by the end of 2013). After an appeals period the preliminary maps will be review and released before the issuance of effective (new) FIRMs. The final FIRMS are likely released in 2015. The PWM is shown in figure C.51. In their official documentation FEMA does not take sea level rise into account.
The flood zones shown on the maps are geographic areas classified according to levels of flood risk, with each zone reflecting the different risks. The different zones are stated in the following table.

1. Different zones
   (a) V-Zone: an area of high flood risk subject to inundation by the 1% annual chance flood event with additional hazards due to storm-induced velocity wave action (a 0.90 or higher breaking wave)
   (b) Coastal A-Zone: an area of high flood risk subject to inundation by the 1% annual chance flood event determined by detailed methods
   (c) A-Zone: an area of high flood risk subject to inundation by the 1% annual chance shallow flooding where average depths are between one and 0.90 meter. Average flood depths derived from detailed hydraulic analyses are shown in this zone
   (d) Shaded Zone X: areas of moderate coastal flood risk outside the regulatory 1% annual chance flood up to the 0.2% annual chance flood level

The zones are also illustrated in figure reffig:Zones.

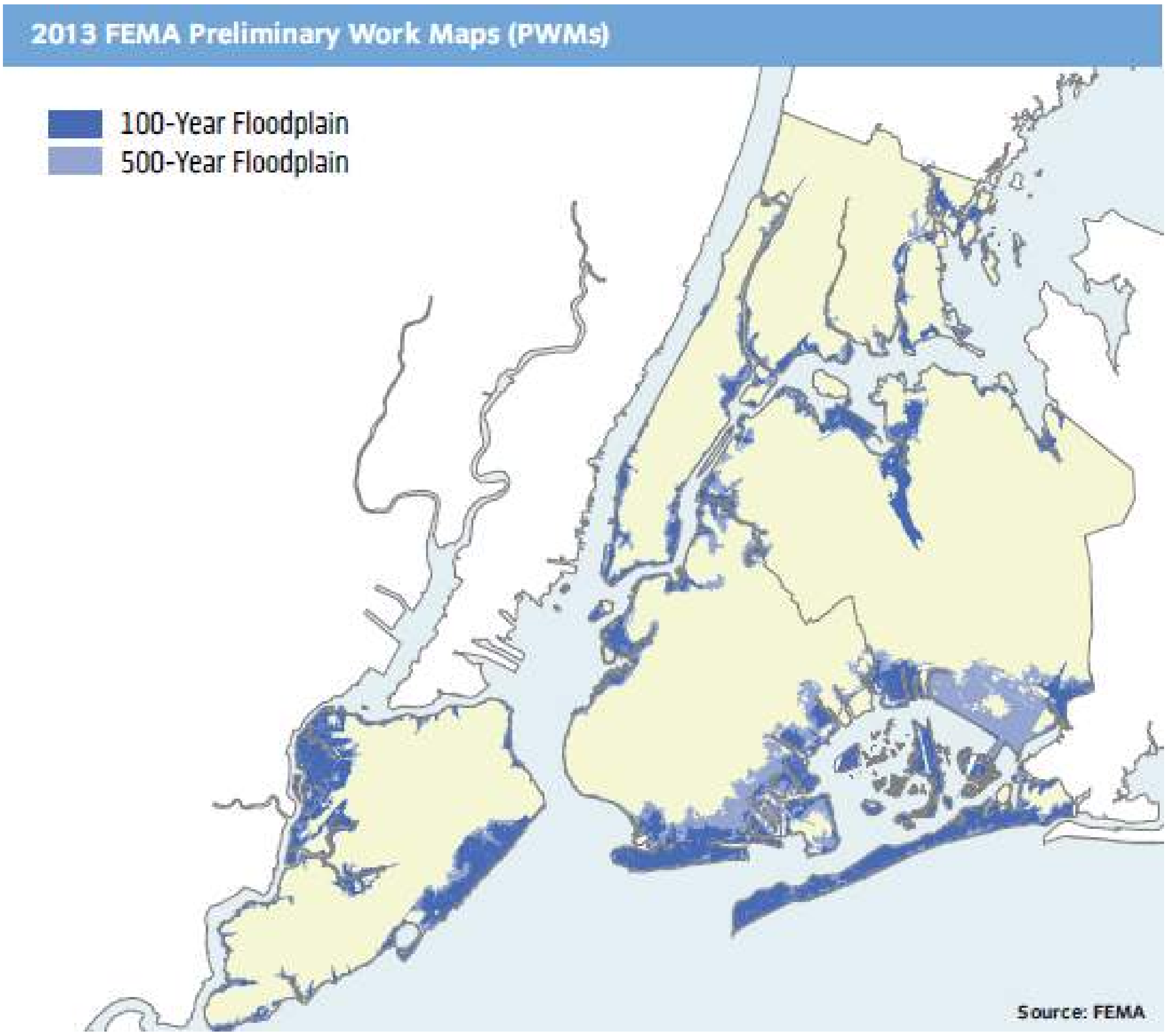


Figure C.51: FEMA Preliminary Work Maps

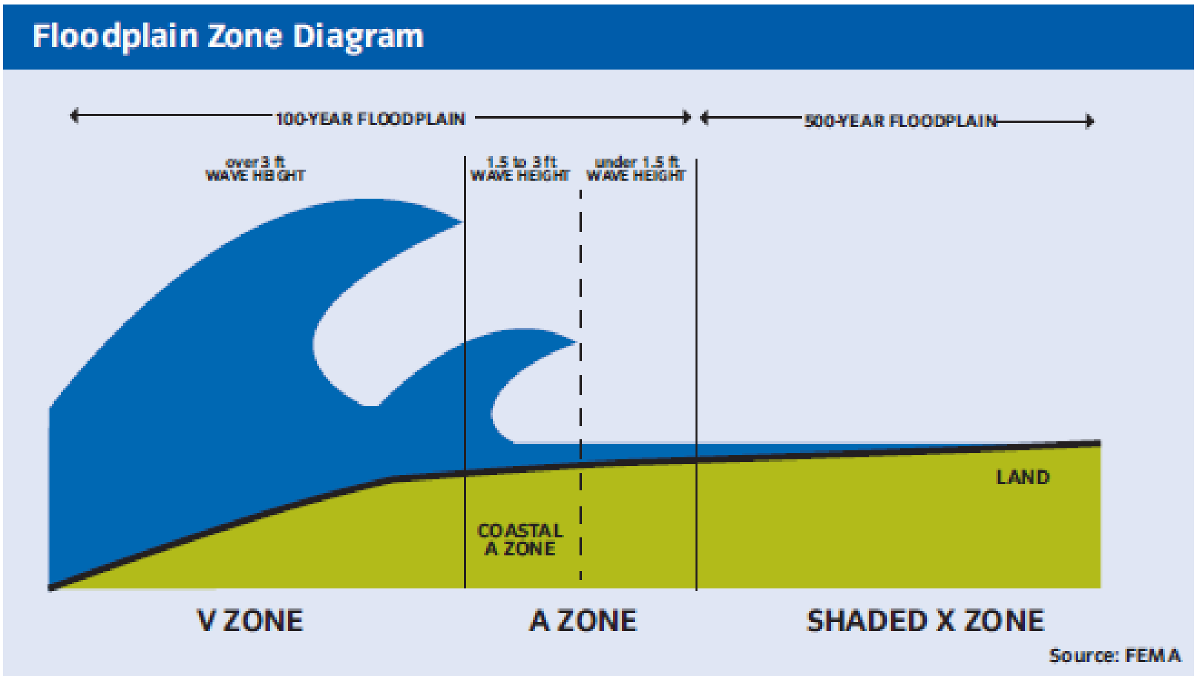


Figure C.52: Floodplain Zone Diagram FEMA

D

Interview Reports

D.1. Interview ir. H.J. Verhagen, TU Delft, 08-14-2013

On Wednesday 14th of August the project group had a meeting with ir. H.J. Verhagen, associate professor at Delft University of Technology. The incentive of this meeting was to learn more about the different possibilities for our specific problem of the Jamaica Bay. Mister Verhagen is a professor of both the master courses "bedbank and shoreline protection" and "breakwaters and closure dams", and therefore the main focus of our meeting was to learn more about the shorelines, salt marshes and geotubes.

Living Shorelines

Living shorelines is a very broad concept. What it means is not very obvious, but ideally the shoreline is protected from coastal erosion by means of a natural shoreline instead of a hard structure like a revetment. The natural processes are enhanced and more habitat for estuarine species is provided.

Important to keep in mind is that the coast consists of three different parts with different functions.

1. The sea defense, with a crest height to retain the water (if a full retaining strategy for a certain hurricane/storm and associated surge is chosen) and prevent inundation of the hinterland. Sea defense does not necessarily has to be directly at the coast. A levee's or sea defense's crest height consists of two parts
   - Waterlevel/storm surge level
   - Waves including run-up. Wave run-up on the defense is depending on type of revetment
2. The stability of the defense to prevent the defense from eroding and therefore maintaining its retention function. This is a shoreline protection if the defense is located at the coast. The stability of the defense has to be designed for waves during the design storm. If the defense lies behind a stretch of buildings, trees, structures or obstacles most of the waves would probably have lost most of their energy, which means that the protection could be less severe to prevent erosion of the defense. A living shoreline as protection of the defense (when defense is located at the shore) could probably not be an adequate solution to prevent large wave run-up
3. Shoreline protection to prevent the coast from eroding. If the sea defense is located at the coast the shoreline protection coincides with the stability of the defense, and has to be designed for big waves during a design storm or hurricane. If the defense is not located at the coast the shoreline protection has to maintain the coast under daily attack of (small) waves. A living shoreline could be a good option for a simple shoreline protection, certainly in this natural area

Salt Marshes

The salt marshes are a very dynamic ecosystem. Therefore it is important not to fix those by for example levees. The marshes should be grow and sink and change all the time, their location is not fixed. For a healthy system of marshes it is important that the marshes grow along with sea level rise (SLR). Two conditions for this to happen are, 1 Enough sediment in the water and 2 The sediment should be captured by the vegetation on the salt marshes in case of a storm. Because of their dynamic nature, geotubes to create new salt marshes is probably not preferred. An option could be to construct a geotube in front of the salt marshes as a breakwater. The waves energy is reduced and the marshes will erode less as a result. It is unknown if this is the cause of the loss of marshes in Jamaica Bay. Extra benefit for ecologists for this option is that the slope behind the geotube is gentler so more vegetation is possible.

Geotubes General

Geotubes are considered very durable, especially under water. Problem is when they are exposed to UV-light, then they degrade fairly fast. Therefore geotube above water need to be covered, and optionally with rubble. And geotubes are sensitive for vandalism, this should always be considered. Geotubes are not expensive, but for construction an experienced contractor is needed. Also the origin of the sand in the tubes has to be thought of. Interesting for geotubes in general is the option to put contaminated sludge inside.

Open or Closed System

He suggested to consider both an open and a closed system.

1. The closed system with a barrier in the inlet would have to be mentioned and the global costs of it determined
2. Furthermore he thought that an open system with a levee surrounding the bay would probably be a cheaper option and that the ecological impact is less

Levee

A levee doesn't necessarily has to be at the shore, as mentioned before. It could be better to construct a levee somewhere else where more space is provided or different conditions are applied. In the Jamaica Bay the Belt Parkway around the bay could be an interesting option for a levee. The road would have to be elevated such that it serves as defense. Important is to think about the creeks, how to close these off from the bay.

ECTS

We investigated the option to gain more than 10 ECTS for this project. It is absolutely impossible to get more points. What could be an option is that we (alone or in groups of two) do an additional thesis on this subject (10 ECTS). Requirement is that the scientific depth of the thesis is larger than of a multidisciplinary project.

Recommended Literature

- UR-reports on environmental friendly shorelines. (kennisbankwaterbouw.tudelft.nl, repositories → CUR publicaties)
- Reports on a project called "de Rijkdijk". Ways to make a levee ecological interesting (find on discover library)
- Reports on one of the first 2D models, and especially of the Jamaica Bay. Made by Mr. Leendertse of the RAND corporation in 1972

D.2. INTERVIEW IR. J. VAN OVEREEM, TU DELFT, 08-29-2013

On Thursday 29th of August the project group had a meeting with Ir. Jan van Overeem, associate professor Coastal Engineering at Delft University of Technology, and Director Business Development Water at ARCADIS. Mister van Overeem is an expert on coastal engineering and close collegue of Piet Dircke of ARCADIS. He heard from Piet Dircke about our project. He was very enthusiastic about the project and therefore it was interesting for us to speak with him.

The most important thing mister van Overeem said was that we have to keep in mind that in the bay it is not about the waves. The main problem is the surge level of the water. With the whole idea of living shorelines is good, but remember that a living shoreline alone doesn't stop the water from rising and floodings will occur, they act as a shoreline protection. Integrated with something else it can help protect the land of Brooklyn and Queens.

NOURISHMENTS ROCKAWAY PENINSULA

If the rockaway beach is very steep beach and offshore beach erosion is a problem during storms, a special construction with a toe can be applied. The toe is a sort of sill or bar which stops the sand from sliding away. The slope gets less steep and the beach broader. The bar can be made from geotubes as well, covered with stones. A reference is the maasvlakte 2, where this kind of design is applied. A rough material is used for the bottom so the slope can be steeper and less erosion can take place.

Dunes. Look at the design in Noordwijk, where a sort of dike in dune is applied. Furthermore a seawall in dune is a good option to lesser the dimensions of the dune. A dune may erode, but therefore is has to be fairly big and high. A smaller dune can be applied where the core is a hard structure.

Dune erosion. People who are experts on this topic are Henk Steedzel and Jaap van Thiel.

LIVING SHORELINES

The term living shorelines he never heard of, but the principle he understood of course. He thought the term was a little bit empy, because a lot of people use these kind of terms to sell a design with ecology. Living shorelines are a type of Building with Nature (BWN) as well, which is very interesting.

It is interesting to look at a design from the Netherlands for a dike. This dike very broad, in the way that is not really clear it is a dike anymore. The dike can be used for ecology and recreation, and therefore it can be seen as a sort of living shoreline as well.

MARSH ISLANDS

Mister van Overeem did not think that the restoration of the salt marshes in the bay would help much for flood protection, if the storm lasts for long time. The water level would slowly rise in the bay until it reaches the level of outside the bay. For a shorter storm is may help a little bit, and it is a good option to examine the special configuration of the marshes to further reduce the water level and waves in the bay. Simple calculations can be made if the characteristics of the storm are known. The special configuration of the marshes where marshes are laid in strokes around the inlet, when it helps for flood protection, can be called Building with Nature. Use these terms to help sell your product, it creates extra value.

A problem could be for the marshes in strokes around the inlet that with a long enough storm, and therefore a high surge level in the bay, the water has trouble getting out of the bay. The marshes keep the water inside so the water level lasts much longer, and that could increase the damage.

GENERAL COMMENTS

Do not forget to stand by your own ideas and principles. Do not let everyone tell you exactly what to do, because our own ideas are important and valuable. American people can be very stubborn, but we have to do our own thing mostly and calculate if the systems works in a solid way.

He does not want to be a direct supervisor and therefore does not want every email update from the project. What he does want is an invitation for the presentation at the end of the project when we are back in the Netherlands. Also he would like to get a copy of the final report. With specific questions for him we should first go to Piet Dircke. If he is too busy or has another reason why he cannot help us, we can ask mister van Overeem. He more an enthusiast than a supervisor.

Recommended literature

- Dune erosion: “Leidraad Sterkte Duinen” (Dutch norm for dunes). Made by the ENW (used to be TAW)
- Dune erosion: “Coastal Dynamics Reader” or “Handleiding Duinafslag”. Contains simple manual calculation for calculation of the required dimension of the dune

D.3. INTERVIEW PROF. DR. IR. M.J.F. STIVE, TU DELFT, 08-15-2013

On Thursday 15th of August the project group had a meeting with Prof. Dr. Ir. M.J.F. Stive, professor at Delft University of Technology of the chair Coastal Engineering. The purpose of this meeting was to learn more about the different possibilities for our specific problem of the Jamaica Bay. Mister Stive is a lecturer of master courses on coastal dynamics and an expert on the topic of coastal engineering and tidal deltas. The Jamaica Bay is a tidal delta and the Rockaway Peninsula suffers from erosion. Therefore the main focus of our meeting was to learn more about the possible solutions (e.g. nourishments) for the Rockaway Peninsula and the Jamaica Bay as tidal delta with salt marshes.

NOURISHMENTS ROCKAWAY PENINSULA

The Rockaway Peninsula looks like a very good location for a type of sand motor. Traditionally nourishments are carried out in the Netherlands and the USA for short term coastal planning. Nourishments are to widen the beach and heighten the dunes. The locations to nourish are 1 at the beach, 2 at the foreshore and 3 as a type of sand engine (long term planning). The costs of this three options will run off from 4-9 € per m3 to about 5 € per m3 to 3 € per m3. This last price is estimated for the sand motor. It shows that the long term planning (with sand motor) is much cheaper. As mentioned before, this location looks like a good location for a sand motor type of nourishment.

MARSH ISLANDS

Mister Stive thinks the most important reason for the degradation of the salt marshes is that not enough sediment is available. He doubts that the land reclamation for JFK airport is a reason for the disappearance of marshes, because the tidal prism is reduces as a result of the land reclamation. And the tidal prism is proportional to the intertidal area. If the prism reduces (due to JFK airport) one might expect the intertidal area to reduce as well, which means the marshes would increase and that is not the case. Possibly the subsidence of the area are a factor in this process, but unknown is if subsidence is a problem.

GENERAL COMMENTS

The system of the Jamaica Bay is very complex. Therefore is it extremely hard to fully protect the area against flooding. The system as it is now is not closed at all and very leaky. To close the system will be a difficult task. Special attention should be given to the creeks which end in the bay to prevent leakage. The area is very interesting regarding governance and politics.

When making a Delft3D model of the Jamaica Bay, try to make use of a flexible mesh instead of a normal rectangular or curvilinear mesh. Constructing the model would be much easier. Ask Ap van Dongeren for assistance.

If erosion of the Rockaway Peninsula has to be evaluated, Unibest could be used

Model XBeach could be used for modeling the erosion during a storm. Could be interesting for the Rockaway Peninsula. However a number of cross-section of the Peninsula are needed. Fairly easy model.

Try to get data on the soil in the area, is it rock or sand for example? Maybe Arcadis or even the Army Corps of Engineers can help obtaining this data. Important as boundary condition.

It could be interesting to consider an economic optimum for the protection of the Rockaway Peninsula. An estimation of the total economic value of the Rockaway Peninsula has to be made, including the damage when flooded. In this way the costs of the investment can be optimized.

RECOMMENDED LITERATURE

- Try to find old maps of the area, especially for the Rockaways. They tell you if erosion has taken place. Go look at the beach and see if new houses are built in front of old houses → then accretion of the coast
- Soil statistics of the area, from Arcadis or Army Corps of Engineers
- Reports on the restoration of the marshes in Venice
- Reports from Ecoshape on the Galgenplaat, Oosterschelde. A lack of sediment supply was the case here

- MSc thesis Ties vd Hoeven (kennisbankwaterbouw.tudelft.nl, repository)
- Reports from Ecoshape on oyster reefs
- Report from Ecoshape on “Building with Nature”

D.4. INTERVIEW DR. PHILIP ORTON, STEVENS INSTITUTE, 10-1-2013

Philip Orton is a research scientist at Stevens Institute of Technology in Hoboken, New Jersey. He is currently involved in studies about estuary and coastal ocean physics, storm surges, climate change and sea level rise (SLR) and numerical ocean modeling. He is part of a "Rebuild by Design" (RBD) team and he studied the Jamaica Bay for a while now. Therefore he is very interesting for us to speak to. Our supervisor Edgar Westerhof and Hugh Roberts of ARCADIS introduced us to him.

SOCIOLOGIC-ECONOMIC ASPECT

Philip thinks the area is really variable. You have poor and more developed areas/communities. For financial purposes, Battery Park has been more in the spotlights up until know. Jamaica Bay, however, hosts the most people. One of the problems of the JB is that the organizations are not consistent. There are a lot of governmental and non-governmental organizations involved in the JB, which makes it complex. The Breezy Point and Roxbury communities are very separate towns, make own solutions and dislike government interference. But in Breezy Point nobody died during Sandy, and on the rest of the Rockaways 10 people died. While the Breezy Point area was struck very hard, it is intriguing that nobody died.

MARSHES

Philip thinks that nutrients concentrations have a substantial cause in wetland loss. The newly dredged and nourished wetlands are looking healthy, however they are made of sand instead of peats. Sand could be more affected by erosion then peat. Oyster reef marshland restoration seems interesting.

Wetlands only grow above mean sea level. Therefore, you need depth alterations in the bay for the wetlands to maintain. A short-study has been done about an indication of total wetland restoration costs. This would be approximately 1 billion dollar. This seems a lot, but in comparison, a barrier would costs multiple billions.

OPEN VS CLOSED SYSTEM

Initially Philip prefers an open system for Jamaica Bay. He is pro green solutions if possible. However, it is doubtful what a green solution might be. "Retreat" cannot be considered as a green option, because you have to facilitate the people elsewhere. In that case, a barrier can be a 'green' solution. A study has been done about the Hudson River Estuary, with Hurricane Irene as threshold. Possible barriers are considered, showing a decrease in surge level at the protected side of barrier. However, areas in front or adjacent of the barrier, higher surge levels can be expected.

DESIGN LEVEL

As Philip showed in a graph, the difference in surge level between a 1/100 and a 1/1000 year storm is larger than compared to the Netherlands, this difference can come up to 6 meters. Therefore, a 1/500 year SSL can do substantially more damage if a measure is only designed for a 1/100 year SSL. Little local measures will be hit the most during an extreme event. A 1/1000 design level should be the level to meet. Piet Dircke believes a small barrier can still reduce surge levels in such an extreme event.

SLR

Sea level rise will accelerate the coming 100 years. But, 1 meter by 2100 would be a sufficient to take into account in the design. SLR development can result in support for measures. The SLR rate has been almost linear for the New York area. SLR should not give higher and lower annual temperatures. Thanks to the increasing heat capacity of the sea. Instead of seeing SLR as a human threat, focus should be on a good evacuation plan. Storm surges are affected by non-linearity induced by SLR. So, in modelling of future events, SLR cannot simple be add as an additional 80 cm.

MODELING

The Rockaway Peninsula is very much distinct from the inside of the bay, therefore it is good to make this distinction. Models of extreme storm surges show that the outside of the peninsula has to cope with a lot higher water level, mostly from waves and wave run-up. During Sandy the surge heights at outside were a little bit higher than inside of the bay. This is probably because of the time it takes for the water to reach the inside of the bay and the lower waves.

Roxbury is eroding very much. Philip thinks that the main reason of the strong tidal current in the inlet of the JB + the strong waves during storms. Waves stir up the sediment and tidal current moves it.

The JB is a friction dominated system when inlet or bay itself is shallowed. For example the Hudson Sound contains a standing wave. The tidal movement in the JB moves with a progressive wave. So when the inlet is shallower, the system becomes more friction dominated and therefore the mean water level in the bay gets higher. Water 'feels the bottom' more at low tide and therefore more water stays inside the bay. Peak surges and high tides will get lower though.

A cell size of 30 meters seems good enough. Regarding the DEM, alterations have been made by Sandy, especially at the Rockaways. However, the main aspects that we are considering, the inlet and the channels, should be more or less the same. Tons of data is being processed into a new map, but this map is not ready to be released yet. Philip is also not able to provide with better maps, since his maps are low resolution.

Although second order effects, wave modules should be included in the model, since they do influence the surge level. Tip: make layers.

Marshes are usually modelled with a manning factor of about 0.035 (see tables for friction of different kind of vegetation). USGS, wetland and sediment model for JB, currently under creation by USGS ("Hongqing Wang" wangh@usgs.gov).

D.5. INTERVIEW PETER WEPPLER, LISA BARON AND MELISSA ALVAREZ, U.S. ARMY CORPS OF ENGINEERS, 10-7-2013

The questions are discussed, they were already sent to Peter a few days before this meeting.

MOST IMPORTANT:

- The USACE works within the JB planning region on several studies (JB feasibility study, JB marsh islands, Rockaways shore protection study)
- Plumb beach: a day before Sandy hit, temporary groin and geotube were places with sand. It saved the Belt Parkway and reduced a lot of damage.
- In general, the USACE utilizes coir logs (are made of coconut mats) for marsh lands restoration. They did a test with geotubes but nothing really happened with that.
- In general, the USACE strives to rebuild the 1974 marsh footprints.
- The main focus is changed after Sandy
- pre Sandy: restoration focused
- post Sandy: focus on storm damage protection, more a hard structure mixed with a green structure. Combination of restoration and flood risk mitigation.
- It is not allowed to build bird breeding grounds within 5 miles radius of JFK.
- You need a special permit from the NPS which says you need to use 90% sand, meaning it has to be cleaned after dredging.
- The fetch sites of the islands are very vulnerable to erosion. If you can create a barrier system it would be very helpful.
- USACE did not take SLR into consideration, however USACE used only the top range of the averages, therefore you have indirectly a higher water level. Currently the USACE do takes into account climate change and SLR.
- There is a consensus in the fact that there are multiple issues which are causing the degradation of the marshes. There is no one specific thing.
- They did not do any modeling regarding the effectiveness of marsh restoration due to the associated costs and a lack of time.
- The USACE had the opportunity, when the NY harbor was dredged, to reuse this dredging material. It was an opportunity. When the harbor is dredged the sand often just goes offshore.
- USACE dredges to a specific depth of 22 feet.
- NYC Parks is in charge of the construction of the board walk. The Corps and NYC Park are in weekly contact witch each other.
- USACE is interested in: Delft3D model, foto's taken during site visits, presentation and maybe second meeting in later stage.

GENERAL

Lisa is the project manager for the ecosystem study. There are 8 planning regions and one of the planning region is Jamaica Bay. The USACE works within the JB planning region on several studies. The three main studies are:

- JB feasibility study: restoration of the perimeter wetlands on the shoreline
- JB marsh islands: beneficial use of the dredged material
- Rockaway shore protection study

USACE built three islands fully from dredged material and did the seeding plus planting. Furthermore the Corps placed sand at Black Wall and Rulers Bar and subsequently the communities/ecowatchers did the planting.

Plumb beach: a day before Sandy hit, temporary groin and geotube were places with sand. It saved the Belt Parkway and reduced a lot of damage. This is a critical area, therefore the fundings were secured with local funding.

About this Geotube project: it was a temporary measure, but still present. However, in general, the USACE utilizes coir logs (are made of coconut mats) for marsh lands restoration. They did a test with geotubes but nothing really happened with that. The projects of the Jamaica Bay are part of the Gateway National Park Area. This National Park Service was a little bit skeptical about hard structures, because they prefer natural material. Coir Logs are made out of coconut, so the NPS gateway allows such materials in the Park Area. However, above grade they deteriorated within 2 months due to the sunlight and salt water. The ones under grade are still there. It is a good material to grow plant on, due to the roots they do not erode that much. They were originally used to hold the sand when it got pumped, not for erosion control. The base consists of 3 logs, followed by 2 at the second row and 1 at the top (like a pyramid). The top one got exposed very quickly, the second row of the two is exposed now. However, the system seems stable right now. The resistance against hard structures/engineering measures is reduced since Sandy. People/parties are more open to other solutions right now. In general, the USACE strives to rebuild the 1974 marsh footprints. That has driven the designs in order to create the marsh islands.

The main focus is changed after Sandy:

- pre Sandy: restoration focused
- post Sandy: focus on storm damage protection, more a hard structure mixed with a green structure. Combination of restoration and flood risk reduction

A lot of the stakeholders that wanted restoration only, are now more open. Also placing islands more strategically regarding storm surge reduction, could be an option. In 1974 the NY state started regulating the marine environment so that is their baseline.

Furthermore t, it is not allowed to build bird breeding grounds within 5 miles radius of JFK. One has to take that into account when designing marshes at JFK. USACE is also focusing, besides the Atlantic side, at the bay side banks of the Bay concerning the flood risk management study.

A model is handy to justify the measures for/by the USACE.

The original Rockaway Beach study was for the beach and the bay side, the focus was on beach erosion control, recreation and hurricane protection. They proposed to build a tidal gate but the Federal Government decided to cancel this idea.

It is not necessarily if the USACE is open to innovative solutions but whether the park owner is open for these kind of solutions. If you use contaminated dredge material it will be an issue. You need a special permit from the NPS which says you need to use 90% sand, meaning it has to be cleaned after dredging. Furthermore you cannot prove whether after 100 years the geotubes are still intact. They could be deteriorated. Because of this you have to use clean dredging material, they say. The other fact is that the USACE has already done five islands without geotextile, which were effective, therefore you have to prove that this solution is much better than the previous solution (without geotextiles). Otherwise the NGO's probably would not accept it.

You have to make a distinction between full restoration and enhancement of the islands. They need a different approach. For example, enhancement could be done with just rainbowing. However, you can propose to design with contaminated dredging material but be aware of these facts. The public comments were very negative about it.

You need a peat layer at a certain level in the subsurface to plant vegetation otherwise the plants do not grow. One has to take that into account when you apply rainbowing for example. The traditional peat that was present in the marshes has degraded during time. However, when the roots of the plants are strong enough they can 'capture' sediment and therefore the marsh can gain height.

The fetch sites are very vulnerable to erosion. If you can create a barrier system it would be very helpful.

Like mentioned before the footprint of 1974 is the preferred condition. However, if some modifications are very expensive, adjustments of this footprint are possible.

USACE has done tide gauges and benchmarks, so you can determine the tidal range. They compare the results with NOAA. USACE did not take SLR into consideration, however USACE uses only the top range of the averages, therefore you have indirectly a higher water level. Currently the USACE do takes into account climate change and SLR.

D.5.1. STATE OF THE BAY

Historically the bay had a lot of creeks which were filled, in order to have salt marshes (fresh water is a problem). The dynamics of the system have changed over time so these modifications did affect the Bay. On the opposite, the dredging for NY Harbour did also affect the Bay. Naturally it is a shallow system but currently, due to the changes, it is has become a deep water system. If you would allow too much fresh water, invasive species like Phragmites would occur. The ecosystem would be changed and restoring of salt marshes is difficult.

There were old timber groynes present in the past. When the groynes stopped working, the sand was transported down. Breezy Point grew when the groynes stopped working because nothing was present anymore to slow the transport of sand down. The groynes which are currently present, were built in the 60s, as a part of an old project.

MARSH ISLANDS

There is a consensus in the fact that there are multiple issues which are causing the degradation of the marshes. There is no one specific thing: erosion aspect, sediment starved system, waves from the boats which are constantly hitting the shoreline, high nutrients and deepening channel chemical composition are all contributing to the losses of marsh islands.

Improved flora and fauna which are present in the bay due to the better water quality. Peter advices us to interview John McLaughlin from the DEP.

USACE would like to have the 3D-model. They did not do any modeling regarding the effectiveness of marsh restoration due to the associated costs and a lack of time. If, for example, the model shows a certain strategic position for, for instance, an island, that would be then a good option, even if there used to be no island in 1974. Furthermore you can persuade involved parties that it is better to change the configuration in contrast to the historical plans.

The islands are quite stable right now regarding erosion. The Jamaica Bay ecowatchers was the main group that highlighted that the marshes were eroding in the past. However, the USACE had the opportunity, when the NY harbor was dredged, to reuse this dredging material. It was an opportunity. If the USACE took, by then, the time to model the effectiveness of the marshes, they would lose the sand. It was a choice between the losses every year and the uncertainty.

Important key piece of information: when the harbor is dredged the sand often just goes offshore. When they do maintenance of inlets, channels or do construction at the harbor, it is the least costly, environment friendly and acceptable way of doing business.

The accelerated rate of loss of the marsh islands was noticed by comparison of maps. Every year area photos are taken and compared. During the winter the majority of the erosion is present on the North-West side due to the Nor'easters.

For the low marshes one single vegetation is used, for the high marshes 2 or 3 species are planted over there. This vegetation is the native vegetation that can withstand the salt conditions. (Low marsh versus high marsh presence = 85% vs 15%). Marshes cannot keep up with SLR, one of the reasons is the sediment starve marsh in the Bay.

A lot of fresh water is drained into the Bay, e.g. the DEP WWTP and storm water. Sea lettuce, a single cell plant which grows very fast, is a big problem in the Bay because of the nutrients concentration.

NAVIGATION CHANNEL

The channels are definitely not dredged to 30 meter (about 100 feet). USACE dredges to a specific depth of 22 feet. The largest depth is about 50 feet in the Bay.

There was an inlet present a long time ago (around 1840) n the Rockaways but it was not really a channel. (According to Janbert's figure. The USACE does not know anything about this.)

The Army Corps would like to receive the indexed photos, which the project team has made in the Bay. Furthermore the USACE will provide the project team with their proposals/engineering features regarding storm surge mitigation and restoration perspective.

CURRENT PROJECTS

NYC Parks is in charge of the construction of the board walk. The Corps and NYC Park are in weekly contact witch each other. The solution is going to be integrated with the NYC Parks. However, the Corps makes decisions based on a cost-benefit analysis and sometimes that causes a problem.

D.6. Marlen Waaijer, Norton Basin Edgemere Migratory Bird Sanctuary, 10-21-2013

Marlen Waaijer lives at 455 Beach 37th Street. According to her, sometimes during spring tide, a couple of the streets inundate. She says this is because of the storm drains constructed by the DEP. She told us the DEP is changing the sewage system into a separate system. She says that the DEP does not want to invest in flap systems for the flood drains that close during spring tide, because of high maintenance.

Marlen thinks it is strange that there are people living on the Rockaway Peninsula. The peninsula should be a natural protection for the bay. Over wash should be normal for these barrier islands.

Marlen also elaborated on the people living in the Rockaways. The people originally living there migrated from similar coastal areas in other parts of the US. However, the people that moved to the Rockaways more recently were forced by city planning to go to the Rockaway peninsula. She thinks that the people living in this coastal area should accept that a couple of times a year/decade their basements are going to flood.

Also Marlen finds a flood wall a really unattractive solution. She likes the view from her home and thinks that nature in the shorelines can help reduce the flood risk. She did get a grant to maintain the shorelines in het area. For a couple of years, together with a couple of other people she kept the shorelines clean and removed the invasive species from the shores.

Sandy

According to Marlen, the flooding that occurred during hurricane sandy came only from the sea. She states that the ocean water streaming through the streets was too strong for the rising water level in the bay to flood the peninsula.

Dying Marshes

Marlen also states that a large part of the intertidal marshes dies in the winter. The debris from the dying marshes is deposited at the shoreline.

Electricity

Before the inundation occurred in the Rockaway Peninsula, the electricity system malfunctioned. According to Marlen this was a good thing, because otherwise there would also be a threat of fire during the storm. This is what happened in Breezy Point, where several houses burned in last year's storm. Marlen states that people were angry at the government for not shutting down the electricity all together.

D.7. INTERVIEW JOHN MCLAUGHLIN, DEPARTMENT OF ENVIRONMENTAL PROTECTION, 10-15-2013

At the beginning of the conference call we all introduced ourselves and told John a little bit about our project. John is the Director of Ecological Services for the New York City Department of Environmental Protection (DEP), and we got in touch with him through Peter Weppler of the US Army Corps of Engineers (USACE). John is originally an ecologist and biologist. John told us he would try to answer our questions as good as possible, and that if he could not answer the question he would refer us to someone else. The topics and questions that are discussed are the following:

GENERAL

- Can you explain briefly what studies you have done in the NY region? How has the DEP been involved in the past decades and has this involvement changed overtime?
  - In 2007 the DEP published the Watershed Protection Plan (WPP) with strategies to protect the watershed, including the Jamaica Bay (JB)
  - In late 1999/early 2000's the DEP published a Water Quality plan with a study of the relation between the water quality and the 4 wastewater treatment plants (WWTP) around the JB. About 67 scenarios were run, ranging from all 4 WWTP's discharge to the ocean to shifting the discharge to the bay. The outcome was that the water in none of the scenarios met the standards of water quality. So the WWTP were not the biggest contributor to the poor water quality. The circulation (because of deep pits, shallow areas, filled ares etc) is impacting the water quality as well as the WWTP's. In parts of the JB near JFK Airport the water takes about 30 days to refresh.
  - Much more reports/plans, like the "Greenhouse gas management study". All could be found on the website of NYC DEP.
- How have policies changed overtime, regarding Jamaica Bay (pre-Sandy vs. post-Sandy and before that)?
  - The DEP published a Climate Change Report in May 2008, pre-Sandy.
  - A few weeks from now the DEP will also publish a post-Sandy Climate Change Report, with most impacts on infrastructure, how to move forward regarding resiliency and the impact of sea level rise (SLR). The differences with the May 2008 report are the update SLR, based on the IPCC projections and new FEMA flood maps and post-Sandy thought about impact on infrastructure and resiliency.
- What are the boundaries of the activities of the DEP?
  - The USACE can only be involved in the inside of the JB, the DEP is involved in the perimeter as well.
  - The DEP is responsible for all wastewater treatment and supply of drinking water for NYC and upstate. About 13 million people live in this area, there are 6000 miles of sewer, 4000 miles of water main and 14 WWTP's.
  - The DEP manages all the stormwater in JB. The majority (60-70%) of the sewer systems in JB are combined systems. When a storm hits, 90% of the wastewater is stormwater, the rest is sanitary. See "NYC Green Infrastructure Plan" report for example on improving the CSO tanks.

MARSHES

- The marsh islands have been degrading the last century. As far as we know there is no consensus about what caused this degradation. What is the DEP perspective on this matter?
  - Many components:
    - First the JB was shallow, now it is much deeper (channels).
    - There has been a lot of filling (300 million kubic yards of fill placed) and dredging (for navigation mostly)
    - WWTP

        - Storm water outfalls (CSO)
        - The Rockaway Peninsula was a barrier island before. Now overwash missing
        - The tidal flow is the same, and the JB changed a lot and the inlets are smaller. Therefore the tidal range has been altered, between late 1800's and 1930 it raised by 1,5 foot.
        - The JB is sediment starved
    - The mean tidal range has risen by 1,5 foot. The wetlands should be able to grow with the rise. Island wetlands (marsh islands) are fixed, perimeter wetlands can move with the rise of the waterlevel. Those perimeter wetlands are bulkheaded now because of urbanization, so they cannot move as easy. But they are doing well actually and are accreting even.
    - Higher water level: wetlands cannot photosynthesize and drain as good. Restoration was needed. Marshes have been restored by USACE and DEP (contributed and funded). Higher marshes can grow better.

- We have heard that marshes can pull themselves out (gain in height due to changing circumstances). How does this work?
    - Yes, that is correct. The vegetation grows in organic matter. When there is more vegetation, there will be more peat when this vegetation dies. So the vegetation can lift itself.
    - Marshes grows regarding biomass: 2.3 mm per year, while SLR is 1.4.

- Can the vegetation of a salt marsh grow on sandy soil?
    - The vegetation can grow on sand. The soil will become mucky and peaty. Sand is an obvious soil type for restoration.
    - Marshes started 3000 years ago on sand. Because of organic matter, peat came. Peat is very compressible. The sandy fills (first restoration project) got lost in muck and peat because of compression, therefore not too much sand can be placed during restoration projects.

- Interesting note: when you see a picture from late 1800's (forwarded by John via email) you can see that the entire perimeter of JB was wetlands. The Sandy inundation followed almost exact the same line as the edge of the wetlands. This is no coincidence, the water would have gone there when there still would have been wetlands in place.

- The marshes are now being restored to the 1974 footprint. What is the reason for using this particular footprint?
    - The reason is the clean water act (1972). Then the wetlands were first regulated. Aerial photography is used. The footprint is not exactly the same, but the area should be the same. The area is flexible because the channels have been changed.
    - Logical choice? Yes, the maps were not as good as before, it is became regulatory from that point on and the bay has been changed a lot in time.

- Are the restored wetlands stable now?
    - Yes, the restored wetlands are stable and thriving, 7 years of monitoring.
    - There were 16000 acres of wetland, now it is only 1000 acres. A lot have disappeared but nature has a tipping point, so it could be stable now.
    - Restoration is simply restoring elevation and giving sediment that washed away, so actually a quite natural system.
    - Although the bay is different, there is more open water, so more waves.

- Is the DEP involved in the planning of the marshland restoration? And how?
    - DEP is a major financer for USACE projects, like marsh restoration.
    - Active partner in planning with National Parks Service, NYS DEC. Involved in choosing next islands, it is an open process

- What do you think about innovative measures?
  - If you talk about restoration of marshes: you cannot do much more than fix the right perimeter and elevation, using the right sand or soil.
  - Innovative things on maintenance side:
    - Thin layer spraying. Routine basis spray on top of marshes. Principle: address minor erosion before major erosion occurs
    - John is not in favor of using geosynthetic tubes, i.e. for marsh restoration. They are subject to 3D forces. In 2006 restoration the tubes broke, sand was washed out.
    - Vegetation: looking at ways to make them more cost effective. Plugs of vegetation (pre-grown) are 3 dollars per piece. Last summer experiment, just placing sand and feeding it. Feeding is far cheaper, but they have to keep on monitoring. Also tested: no feeding.

WASTEWATER TREATMENT

- What kind of sewage treatment is being used currently in the Jamaica Bay Area?
  - The WWTP's around the bay are secondary treatment. Upgrades: All treatment plants around 32.000 pounds nitrogen per day. That was 54.000 pounds in the mid 90's. Investment through 2020: 20.000 pounds. Nitrogen discharge
  - Some separate, some combined. Rockaway peninsula: combined system, the CSO's rarely discharge, because the system has over capacity, some area's don't have sewage and the soil is sandy (infiltration). Their capacity is 20 million gallons per day.
  - Mainland side: 30 million gallon tank + 20 million inline storage. Total storage is 50 million gallons. You can see this as sort of an improved combined sewer system. The CSO's on the mainland do tip/overflow.
- Do you see potential in improving the water quality by restoring wetlands?
  - Yes, absolutely. Need to restore natural part of the system. Other bay has changed, historically oysters filtered the entire volume of bay.
  - Oyster pilot -> oyster reefs in JB. Reproduction is challenging in JB, this is still being studied. But this could be a scale proble.
  - Report, read about Chesapeake Bay (oyster reefs) on their website.
  - Eelgrass pilot
  - Algal turf scrubber
  - Ribbed mussels
- Is the DEP considering creating / designing wetlands specifically for the purpose to clean CSO water or Sewage Treatment Plant effluent water?
  - Done in a lot of places. Here the volume is too great to do that. The 4 plants around JB discharge around 250 million gallons a day. Too high flow rates for the wetlands to treat is.
- What does the DEP think about innovative projects, like algae turf scrub and pumping water from the wastewater plant in the Rockaways to another location?
  - As said before, DEP believes natural systems can do quite some good for the ecology.
  - For example, we made bio-fuel from algae (butanol). It is expensive though.
  - DEP initiates those efforts.
  - But it has to be economically viable, which most are not yet.
- The wastewater treatment plant in the Rockaways is located next to a school. What is the reason it was built here in the past?
  - WWTP was built in 1952. Suspect the school was not there. In 1952 the Rockaways did not have a lot of population and land was plentiful. The plants first were built in the middle of nowhere, after this JB became a national park.

- In what way are the WWTP's designed for storms? Can they withstand a 1/100 year storm without problems or should they have additional measures?
  - The reason it overflowed, is that the ocean and the bay met. At some places on the Rockways there was 5 feet of water in the streets.
  - All plants are designed for 2 times the dry weather flow capacity. It did overflow because of the infinite amount of ocean water.
  - No final decisions about reinforcing WWTP's.
- Pipeline under the JB (making the WWTP on the Rockways a pumping station), still an option?
  - That is still one of the options being considered
- The Jamaica Bay area is densely populated, any changes in development oo hardening of WWTP's will be a long year process, and how is the DEP addressing changes because of Climate Change (i.e. sea level rise, storm frequencies).
  - Full assessment post-Sandy, Sandy was a big hit.
  - In some locations pumps failed because electricity failed.
  - It is an option in some cases just to let it fail if the WWTP is not critical.
  - All options are still under review.

**The call is resumed at 3 PM.

WATER QUALITY IN JAMAICA BAY

- Why does the water quality differ within the bay on several locations?
  - Circulation changes, because of bathymetric changes, filling and dregding. There are dead ends with little flushing.
  - Quality is also seasonal. Primary breakdown is from end August to September. The water heats up, when colder the quality is better. Bay is eutrophic.
- Is there a relation between WWTP's and the quality of sediments in the bay? The water quality improved, but did the sediments quality improve as well?
  - The water quality of New York harbor and thus JB is the cleanest in over 100 years.
  - There has been little work on the sediments
  - In general, the CSO discharges occurring now, are cleaner to what they were in the past. (less industry)
- Is the DEP known with the concept to re-use dredged materials within geotextile tubes, with use of polymers, tubes that can be used in off shore, marine kind of structures?
  - The USACE has
  - DEP have used dredged material. Two landfills in other areas under jurisdiction of DEP. Used for perimeter and wetland restoration. Grading system fill, on top of the landfill was a coastal forest. The grading wasn't sand, it was questionable soil with added Portland cement, 3 – 6%. Therefore the PH was high and it cannot be used as material to plant vegetation on (should be 5.5 – 6.5 PH).
- What does DEP think of using polymers to stimulate segregation of sediments and water, in order to use geotextile tubes?
  - John is not familiar with this technique
  - Could be good as grading material in soil, but may not be so useful for planting.
- Can you tell us more about the quality of the sediment in Jamaica Bay? Where do we find the more and where do we find the less polluted material?
  - Not known

ROCKAWAYS

- What sewage system is used within the Jamaica Bay Area (combined or separate)? We have heard that the DEP is working on expanding the separate sewage system within the Rockaways, Is this correct and if so, why?
  - DEP is planning on installing storm drains. These are added separate storm sewers to the current combined system.
  - Tide gates are on some of the drains to close them of during storm surge. They don't work well and precipitation cannot go out during a closed period. A storm drain has to be on the street. Land is subsiding.
  - Building codes have changed. FEMA plus 1,5 feet (24 inches?)
- Do you see any nearby changes in policy that would lead to construction of "separated drainage systems" throughout the city? Including the potential of Green Infrastructure? It would be in the DEP's interest to reduce the volume of water flowing to WWTP's during a rain event, is the DEP actively stimulating Green Infrastructure developments?
  - Yes, yes and yes.
  - Committed to spend $192 million through 2016
- One of the biggest problems within the Rockaways during Sandy was the overflows. Is it true that during extreme events water comes out of the landside of the overflows (so instead of draining the Rockaways it transported water towards it)?
  - Not really true, because the ocean and the bay met at most places of the Peninsula

LIVING SHORELINES

- Part of our study is designing living shore lines for the Jamaica Bay banks. What types of vegetation are most suitable?
  - Wetland vegetation
  - Sand dunes vegetation on the upland, beach grass, ammophila. Deep root system, hold the dunes in place.
  - Back dune with bay berry, holly, sumac, amalancia.
  - Look at the Marine section of Ecological communities in New York State. Species by species breakdown.
  - Pitch pines is good.
  - Oaks do very well in a marine environment.

SEA LEVEL RISE

- What is the DEP's opinion about sea level rise? Do you take it into account? And if so, how?
  - It's rising. The DEP does take it into account. New report on climate change will be published in a few weeks, it is currently being reviewed by city hall.

CURRENT AND FUTURE EFFORTS

- What are current and future projects or developments, what can people expect from the DEP in the next 10 years in the Jamaica Bay area?
  - Continue to renew all natural systems and pilots we have talked about.
- Also the Port Authority is an important stakeholder within the Jamaica Bay. What department within the Port Authority do you talk to, and do you work together on projects?
  - They are a partner in all the process in wetland restoration. PA does their own projects as well. New York State DEC and of course USACE are also a large player in marshland restoration.
- With what other city authorities does the DEP work within the Jamaica Bay Area?

  - NOAA
  - NY Department of state, state wide level, because also long island that may see flooding.
  - US fish and wildlife service

TERMINOLOGY

- High islands: generally islands (high marshes). They are no wetlands
- Marsh islands are mostly called marsh islands (low marshes), while they could be wetlands
- Wetlands are along the perimeter

D.8. JEANNE DUPONT, ROCKAWAY WATERFRONT ALLIENCE, 10-1-2013

After a presentation of project Jamaica Bay, Jeanne DuPont references to the park (with a bike lane and a walking lane) that is created on the west side of Manhattan. It is a great success, and people in the Rockaways would like to have a park like that on the western bay side of the Rockaways. Jeanne thinks this would be a great way to make the Rockaways more attractive. However, because of Sandy, people think that the wall that is currently present was the only protection they had from a storm. The wall prevents the possible park.

Also, Jeanne talks about the storm drains in the Rockaways that during Sandy caused a stream of water going into the Rockaway peninsula instead of streaming out. She tells us that right now the DEP wants to integrate a separate sewage system in all of the Rockaways, and is currently working on draining systems in her street. She thinks this is not a good thing, because of the drains letting water in during a storm. She tells us, every year the Rockaway Peninsula gets inundated at some points.

BOARDWALK

Jeanne states that the US Army core of engineers is going to restore the boardwalk the way it was. The only difference would be that the boardwalk is going to be made out of concrete instead of wood. In the community there are a lot of people who want a hydraulic structure to protect them, but Jeanne thinks the water will be redirected to another location, which is bad. Jeanne thinks ecological solutions are the way to go. She references to the neighborhood where she lives. The people have been creating sand dunes for the past 10 years. Other parts of the Rockaways said they were crazy to take away the beautiful view. She tells us that a large part of the first dune was compromised, but the sand of this dune was collected by the second dune (on which grows a lot of vegetation). Her neighborhood was one of the few which did not get inundated.

Jeanne also refers to Claus Jacobs, from Columbia University. He is honest and states that in 100 years, the Rockaways will only be a sand bar if nothing is done. He thinks that the Rockaways should build "up". A possibility would be to build the houses further back, and put a dune in front of it. She also took us to a spot where there is a bird habitat situated in front of buildings. These buildings did not suffer a lot of damage.

Furthermore, there are 13 different communities within the Rockaways itself, which is ¾ mile wide. They have to cooperate, otherwise nothing will happen. There is a great separation. Where the public transport stops, there are a lot less minorities. People do not know that they are influenced by climate change.

The RWA used the old firehouse near the 60th street subway station as a distribution center for food and all sorts of stuff. Even when the power was back up, there were still people coming to the station to ask for food. People are really poor and they have never gotten free stuff. That is why Jeanne thinks the people in the communities started hording free stuff.

Today the RWA wants to empower the people to be self-sufficient, also when it comes to flood risk. However, she is afraid that the storm of 2012 will be forgotten soon, and things will go back to normal without a good way to reduce flood risk.

The Rockaways have a combined sewer system. The DEP wants to make it all separate in the Rockaways, which means they have to build more storm drains. De WWTP was built after the school next to it. Also the WWTP was really running over during Sandy.

Also at this WWTP, the DEP uses the effluent and algae to create bio methanol.

D.9. INTERVIEW ELAINE MAHONEY, FEMA, 10-11-2013

Before we started asking questions Elaine had some questions/comments about our project plan/research, which she read beforehand.

1. Why did you choose a 1/100 year storm?
    - We chose it because we heard from several direction that it is the standard level to design at in the United States. Elaine: that is correct, it is the standard.
    - Elaine: think about the return periods (for example 1/100 year versus 1/500 year storms), what the extent of it is and what it actually means. Think about if the 1/100 year storm is a good level to design at.
    - Superstorm Sandy was classified as a 1/700 year event based on a statistical analysis of the trajectory and pressure systems. However, the inundation did exceed what at the time was supposed to be the 1/100 year event presented on the FEMA floodmaps from 1983. The inundation due to Sandy would be similar to the inundation 1/100 year flood event based on the new preliminary work maps (PWM) by FEMA.
2. History of the bay with wetlands. The bay has been dredged substantially and marshes have disappeared. Matching flooding after restoration of the marshes would make sense. So take a look at historic storms and its inundation, because the future situation will look more like the past because of restoration projects.
3. Are you planning on compare the results of our solutions with the solutions proposed by the city of NY in June 2013, which could really be interesting? We: no, probably not because of limited time.

The topics and questions which were discussed are the following:

GENERAL

1. General thoughts on Jamaica Bay (JB)?
    - It is a hotspot of engineering activities and research, not only attention for Manhattan although it looks like for Manhattan is more attention. The people in JB are not really interested in storm surges. There is a lot of public housing. In the 60's the people have been moved from Lincoln Center to the Rockaways ('kicked out') because that area needed to be redeveloped.
2. Flood insurance. How does it work?
    - There are a couple of issues concerning flood insurance.
        - Before Sandy the insurance for primary homes was obligated. For second homes it was not. A lot of people were not ineligible for insurance.
        - Problems after Sandy:
            (a) People did not get the money they deserved
            (b) It was their primary home
            (c) And they could not lend any money from the bank
            Extra problems were: max amount of money for refund was 30.000$, only living places could be insured (no lobby, garage, or 1st floor shops) and there was a loophole for COOPS (ineligible)
        - The programs is always in depth (since Biggert Waters act). Floods get more expensive.
            (a) It is a good protection from people going to live in a flood zone
            (b) On the other hand could only rich people afford to live there, plus the poor people who already live there are in trouble.
            There is a lobby for the Biggert Waters act to be changed, now the priority with the shutdown is not with this change.
    - Concerns: new storms are necessary for people to remember. People forget fast. Plus the culture is different, 24hr newsfeed and New York is a fast place.

3. If it is not possible to speak with Dan Zarrilli, try Mike Morrella of Lea Cohen.

4. What happens if the mayor changes in a short while? Problems with the green and resiliency vision of the city?

    - That could be a problem. But the office is working on getting the resolutions (plans), so the new mayor cannot affect it anymore. The goal is to make the report city law before the new mayor will be in office.

SIRR Report

1. PlaNYC is not the correct term for the SIRR report, remember that!
   FEMA's role in SIRR report?

    - They helped with Sea Level Rise (SLR) projections and the projections which should be released in the report, because the IPCC projections are longer than 2050. The SLR projection in 2050 are bad enough, plus these projections have a 90% confident rate.

Flood Maps

1. When are the flood maps updated?

    - The FEMA runs different scenarios for different regions. Now New Jersey and New York have been updated, the rest follows. The new maps are planned to be ready by January 2014, although it could be delayed because of shutdown.

2. Will they differ from the preliminary work maps (PWM)?

    - No, to make the maps official is mostly political issues. The maps will be (almost) the same as the PWM.

3. How are the flood maps computed?

    - The model ADCIRC is used together with a DEM and SLOSH to compute the flood maps for certain flood events. She could redirect us to the technical team when we have specific questions about SLR or the modeling. The grid size of the calculation is about 3x3 meter, while for the more general SIRR report the grid size was 30x30 meters. The goals is to refine the grid even more to incorporate it into the building codes.

4. How is SLR incorporated in the flood maps?

    - SLR is not incorporated in the Flood maps by FEMA. Therefore the codes are the use the Base Flood Elevation (BFE) + 1 foot. The 1 foot stands for the SLR. She believes that SLR will eventually be a part of the flood maps. Now this is not the case, therefore the maps are updated every 20 years typically.
    - The 2020 and 2050 projections are projections with SLR, made by FEMA as well. The flood maps do not incorporate SLR as said before.
    - The FEMA does a lot of work on SLR though. They work together with the USACE, NOAA, IPCC to calculate the SLR in this region. State by state they work together for the whole country. They are looking until 2100, not only 2050. There are 4 scenarios of SLR with the FEMA: low, intermediate low, intermediate high, high.

1/100 Year Storm

1. 1/100 year storm is the design storm for New York. Is this the same for the whole USA?

    - Yes, this is the benchmark for the USA, since the early 1900's, but of course there is much more scientific background now. Issue is still as she stated before, think about what the design level means. She will send us some laws/regulations about this. Personally she thinks that the benchmark level should be 1/1000 year storm.

2. How are the 1/100 year flood levels established?

- The data which is available is extrapolated. Sandy would not really affect the data because Sandy was almost only surge and not a big storm itself (almost no rain). So, due to the unusual nature of the storm and the lack of precipitation it's inclusion in historical data will not have a significant impact on what we calculate as the 1/100 year storm going forward. We will send Elaine the report by Lin et al, where he 'creates' and simulates multiple hurricanes.

D.10. INTERVIEW CORTNEY WORRAL, METROPOLITAN WATERFRONT ALLIENCE, 10-4-2013

Kaj starts with the short presentation about our group and our project plan. After this presentation Cortney want to know a little bit more about our group, our studies and project. Then she started telling about the MWA. It is an umbrella organization of about 740 organizations. The partners consist of businesses, volunteers, support groups etc. The goal is to revitalize the waterfront of New York. Since 1940 the harbor of the city started moving to New Jersey, and that meant that land in Manhattan was abandoned, which could be redeveloped. The mission while developing this area was to integrate all parts of the waterfront, like recreation, industry, ecology etc. The MWA was founded in 2000. After Sandy the MWA keeps all goals – public, ecology and resilience – and not only Resilience in mind. New York has a big waterfront, 520 miles in total. The MWA has a few projects, but is mostly for a broader overview. MWA supports the partners with reaching their goals.

TOPICS/QUESTIONS:

1. To what extend is MWA involved in the Jamaica Bay projects?
   - Not a lot of work in JB, but they do support partners who want more recreation and ecology for example. One project they do are involved in is the ferry service, they want to make a permanent ferry. MWA is advocating for that.
2. Communities in the JB area
   - Lot of poverty. Unfortunately Cortney does not know much about the communities. We were especially interested in the communities in Brooklyn and Queens on the northern border. Those people have a problem with transportation, there is no easy transportation to the bay.

     About the interference of the government regarding flood protection: middle class will probably fight it, poor people will probably not. Important is that people just do not want to lose their house.
3. How is ecology involved in the activities in the bay?
   - The problem is that there is no good data and mapping of the state of the area specific ecology in the bay, no extensive ecological survey. If plans and design are actually going to be build, there should be proof that it is not affecting the ecology, those are regulations.

     Environmentalists are for example not against the restoration of the marshes by USACE. There is support.
4. Are there more plans for recreation in the bay?
   - People are open to recreation, but there are no specific plans except a few parks being built. Examples of good recreation plans are kayak and bike lanes. Make sure one recreation does not affect the other.
5. Do you know anything about the history of JFK?
   - She does not know much about JFK. Go to a library, i.e. the public library to find documentation on JFK Airport.
   - JFK is a part of the Port Authority, big stakeholder. They are getting more and more interested in ecology, also because of regulations.
6. How is it possible to cope with the transportation issue in JB?
   - No new subway will be built in New York, because that is too expensive. New ways of transportation could be buses of the ferry.
7. Is there anything going to happen in JB for flood protection?
   - Yes, she believes there is definitely something going to happen, because there is a lot of federal money and momentum.

8. Do you know anything about the FEMA maps and flood insurance?

    - Look up the NY Times on this topic.

LIST OF FIGURES

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