Climate Change Adaptation and Sustainable Design at the Port Authority of New York & New Jersey

Authors:

Sara Mills-Knapp, LEED AP
Emily Bourdeau
Gregory Falco, LEED AP, EMIT
Cathy Resler
Harold Tovar
Stephen Zoegall, Ph.D., LEED AP

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I. EXECUTIVE SUMMARY

With more than 500 miles of coastline exposed to sea level, much of it supporting high populations and dense infrastructure[1], New York City stands to benefit greatly from adaptation planning to potential climate change impacts. Most major cities around the world at or near coastlines – Singapore, , Tokyo, Amsterdam, London, Los Angeles, and Brisbane among others – have either already implemented or are planning to implement extensive protective measures against climate change impacts. Many of these interventions are applicable to New York and New Jersey infrastructure and are outlined in detail in this report.

> ***We are planning with a small 'p' – there is no big adaptation planning in effect…however [Massport] participated on an adaptation committee put together by the Massachusetts Executive Office of Energy and Environmental Affairs to determine the risks to infrastructure in transportation and through that effort we began brainstorming for adaptation strategies."***
>
> – Jacquelyn Wilkins, MassPort Sustainability Program Manager

The scope of this project was defined by the following guidelines:

a) Define climate change adaptation and resiliency as it relates to infrastructure and buildings.
b) Focus on sea level rise (SLR), storm surge and increased precipitation as the climate change-related impacts of most relevance to the PANYNJ's infrastructure.
c) Research and report on current climate change adaptation practices being undertaken in comparable cities with comparable infrastructure that address these impacts.
d) Recommend adaptation strategies that are most applicable to the function and scope of PANYNJ.
e) Identify the synergies and areas of conflict between PANYNJ's sustainable design guidelines and recommended climate change adaptation strategies.

KEY FINDINGS

- **Based on the most recent and authoritative predictive models, New York City faces significant SLR-related risks and adaptation strategies will be necessary to build the resilience of infrastructure.**
  According to well-established International Panel on Climate Change (IPCC)[2] and New York City Panel on Climate Change (NPCC)[3] models, the New York City and New Jersey area faces significant risks from climate change-associated SLR and increased precipitation. Moreover, according to a presentation by researchers from the University of Utrecht in the Netherlands at the April 2011 European Geosciences Union (EGU) meeting in Vienna, due

[1] Zimmerman, R., 2002: Global Climate Change and Transportation Infrastructure: Lessons from the New York Area. In *The Potential Impacts of Climate Change on Transportation: Workshop Summary*, U.S. Dept. of Transportation, Workshop, 1-2 October. Retrieved April 30, 2011

[2] The IPCC is an international body of scientists, policy makers and experts and is the leading authority on climate change research, planning, framework development, modeling and adaptation strategies.

[3]The NPCC is a local panel modeled after the IPCC in structure and mission.

to a variety of closely analyzed geophysical forces, New York City will experience the most pronounced rise in sea levels – 20% more than the IPCC global average estimate of 28 cm (1 ft.) by 2100.[4] These climate change impacts require the implementation of adaptation strategies in order to build the resilience of regional infrastructure. For the purpose of this report, **adaptation** is defined as the planning and actions undertaken to protect against, accommodate or retreat from the impacts of climate change, specifically sea level rise and increased precipitation[5]. **Resilience** is defined using the National Infrastructure Advisory Council (NIAC),[6] definition, which is "the ability to reduce the magnitude and/or duration of disruptive events … [and] to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event."

- **Globally, implementation of SLR adaptation strategies in comparable cities with infrastructure analogous to the PANYNJ is in its infancy.**

  One recurrent finding of the research and interviews informing this report is that most municipalities around the world with infrastructure similar to that of New York City still remain in pre-implementation stages with respect to SLR adaptation. New York State and New York City are a leader in the adaptation planning effort with several planning initiatives in place. These instances of leadership that are more developed and represent the most applicable examples for the PANYNJ are examined in the case studies section of this report. The focus in most cities is on strategies to reduce the risk of flooding through the management of increased precipitation, but not on long-term SLR planning. However, the few exceptions to this general rule – detailed further in the case studies section of this report – are more advanced in the implementation of SLR adaptation strategies than the states of New York and New Jersey.

- **The majority of SLR adaptation plans and strategies reviewed in this report draw directly or indirectly from the seminal IPCC First Assessment report from 1990 on coastal zone management.**

  The IPCC report, and its descendent SLR adaptation plans identify three approaches for adaptation response; protect, accommodate and retreat. The categories "protect and accommodate" were determined to be generally applicable to PANYNJ facilities. Retreat is not currently considered a viable option by the PANYNJ, but in review of the literature there are regional instances of small-scale relocation programs that can be applied.

  It was also discovered that most adaptation plans use variations on the IPCC framework (outlined below) for preparation and planning of adaptation strategies, this framework for implementation can help:

  1) Develop a system to monitor, detect and predict climate change impacts. The report notes that site-specific scientific data on climate change impacts are often lacking but are critical to the success of local adaptation efforts. Plans that utilize updated scientific information are essential to success.

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[4] Black, Richard. (2011, April 8). *BBC News - New York Set to Be Big Loser as Sea Levels Rise*. BBC - Homepage. Retrieved May 2, 2011.

[5] Modified from NPCC and IPCC definitions and narrowed in scope for this project.

[6] National Infrastructure Advisory Council. (2009). *Critical Infrastructure Resilience Final Report and Recommendations*.

2) Identify the most vulnerable areas and infrastructure. Vulnerability studies require teams with advanced modeling and monitoring expertise. The PANYNJ district and surrounding region has the advantage of being a major metropolitan area that is the subject of continuous advanced climate change projection modeling.

3) Plan for SLR via two paths: emergency management planning and coastal management planning.

Emergency management planning aims to reduce the impacts of flooding and storm surges on exposed coastal areas and infrastructure. Coastal management planning describes longer-term, incremental adaptation strategies, many of which are discussed in this report.

4) Educate residents, tenants and other stakeholders on adaptation plans and progress.

While successful implementation of adaptation strategies remains a top priority, involving and informing local stakeholders makes a significant contribution to the success of these efforts.

5) Create a flexible, easily adjusted plan and put in place clear metrics for measuring success of adaptation strategies.

Being able to measure the success of implemented strategies appears to be an essential component to a flexible adaptation plan that is responsive to developing climate change risk models. Adaptation metric examples include: measuring the number of sewage overflow events, the number of impactful flooding events, and the cost of damages of an event. Comparing this information to baseline measurements can help determine if an adaptation strategy is successful.

- **Strategies to adapt to climate change impacts and build resilience can work synergistically with or conflict with pre-established PANYNJ sustainability guidelines for infrastructure and buildings.**

  This report assesses the synergies and conflicts associated with each adaptation strategy in relation to PANYNJ Sustainable Design guidelines. Most of the strategies and related case studies in this report involve trade-offs between mitigation and adaptation. For example, flood barriers can protect sensitive inland areas from inundation, but also require energy and human resources to operate and can damage surround ecosystems. Many additional synergies and conflicts are discussed in the report.

- **The PANYNJ would benefit from further evaluation of applicable adaptation strategies, continued monitoring of the case studies explored and integration of adaptation and mitigation initiatives, in order to take advantage of specified synergies.**

The applicable adaptation strategies recommended in this report require further exploration and analysis for applicability to PANYNJ infrastructure. In addition, the case studies cited should continue to be monitored for clear success strategies and lessons learned. The planning of mitigation efforts and the preparation for adaptation strategies are best planned in concert, because of the exhibited synergies and conflicts between them. Therefore, the PANYNJ would immediately benefit from an integrated approach to climate change action that addresses mitigation and adaptation simultaneously.

II. INTRODUCTION

a. Project background and scope

The Port Authority of New York & New Jersey (PANYNJ) is a unique bi-state agency focused on operating and developing infrastructure relevant to trade and transportation in New York and New Jersey.[7] The agency has 6 operating arms, 31 major facilities and in 2010 it had a $3.1 billion dollar operating budget for 2010. These facilities include airports, marine terminals and ports, the PATH rail transit system, six tunnels and bridges between New York and New Jersey, the Port Authority Bus Terminal in Manhattan, and the World Trade Center in Manhattan.[8]

> ***"For us, resiliency means the ability to provide continuity of airport operations in the context of changing climate and weather. Although this goal seems straightforward, it has implications for airport design, construction and operational decisions. Our airfields and other facilities should be designed to support the intended operation with restrictions that are climate-change related."***
>
> -Arlyn Purcell, Supervisor, Environmental Programs, Aviation Department, Port Authority of NY & NJ

The PANYNJ Engineering Department provides the Agency with technical assistance on sustainable design and climate change adaptation and resiliency. The two fields are directly related: sustainable design mitigates the impacts of climate change and adaptation refers to preparations for coming climate changes. There are accepted standards for sustainable design; however, guidance in the area of adaptation is an emerging field.

This project provides research and analysis of the intersection of these two fields using the PANYNJ Sustainable Design Guidelines for buildings and infrastructure and recent research and recommended strategies for climate change resiliency. The adaptation strategies are illustrated with related case studies to provide useful examples of implementation. Given the largely coastal distribution of PANYNJ infrastructure and buildings, this analysis focuses in particularly on climate change-associated sea level rise (SLR), storms surge and flooding due to increased precipitation. Based on extensive research and expert interviews, this report describes a broad range of strategic options and implementations that are relevant to PANYNJ services and facilities.

The scope of this project was defined by the following guidelines:

a. Define climate change adaptation and resiliency as it relates to infrastructure and buildings.

[7]Port Authority of New York & New Jersey. (n.d.). *About - Overview of Facilities and Services.* Retrieved April 30, 2011 from The Port Authority of New York & New Jersey

[8] Ibid

b. Focus on sea level rise, storm surge and increased precipitation as the climate change-related events of most relevance to the PANYNJ's infrastructure.
c. Research and report on current climate change adaptation practices being undertaken in comparable cities with comparable infrastructure that address these impacts.
d. Recommend adaptation strategies that are most applicable to the function and scope of PANYNJ.
e. Identify the synergies and areas of conflict between PANYNJ's sustainable design guidelines and recommended climate change adaptation strategies.

To maximize the practical utility of this report, the adaptation strategies presented here are:

- Built, under construction, or in the planning stages
- Designed to offer long-term incremental protection from SLR and storm surges
- Applicable to PANYNJ infrastructure and buildings
- Illustrative of key synergies between adaptation and sustainable design techniques

The few exceptions to these criteria have been included due to particularly innovative planning or execution and/or some other compelling feature.

This report presents strategies and case studies organized by PANYNJ asset type – bridge, tunnel, port, airport, PATH, and associated buildings and facilities – because of the different effects of climate change impacts and potential risk management techniques associated with each. The report organizes each technique within one of three broad adaptation strategies: protect, accommodate, and retreat. This framework was used by many of the coastal adaptation planning reports reviewed and originates from the IPCC's First Assessment Report in 1990.[9]

Given the relatively recent advent of adaptation planning, it is important to note that these strategies and case studies are not presented as best practices. While a few of the strategies have already demonstrated some success, other cases effectiveness have not yet been tested or proven. Incremental infrastructure adaptation to SLR is still a new area of exploration, and therefore this report attempts to identify as many early successes as possible for each infrastructure type while also devoting some focus to emerging innovative interventions.

b. Sea level rise and increased precipitation in New York and New Jersey

In 2007 the Fourth Assessment Report (AR4) was presented by the Intergovernmental Panel on Climate Change (IPCC), an international consortium of leading scientists established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) to study the environmental and socioeconomic impacts of global climate change. Previous Assessments of the IPCC, as well as other independent scientific research, had identified some of the causes and features of global climate change, which the IPCC defines as "a change in the state of the climate that can be identified [...] by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or

[9] Framework for adaptation responses and strategies adopted from IPCC (1990). *First Assessment Report Climate Change: The IPCC Response Strategies - Chapter 5 Coastal Zone Management*

longer."[10] Based on more than 150 years of data and rigorous peer-reviewed scientific analysis, the AR4 study asserts in its synthesis "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level."[11] Concomitant effects of climate change include globally elevated temperatures, erratic weather including storm surges,, sea level rise, increased precipitation and a range of additional disruptive geophysical phenomena.

According to AR4 global sea level rose at an average rate of 1.8 mm per year from 1961 to 2003.[12] This average rate increased to 3.1 mm per year from 1993 to 2003.[13] Scientists attribute this phenomenon to rising global temperatures, which in turn hastens the melting of polar ice sheets, mountain glaciers and snow cover. Moreover, seawater also expands in volume as it warms in a phenomenon known as thermal expansion.

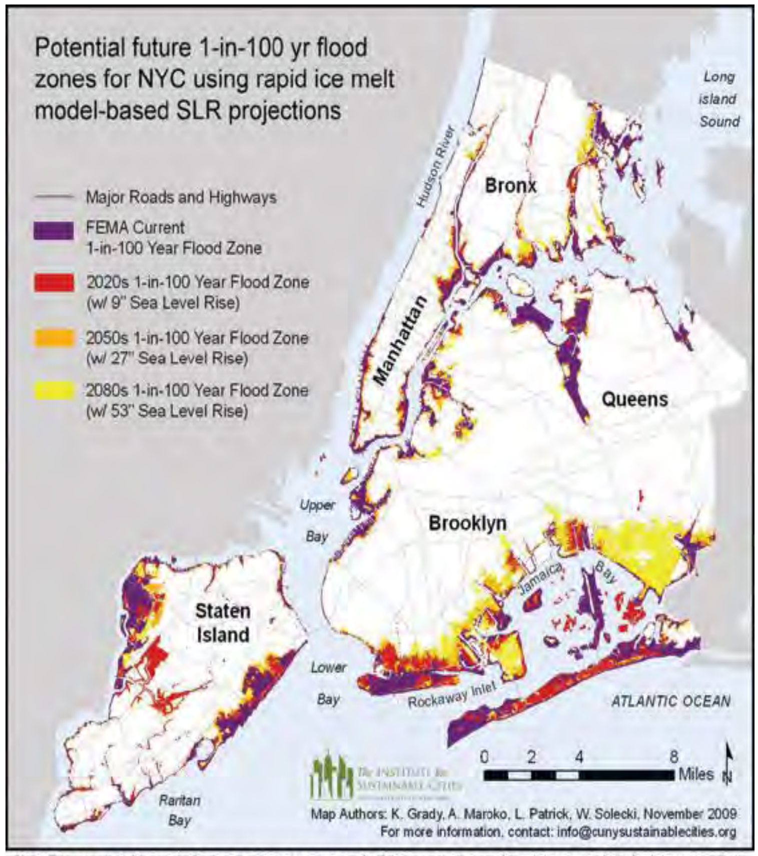

Figure 1.[14]: Shows the current FEMA 1-in-100 year flood zone and potential areas that could be impacted by a 1-in-100 year flood in the 2020s, 2050s and 2080s based on projections of the 90th percentile mode-based “rapid ice melt” sea level rise scenario.[15]

[10] IPCC (2007) Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change p.30

[11] Ibid.

[12] IPCC (2007) Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change

[13] Ibid.

[14] Note: This above map is subject to limitations in accuracy as a result of the quantitative models, datasets and methodology used in its development. The map and data should not be used to assess actual coastal hazards, insurance requirements or property values or be used in lieu of Flood Insurance Rate Maps issued by FEMA. Interpretation: The floodplains delineated above in no way represent precise flood boundaries but rather illustrate three distinct areas of interest. 1) areas currently subject to the 1-in-100 year flood that will continue to be subject to flooding in the future, 2) areas that do not currently flood but are expected to potentially experience the 1-in-100 year flood in the future, and 3) areas that do not currently flood and are unlikely to do so in the timeline of the climate project scenarios used in this research (end of the current century). Sourced from: Rosenzweig, C. and Solecki, W. (2010), Chapter 1: New York City adaptation in context. Annals of the New York Academy of Sciences,

[15] Rosenzweig, C. and Solecki, W. (2010), Chapter 1: New York City adaptation in context. Annals of the New York Academy of Sciences, 1196: 19–28. Retrieved April 28, 2011

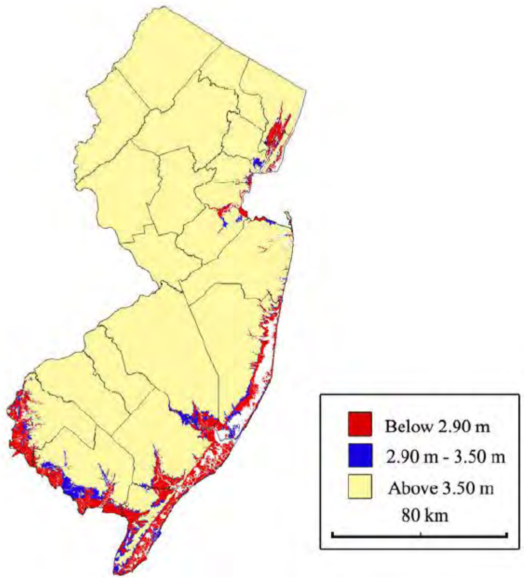

Figure 2. Estimated coastal land area susceptible to episodic flooding applying current 100-year flood water level (2.90 m) and 0.61 m rise in sea level (3.50 m) in New Jersey.[16]

Given these multiple variables, in addition to the region's area-specific phenomenon of land subsidence, estimates of sea level rise for the New York City (Figure 1.) and coastal New Jersey (Figure 2.) region are necessarily broad in range. According to a 2009 report by the New York City Panel on Climate Change (NPCC),[17] based on both IPCC and other predictive models, SLR for the New York City region is expected to increase by:

- 2 to 10 inches by the 2020s[18]
- 7 to 29 inches by the 2050s[19]
- 12 to 55 inches by the 2080s[20]

These predictions cited above include rapid ice melt scenarios, which are particularly challenging to predict and can result in substantially higher SLR.

Recent analysis from the University of Utrecht in the Netherlands has suggested a disproportionately greater risk to New York City of climate change-induced SLR.[21] A presentation given at the European Geosciences Union (EGU) meeting in April 2011 asserts that New York City can expect to see the most substantial rise in sea level – 20% more than the

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[16] Cooper, M.J.P. et al. (2005). *FUTURE SEA LEVEL RISE AND THE NEW JERSEY COAST Assessing Potential Impacts and Opportunities*
[17] Horton, Radley and O'Grady, Megan et al. Climate Risk Information. New York City Panel on Climate Change. New York, 2009. Pg 17
[18] Horton, Radley and O'Grady, Megan et al. Climate Risk Information. New York City Panel on Climate Change. New York, 2009. Pg 17
19 Ibid.
20 Ibid.
[21] Black, Richard. (2011, April 8). *BBC News - New York Set to Be Big Loser as Sea Levels Rise*. BBC - Homepage. Retrieved May 2, 2011.

AR4 global average estimate of 28 cm (1 ft.) by 2100.[22] This predicted range falls within the NPCC predicted range of 12 to 55 inches by 2080.

In addition, the IPCC 2007 report presents an expectation of an increase in global average annual precipitation during the 21st century. Although changes in precipitation will vary from region to region, annual average precipitation increases will occur over the northeastern United States in winter.[23] The 2009 NYPP *Climate Risk Information* report predicts: "Total annual precipitation in New York City and the surrounding region will more likely than not increase. Precipitation is characterized by large inter-annual variability, making these projections more uncertain than those for temperature. Mean annual precipitation increases projected by modeling are 0 – 5% by the 2020s, 0 – 10% by the 2050s and 5 – 10% by the 2080s."[24]

c. Impacts of sea level rise in New York and New Jersey

A large portion of the New York City and New Jersey metro region lies less than 10 feet above mean sea level, and infrastructure in these areas is impacted by coastal flooding during major storm events, both from inland flooding and from coastal storm surges.[25] Much of the PANYNJ infrastructure lies near water bodies susceptible to SLR and related storm surge events, with over half of PANYNJ facilities potentially impacted. (Appendix B.) The Figure 3 to the right shows the schematic locations of all PANYNJ facilities.[26]

Figure 3

d. Regional adaptation planning undertaken in New York and New Jersey

[22] Ibid.

[23] IPCC (2007) Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change p.30

[24] Horton, Radley and O'Grady, Megan et al. Climate Risk Information. New York City Panel on Climate Change. New York, 2009. Pg 3

[25] Climate Change and a Global City: An assessment of the Metropolitan East Coast (MEC) Region Coastal Zone Sector Report: Sea Level Rise and Coastal Hazards(June 8, 2000)

[26] Port Authority of New York & New Jersey. (n.d.). *About - Overview of Facilities and Services*
. Retrieved April 30, 2011 from The Port Authority of New York & New Jersey:

The risks posed by SLR and increased precipitation to infrastructure and buildings in the New York and New Jersey region has prompted a range of action from various agencies, committees and task forces (See Appendix C for detailed information). In 2008, two multi-stakeholder groups were formed to develop adaptation strategies to protect New York City's infrastructure from the effects of climate change: the Climate Change Adaptation Task Force (CCATF) and the New York City Panel on Climate Change (NPCC). The CCATF, lead by NYC Mayor's Office of Long Term Planning and Sustainability, was charged with creating an inventory of existing at-risk infrastructure; to analyze and prioritize the components of each system; to develop adaptation strategies; and to design guidelines for new infrastructure.[27] The Task Force and NPCC provided tools to assess risk and vulnerability in the Adaptation Assessment Guidebook (AAG), which was created to help stakeholders understand the adaptation process, create inventories of at-risk infrastructure, and identify appropriate adaptation strategies. CCATF lead a process to evaluate strategies related to cost, timing, feasibility, co-benefits, resiliency, and efficacy. The state of New Jersey is addressing climate change risks as well through the New Jersey Department of Environment's Office of Climate and Energy. Prompted by the Global Warming Response Act passed by the state legislature in 2007, an interdisciplinary working group was formed and a task force called the Sustainable Jersey Climate Adaptation Task Force was created to identify or develop tools and guidance for local governments.[28]

e. Key Terms: Adaptation, Resilience and Sustainable Design

Climate change adaptation is an emerging field, and has many definitions. One of the leading climate research entities in the UK, The Tyndall Centre for Climate Change Research defines adaptation as "taking any action to prepare for climate change which is intentional or accidental [and includes] any action taken by anyone."[29] This general definition was refined using interviews and research to be applied to the scope of this report. Specifically, adaptation was researched for this report as it pertains to infrastructure that was similar to that in the PANYNJ's portfolio and related to the impact of SLR and increased precipitation. For the specific purposes of this report, **adaptation** is defined as the planning and actions undertaken to protect against, accommodate or retreat from the impacts of climate change, specifically sea level rise and increased precipitation.

Following the National Infrastructure Advisory Council (NIAC),[30] infrastructure **resilience** is defined as "the ability to reduce the magnitude and/or duration of disruptive events … [and] to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event." This definition echoes the above stated needs by the PANYNJ to be able to recover quickly and fully from climate change related impacts.

The PANYNJ has recognized the need to **mitigate** greenhouse gas emissions and has adopted a policy that defines mitigation as "reducing the adverse environmental impacts of the design, construction, operation, maintenance and occupancy" of their operations through the development of sustainable design guidelines for buildings and infrastructure.[31] By

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[27] *Mayor Bloomberg Launches Task Force to Adapt Critical Infrastructure to Environmental Effects of Climate Change.* (2008, August 12). NYC.gov. New York City, Retrieved May 2, 2011:

[28] Schell, C. (2010). *New Jersey ~ Adapting to Climate Change.*

[29] Tompkins, E.L et. al (2009). *An Inventory of Adaptation to Climate Change in the UK: Challenges and Findings.*

[30] National Infrastructure Advisory Council. (2009). *Critical Infrastructure Resilience Final Report and Recommendations*.

[31] Port Authority of New York and New Jersey Engineering Department. (2007) Sustainable Design Project Manual.

sustainable design, this report refers specifically to the range of environmentally protective and restorative criteria outlined in the PANYNJ Sustainable Design Guidelines. Much of the analytical focus of this report has been devoted to identifying infrastructure adaptation techniques that lie at the nexus between resilience and sustainable design. A matrix is also presented that illustrates synergies or conflicts between adaptive interventions and specific PANYNJ Sustainable Design Guidelines.

The PANYNJ Sustainable Building Guidelines were designed using the US Green Building Council Leadership in Energy and Environmental Design (LEED) rating system as a foundation. These guidelines apply to new construction and renovations that are above 20,000 square feet and exempts projects smaller than 5,000 square feet. The PANYNJ also developed Sustainable Infrastructure Guidelines that are designed for use on projects outside the building envelope.[32] These project types include work on airfields, roadways, utilities, rail track work, transportation systems, bridges, tunnels and marine structures. The sustainable infrastructure guidelines were developed using multiple references including LEED rating systems and existing city and state infrastructure design guidelines.[33]

III. RESEARCH METHODOLOGY

a. Project Scope

The scope of this project was defined by the following guidelines established at the onset of the project:

a. Define climate change adaptation and resiliency as it relates to infrastructure and buildings.
b. Focus on sea level rise, storm surge and increased precipitation as the climate change-related events of most relevance to the PANYNJ's infrastructure.
c. Research and report on current climate change adaptation practices being undertaken in comparable cities with comparable infrastructure that address these impacts.
d. Recommend adaptation strategies that are most applicable to the function and scope of PANYNJ.
e. Identify the synergies and areas of conflict between PANYNJ's sustainable design guidelines and recommended climate change adaptation strategies.

Using these guidelines research was conducted to identify relevant literature and case studies focused on the impacts of SLR, storm surge and increased precipitation. The research design focused on examples from domestic and international cities in which measures had been

[32] Port Authority of New York and New Jersey Engineering Department. (2010) Sustainable Infrastructure Guidelines.
[33] Ibid.

implemented to adapt or mitigate potential losses of at risk infrastructure. The criteria for selecting cases included; applicable climate risk type, applicable type of infrastructure, reasonable scale relative to PANYNJ facilities, illustrative of synergies between adaptation and sustainable design techniques, and whether the planning process was complete. The process did not include a focus on detailed economic assessments of various adaptation strategies as this was outside the scope of our analysis.

b. Initial client input

Denise Berger and Susanne DesRoches from the PANYNJ Engineering Department provided the Agency's technical sustainable design guidelines for infrastructure and buildings. In addition, the team identified professionals and academics in the field to interview and several existing reports that estimated the risks climate change imposed on the New York and New Jersey metropolitan area.

c. Literature review

A literature review formed the foundation of our research. Major sources of data included presentations and papers from the PANYNJ and other municipal and national agencies, departments of transportation and interior, intergovernmental and nongovernmental organizations, engineering and consulting firms, academic studies, and select media coverage. The literature review was subdivided into three categories: general climate change adaptation (e.g. IPCC recommendations), case studies, and sources recommended by the client. Case studies were selected on the basis of feasibility, relevance to PANYNJ infrastructure and sustainability guidelines, overall effectiveness, and technical synergies. Authoritative data were prioritized, and citations have been provided for further reference.

d. Expert interviews

Interviews were conducted with experts recommended by the client and leaders in the field identified using the same applicable criteria selection. Interviewees came from a range of backgrounds including academia, engineering and architecture consulting, transportation administration, and policy. Experts interviewed include:

- Thomas Abdallah, C.E.E., of the MTA/NYC Transit
- Aaron Koch, Policy Analyst in the NYC Mayor's Office for Long-Term Planning
- Kristin Lemaster, Environmental Engineer at CDM, an engineering consulting firm
- Arlyn Purcell, AICP, LEED AP, Supervisor, Environmental Programs, Aviation Department, PANYNJ
- Cynthia Rosenzweig, Ph.D., Senior Research Scientist at NASA Goddard Institute for Space Studies and co-chair of NYC Panel on Climate Change
- Etienne Rouverand, Head of Sustainable Design and Senior Architect at ADPI , an airport and infrastructure design firm
- Jacquelyn Wilkins, Sustainability Program Manager at MassPort

Interview questions were created to target and identify climate resilience strategies and innovative adaptation practices. Inquiries were tailored to each person's area of expertise.

e. Analysis

The completed research was analyzed to identify any repeated practices or a general approach to adaptation implementation. The analysis yielded several themes that informed the key findings and structure of the report.

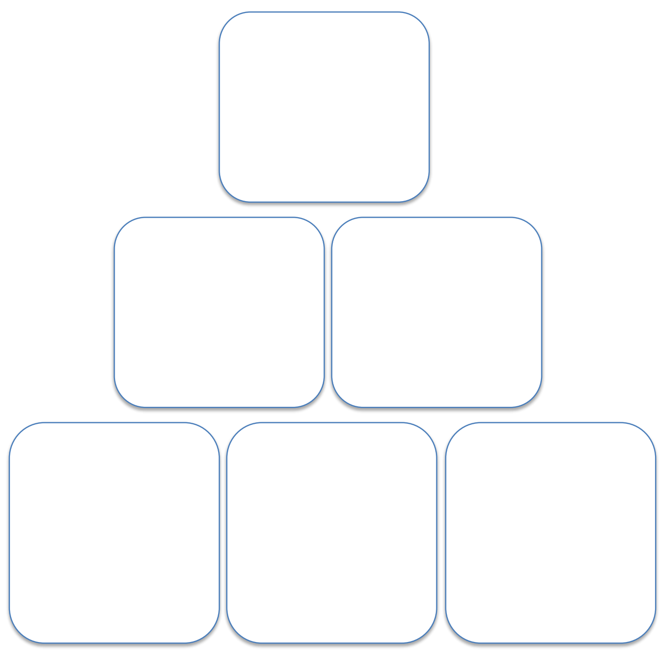
f. Deliverables

The project deliverables agreed upon with the client include:

1) An executive summary of findings
2) Full report identifying strategies and case studies
3) A matrix comparing identified strategies to existing PANYNJ sustainable design guidelines.
4) A collection of resources used to further guide PANYNJ's study of adaptation strategies
5) PowerPoint group presentation to PANYNJ staff.
6) PowerPoint presentation to Columbia University peers in the School of Continuing Education and the Sustainability Management program

IV. ADAPTATION STRATEGIES & CASE STUDIES

Overview



IPCC First Assessment. Working Group 3.

The framework for planning adaptation responses was created by the IPCC's First Assessment Report in 1990.[34] The research done for this report shows that this framework is still currently being applied to structure most adaptation related planning and research. As stated, the implementation of adaptation planning is in its infancy, but this framework has existed for the past two decades. Adaptation responses fall into two broad categories: **structural** and **operational**. Structural strategies denote large, capital-intensive projects that involve extensive planning, design or redesign. Operational strategies entail more incremental changes including enhanced maintenance, modification or redesign. Under these two response categories are three potential strategies: **protect, accommodate**, and **retreat**.[35]

[34] Framework for adaptation responses and strategies adopted from IPCC (1990). *First Assessment Report Climate Change: The IPCC Response Strategies - Chapter 5 Coastal Zone Management*

[35] Ibid

Protection strategies encompass a broad range of interventions designed to hold back sea water from inundating development, including sea walls, development of manmade topographical features to prevent erosion, and integrated pump systems. Accommodation strategies allow some inundation to occur, but protect infrastructure from damage and continually maintain operations and resiliency of infrastructure. Retreat, often the last resort, entails the managed withdrawal from coastal areas where neither protection nor accommodation is possible.[36,37]

The categories "protect and accommodate" were determined to be generally applicable to PANYNJ facilities. Case studies for these categories are presented in the following sections of this report. This effort did not include analysis of retreat strategies to determine applicability to PANYNJ as this was outside of the scope. Case studies of small-scale coastal relocation projects are included as informational examples.

> ***"Ultimately, I believe that we will need to undertake a wide range of strategies to build resilience in New York City. I do not believe that there is a silver bullet or a "one size fits all" solution to the impacts of climate change. To build resilience we will need to have redundant systems of protection that will likely be a mix of localized structural solutions as well as non-structural and "soft infrastructure" solutions."***
>
> -Aaron Koch, Policy Advisor, Mayor's Office of Long Term Planning and Sustainability

PROTECT	ACCOMMODATE	RETREAT
a. Barriers (permanent) b. Barriers (temporary) d. Coastal armoring e. Coastal sand dunes, beach nourishment	f. Pumps, sumps, catchments g. Enhanced maintenance h. Wetland protection, restoration i. Underground stormwater storage j. Natural stormwater management k. Green roofs l. Elevated buildings m. Floating infrastructure n. Waterway deepening/dredging	o. Managed relocation

[36] Few, R., Brown, K. and Tompkins, E.L. (2004) *Scaling Adaptation: Climate Change Response and Coastal Management in the UK.*

[37] IPCC (1990). *First Assessment Report Climate Change: The IPCC Response Strategies - Chapter 5 Coastal Zone Management*

PROTECTION STRATEGIES

As defined above protection strategies are designed to provide a barrier that protects inland infrastructure from fresh or seawater. These strategies are all structural approaches to adaptation. The following strategies are included under this section because they all prevent water from inundating land and infrastructure through a type of barrier.

a. Barriers (permanent)

A large, permanently installed protective structure that manages water flows into bays or other areas.

Dams are designed to impound water and come in a variety of configurations (arch, barrier, buttress, gravity, embankment) based on site topography and anticipated physical stresses.[38] Typical building materials include timber, rock, concrete, earth, and steel.[39] Embankment dams, the most commonly deployed type in the U.S., are made of earth and rock encasing a dense, waterproof core.[40]

Floodgates have portals that can be opened or closed to manage crest heights in canals, rivers and other inland waterways. They are often built at waterway entry points and can also be incorporated into dams to control spillway levels. Flood barriers, a subtype, consist of a series of adjustable doors specifically designed to protect waterways and wetlands from storm surge-associated flooding.

Advantage

✓ Can protect large areas of land and infrastructure from SLR and storm surge-related flooding

Disadvantages

- x Generally expensive to construct, inspect, operate and maintain[41]
- x Local ecological impacts of altered tidal and water flow patterns need to be carefully assessed[42]

Synergies and conflicts with sustainable design principles

> Dams and floodgates can protect the ecological health of wetlands and floodplains and soils by preventing inundation. The lower portions of

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[38] WGBH Science Unit and Production Group, I. (n.d.). *Dam Basics*. Retrieved April 30, 2011, from PBS Online
[39] New York State Department of Environmental Conservation (NYS DEC) (n.d.). *Dam Safety, Coastal & Flood Protection*. Retrieved April 30, 2011, from NYS DEC.
[40] Tam, Laura . (2009). Strategies for Managing Sea Level Rise. *Urbanist* . Retrieved from: San Francisco Planning and Urban Research Association (SPUR)
[41] Ibid.
[42] Ibid.

permanently installed dams can also be fitted with screens to prevent saltwater infiltration.[43] While some types of dams can be built with local and regional materials including rocks and soils, most incorporate energy- and GHG emissions-intensive concrete. Floodgates typically incorporate large quantities of steel and require energy to operate.

Relevance to PANYNJ

⇒Although dams are usually constructed to manage water flows or in hydroelectric operations, embankment dams can provide significant coastal protection against SLR and intensified coastal storm surges, especially in a low-lying area such as those around PANYNJ aviation facilities. Moreover, embankment dams and floodgates could be deployed to protect the wetland area around the airport, which New York City is currently planning to rehabilitate. However, the high construction and operation costs associated with dams and floodgates – particularly the flood barrier subtype - would likely entail significant regional coordination and federal support.

Case study

» Thames Barrier (UK)

The London Underground was built directly underneath the River Thames as well as other bodies of water. A combination of flooding- and precipitation-related challenges including ground water rise, seepage, flooding, and frequent storm surges – resulting in fatalities during 1928 Thames flood and North Sea Flood of 1953 – compelled the municipal authority to construct a flood barrier downstream of central London. Construction began in 1974 and concluded in 1982.[44] The second largest adjustable flood barrier in the world, the Thames Barrier cost $872 million (£534 million) to construct.[45] As of 2010, the Barrier has been raised 119 times: 76 to protect against tidal flooding, 43 to alleviate fluvial flooding.[46] These closures have protected London in general, and its subways and tunnels in particular, from storm surge flooding.[47] SLR has forced operators to execute more frequent closures: the gates were closed four times in the 1980s, 35 times in the 1990s, and 80 times from 2000-2010.[48]

Key challenges

Storm surge, SLR

Primary strategy

- Permanently installed flood barrier

Additional applicable strategies

- Pumps and sumps

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[43] PIANYC InCom Working Group 06 (1993). Problems Created by Saltwater Infiltration. *PTC1 report of WG 6 Iissue*. p. 17

[44] Environmental Agency *Thames Barrier Closures*. Retrieved April 30, 2011 from UK The Environmental Agency

[45] Ibid.

[46] Ibid.

[47] Ibid.

[48] Ibid.

- Entrance barriers

Image of the Thames Barrier[49]

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b. Barriers (flexible, modular, temporary)

Similar to permanent barriers, but these structures are temporary and moved into place only upon recognition of imminent flooding danger. They can be inflatable or modular structures made out of various types of material.[50]

Advantages

✓ Less expensive than permanent barriers and easy to install

✓ Temporary deployment means sediment and wildlife can pass through when not in use

✓ Can be adjusted to respond to incremental changes in sea level rise

Disadvantages

x Takes time and planning to be deployed

x Efficacy requires consistent monitoring of weather conditions

Synergies and conflicts with sustainable design principles

⇒ Inflatable barriers require energy to prepare for use. Possibility of local materials use generally limited. However, modular design generally entails minimal local environmental disturbance to assemble and install. Provides protection against storm-surge inundation for existing inland areas.

Relevance to PANYNJ

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[49] Environmental Agency *Thames Barrier-At Home and Leisure: Flood.* Retrieved April 30, 2011, From UK The Environmental Agency

[50] National Flood Forum: Blue Pages Master Document. July 2009

» Potentially useful strategy for sensitive inland areas, for example, wetlands adjacent to PANYNJ aviation facilities, that are ecologically fragile and therefore cannot accommodate large permanent barriers. According to the PANYNJ, they studied inflatable dams for protection of LaGuardia Airport from flooding as permanent barriers would be hazardous to aircraft operations.

Case study

» Tempe Town Lake inflatable dam The Tempe Town Lake is a man-made, constructed lake that was built by the city in 1999.[51] A flood levee and dam control system was built to contain the water and prevent flooding of downstream areas.[52] The dam consists of a system of eight inflatable dams, four on each side. The system consists of three elements: a flexible rubber-coated fabric tube fixed to a concrete base slab; an operating system controlling tube inflation and deflation; and an automatic safety device which guarantees tube deflation in flood situations.[53]

The inflatable dams were designed to be resistant to solar radiation and were expected to be durable, lasting up to 30 years.[54] However, in July 2010 the dams burst causing many gallons of water to flood a downstream dry riverbed. [55] The town disregarded a manufacturer safety recommendation. The town believed sufficient precautions were already in place to ensure the dam's proper performance.[56] The research did not show that this was representative of inflatable dam performance overall but is an interesting example of possible obstacles.

Key challenges

Flooding from lake elevation from increased precipitation

Primary strategy

- Inflatable barrier

Additional applicable strategies

- Can operate in concert with permanent barriers

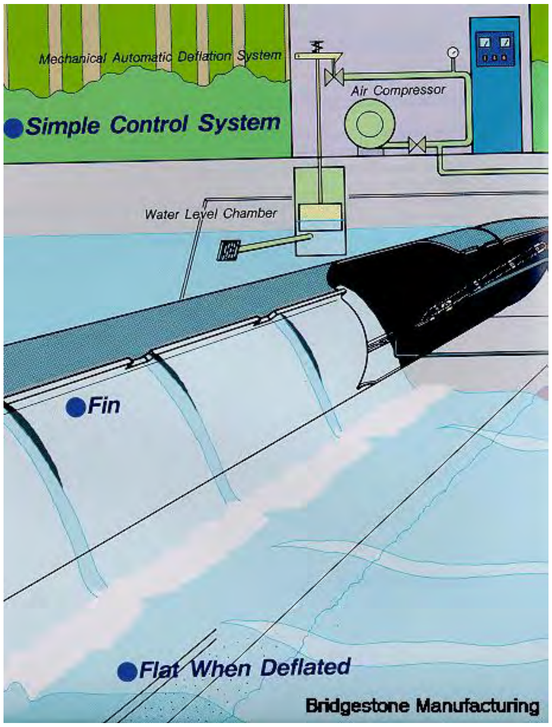

Diagram of inflatable dam[57]

[51] Tempe Town Lake on the Rio Salado. *Town Lake Water.* Retrieved May 2, 2011, from the City of Tempe, Az
[52] Ibid.
53 Tempe Town Lake on the Rio Salado. *Inflatable Dams*. Retrieved April 30, 2011, from the City of Tempe, Az
[54] *Tempe Town Lake Dam Bursts, Flooding River Bed* . (2010, July 21) CBS News. Associated Press, Retrieved May 2, 2011
[55] Ibid.
[56] Ibid.
[57] Ibid.

Case study

Modular floodwall at St. Paul Airport[58]

» St. Paul Airport (St. Paul, MN)

The St. Paul airport, located along the Mississippi River, has flooded three times in the last 15 years. The airport is home to a National Guard base that threatened to withdraw from the airport if the frequent flooding issues were not resolved.[59] Local complaints delayed the building of a permanent floodwall because of the fact that it would blocked views and "created an eye sore."[60] This barrier type is exceptionally flexible and easily deployed solution for flooding prevention.[61]

Key challenges

Flooding from increased precipitation

Primary strategy

- Modular steel-plate floodwall erected when flooding is predicted

d. Coastal Armoring

This is an artificial hardening of the coastline to prevent sea waves and tides from eroding and damaging the coastline and assets located inland.[62] Coastal armoring

[58] Flood Control America. (2009). *Featured Project IFCW™-Holman Field, St. Paul, MN.* Retrieved April 30, 2011 from Flood Control America Projects

[59] Douglas, J. (2011) *Deployment of Floodwall At St. Paul Downtown Airport Underway*. Retrieved from Minnesota National Guard In the News

[60] Product website. Flood Control America. (2009). *Featured Project IFCW™-Holman Field, St. Paul, MN.* Retrieved April 30, 2011 from Flood Control America Projects

[61] Douglas, J. (2011) *Deployment of Floodwall At St. Paul Downtown Airport Underway*. Retrieved from Minnesota National Guard In the News

[62] Bird, E. (Ed.). (2010). *Encyclopedia of the World's Coastal Landforms* (1 ed.). p.128

strategies are some of the oldest flood protection tools and include hard structures such as concrete sea walls, bulkheads, and riprap or softer forms such as levees or flood-banks. [63] Seawalls and bulkheads are continuous, rigid walls while riprap is any large rock (1 to 6 ton) or other hard material piled up to create a barrier.[64] Levees or flood-banks are soft earthen walls designed and constructed to contain, control, or divert the flow of water to provide some level of protection from flooding [65]. United States has thousands of miles of leaves systems; some date back as far as 150 years while others have been completed recently or are under development.[66]

Advantages [67]

✔ Can be easily combined with other forms of protections

✔ Protects buildings and infrastructures and maintains property values[68]

✔ Can be used against both storm surge and baseline sea level rise

Disadvantages [69]

x Armored shorelines are more impacted by erosion and increase erosion of nearby beaches
x Negative impacts to coastal wildlife and habitat
x Negatively effects beach view and reduces amount of beach and access to the beach

Synergies and conflicts with sustainable design principles

>Coastal armoring can negatively affect the health of wetlands by reducing the amount of area that wetlands can expand into. As sea levels rise wetlands will naturally move inland, protecting inland property from flooding. Coastal armoring blocks this natural migration of wetlands and the wetlands are submerged under the rising seas.[70]

Relevance to PANYNJ

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[63] Tam, Laura . (2009). Strategies for Managing Sea Level Rise. *Urbanist* . Retrieved from: San Francisco Planning and Urban Research Association (SPUR)
[64] Stamski, R. (2005, June) *COASTAL EROSION AND ARMORING IN SOUTHERN MONTEREY BAY A Technical Report in Support of the Monterey Bay National Marine Sanctuary Coastal Armoring Action Plan* v1.1. Monterey,California.
65 U.S. FEMA (n.d.). *Levee System Information for Stakeholders*. Retrieved April 30, 2011 from U.S. FEMA.
[66] Ibid.
[67] Tam, Laura . (2009). Strategies for Managing Sea Level Rise. *Urbanist* . Retrieved from: San Francisco Planning and Urban Research Association (SPUR)
[68] O'Connell, J.F.(2010) *Shoreline armoring impacts and management along the shores of Massachusetts and Kauai, Hawaii* , in Shipman, H. et al. (eds). USGS Publications Warehouse.
[69] Ibid.
70 Glick, P., Clough, J., and Nunley, N.. (2008) Sea-Level Rise and Coastal Habitats of the Chesapeake Bay: A Summary. National Wildlife Federation.

⇒It is feasible to construct coastal armoring to protect buildings and infrastructure areas from storm surge or sea level rise around coastal facilities in the PANYNJ district. They have been used already in Long Island, especially at Fire Island bay shores.[71] The PANYNJ's major airports – La Guardia, Kennedy, and Newark – which are coastal facilities, might be protected during severe storms if coastal armoring strategies were deployed.[72] The Port of LA case study that follows shows that armoring is applicable and can be successful at protecting dense, urban port infrastructure similar to that of the PANYNJ's port districts. According to the PANYNJ armoring has been done at LaGuardia Airport using fabric formed concrete to address a breach in the 1990's.

Case study
» Port of Los Angeles (CA)

The Port's infrastructure is located on 7,500 acres of land, 43 miles of waterfront and 26 major cargo terminals.[73] The port is impacted by sea level rise and storm surges. The exposed infrastructure includes wharfs, piers, bridges, highway systems and rail connections and storm and sewer drains.[74] The proposed interventions have not been implemented, but the proposal calls for extending and raising existing adaptation strategies, most explicitly the coastal armoring strategies. This analysis of urban port vulnerability and proposed solutions are a comprehensive look at the adaptation strategies that are applicable to dense, urban, port infrastructure. It also is a good example of the need for flexible strategies that can be added to or adjusted in the future.

Key challenges
Flooding due to increased precipitation, storm surges, and sea level rise.

Primary strategy
- Expand existing coastal armoring through the reinforcement and development of higher seawalls and jetties

Additional applicable strategies
- Reinforce and raise wharf and piers
- Raise the bridges, highways and rail connections
- Raise, reconfigure and resize the storm and sewage draining systems

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71 Nordstrom, K.F., Jackson, N.L., and Rafferty, P. (2010,) *Mitigating the Effects of Bulkheads on the Bay Shore of Fire Island National Seashore*. Shipman et al. (eds). Puget Sound Shorelines and the Impacts of Armoring—Proceedings of a State of the Science Workshop May 2009.
72 Stutz, B. (2009). New York City Girds Itself for Heat and Rising Seas. *Yale Environment 360*
73 Atkins, C. (2011) *Assessing the Need for Adaptation: The Port of Los Angeles/RAND Corporation.* Port of Los Angeles.
74 Ibid.

e. Coastal sand dunes, beach nourishment and fill[75]

Dunes are important ecosystems supporting unique plant and animal habitats.[76] Vegetation grows over the dunes and its roots help to bind the sand and stabilize the dunes. [77]Man-made dunes are the result of dune protection programs that have been initiated to enhance local dune restoration, [78]which usually consists of setting up a series of fences to trap the sand, then planting the proper vegetation to trap and hold the sand in order to build and stabilize the dune.[79] Similarly, beach nourishment is the process of adding sediment to a beach to rebuild the beach and to provide a buffer against coastal erosion. The sand may be dredged from nearby and pumped onto the beach or transported in from outside areas. It is considered a soft method of stabilizing the shoreline.[80] Dunes and beach nourishment protect the shoreline and beachside infrastructure from coastal storms and flooding, helping to reduce losses of and damage to inland coastal development.[81] Beaches are prone to erosion by natural process and by human activity, for this reason communities are advised to prohibit all alteration of sand dunes.[82] Activities like removal or cutting any vegetation, installing bulkheads or placing ripraps should be prohibited as they increase dunes susceptibility to erosion.

Advantages

✔ Reduce storm damage to coastal structures and protect shorelines against erosion[83]

✔ Dunes provide shelter from the wind to inland structures[84]

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75 U.S. Army Corp of Engineers. (2007). *Shore Protection Assessment: Beach Nourishment-How Beach Nourishment Works.*

76 U.S. Army Corp of Engineers. (2007). *Shore Protection Assessment: Beach Nourishment-How Beach Nourishment Works.*

77 Ward, W.T. (2006) Coastal Dunes and Strand Plains in Southeast Queensland: Sequence and Chronology Abstract. *Australian Journal of Earth Sciences: An International Geoscience Journal of the Geological Society of Australia.* Volume 53, Issue 2.

78 Paxton, T.P. (n.d.). *Monmouth County Planning Board's Eco-Tups: Coastal Dunes.* Retrieved April 30, 2011 from Monmouth County Planning Board, Environmental Planning Section Monmouth, NJ

79 Richard Stockton College of NJ New Jersey Beach Profile Network. (n.d.). *Monmouth County*. Retrieved April 30, 2011 from Richard Stockton College of NJ.

80Carey, W., Maurmeyer, E., and Pratt, T. (2004). *Striking a Balance A Guide to Coastal Dynamics and Beach Management in Delaware* Second Ed. Retrieved from Delaware Department of Natural Resources and Environmental Control (DNREC), Division of Soil and Water: Conservation:

81 Miller, T.E. et al. (2009, June 17) Climate and Coastal Dune Vegetation: Disturbance, Recovery, and Succession. *Plant Ecology-An International Journal*

82 Paxton, T.P. (n.d.). *Monmouth County Planning Board's Eco-Tups: Coastal Dunes.* Retrieved from Monmouth County Planning Board, Environmental Planning Section Monmouth, NJ

83 Paxton, T.P. (n.d.). *Monmouth County Planning Board's Eco-Tups: Coastal Dunes.* Retrieved from Monmouth County Planning Board, Environmental Planning Section Monmouth, NJ

84 Waikato Regional Council New Zealand Government. (n.d.). *Dune Erosion*. Retrieved April 30, 2011 from Waikato Regional Council New Zealand Government Environment

✔ Provide habitat for a wide variety of plants and wildlife[85]

Disadvantages

x They are fragile habitats and are affected by severe weather or from recreational activities[86]
x Sediment used for nourishment may harm habitat or wildlife in the target area[87]
x Imported sediment may differ in chemical makeup or structure and be detrimental[88]
x May reduce light availability in waterways and effect nearby reefs or smother aquatic life [89]
x Imported sand can cause erosion and disrupt ecosystems where sand was taken from[90]

Synergies and conflicts with sustainable design principles

> For many years, natural dunes were removed or altered to accommodate development,[91] leaving oceanfront properties more susceptible to damage from waves and wind during storm surges. Many synergies exist between the PANYNJ sustainable design guidelines and with coastal dune and beach nourishment projects most notably the guidelines for sites that address soil use, and appropriate vegetation. Conversely, possible conflicts with sustainable guidelines arise with coastal dune and beach nourishment projects in the area of protecting wetlands and floodplains. As mentioned, sediment used for beach fill can harm surrounding habitat, especially if it is fill foreign to the area.

Relevance to PANYNJ

⇒PANYNJ does not manage beaches as part of their infrastructure, however, many PANYNJ facilities and infrastructures lie along or adjacent to bodies of water including but not limited to the Hudson River, East River, Upper New York Bay, and Newark Bay that are susceptible to flooding hazards from storm surge events. Coastal dune state programs in New Jersey (specifically, Monmouth County) and Delaware can be used as a model for PANYNJ if implementation of dunes was desired. Where there are feasible coastline conditions, enhanced local dune restoration programs could make PANYNJ oceanfront lands less impacted by winds, high waves and storm surges associated with sea-level rise.[92]

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85 The Geography Site (2008). *Sand Dunes*. Retrieved April 30, 2011 from The Geography Site.
[86] Barber, D. (n.d.). *Beach Nourishment Basics.* Retrieved April 30, 2011 Bryn Mawr College Department of Geology
[87] Ibid.
[88] Ibid.
[89] Ibid.
[90]Grant, D. (n.d.). *Beach Renourishment: Are All The Dollars Making Cents?* Retrieved April 30, 2011 Brookdale Community College
91Paxton, T.P. (n.d.). *Monmouth County Planning Board's Eco-Tups: Coastal Dunes.* Retrieved from Monmouth County Planning Board, Environmental Planning Section Monmouth, NJ
[92] Delaware Department of Natural Resources and Environmental Control Public Affairs. (2008). News from the Delaware Department of Natural Resources and Environmental Control Vol. 38, No. 568

Case Study

» New Jersey Coastal Engineering Beach Nourishment Program and Shore Protection Fund

In New Jersey, beach nourishment is the fundamental component of the state's shore protection plan.[93] Almost every segment of the New Jersey coast has been maintained or protected by a local or state funded beach nourishment project since 1962.[94] Newly placed sand protects infrastructure from high waves, inundation, and areas of increased vulnerability. Prior to undertaking a project and determining a site location, a detailed cost-benefit analysis is usually performed to determine if the benefits of incremental protection exceed the cost of constructing and maintaining the beach in the long run.[95] Beach nourishment projects are generally designed to provide protection against the occurrence of a storm that has a 1% probability of being exceeded in any given year for a period of 50 years.[96] Consideration is usually given to constructing a beach that will protect coastal structures over their useful lifespan and includes the building of protective dunes as a buffer.[97] Due to the cost, nourishment projects are generally restricted to implementation in densely populated coastal regions with significant secondary benefits including, maintenance of federal navigation channels that significantly contribute to the local and regional economy.[98] As a more specific example, the beach at Atlantic City is very wide due to continuing beach nourishment through pumping of sand onshore every five years or whenever it is needed to protect the infrastructure. The beach nourishment and dunes are mostly needed as storm protection; materials used for deposit include a range of sediments (small pebbles to clay, but mostly sand) that are routinely dredged up from the ocean bottom a few miles offshore.[99]

Key challenges

Storm surges

Primary strategies

- Dunes and nourishment

Additional applicable strategies

- Sea floor dredging

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[93] Herrington , T.O., (n.d.). *New Jersey Sea Grant College Program Manual for Coastal Hazard Mitigation.* Retrieved April 30, 2011 at NJ DEP Coastal Management.
[94] Ibid.
[95] Ibid.
[96] Ibid.
[97] Ibid.
[98] Ibid.
[99] Leatherman, S. (n.d.). *New Jersey*. Retrieved April 30, 2011 from Dr. Beach.

Federal beach nourishment project in Atlantic City, NJ *Photo -US Army Corps of Engineers*[100]

Ocean City, New Jersey beach nourishment project..[101]

Managed Atlantic City, NJ : Beach and Dunes[102]

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[100] New Jersey Department of Environmental Protection (NJDEP). (2009, October 15). *Coastal Engineering-Beach Nourishment.* Retrieved April 30, 2011

[101]Rutgers University Institute of Marine and Coastal Science (n.d.). *Ocean City Fill image* Retrieved April 30, 2011

ACCOMMODATE STRATEGIES

As defined previously in the report, accommodation strategies allow water inundation to occur, but manage the flow and rate of inundation so that infrastructure is not damaged. These strategies can be either structural or built strategies or operational in their approach to adaptation.

f. Sumps, pumps and catchment systems

Sumps and catchment systems are used to collect excess rainwater that is not absorbed by impervious surfaces. Pumps are used to remove the storm water from a sump, catchment system or basin.[103]

Sumps, pumps and catchment systems are common strategies for coping with increased precipitation and storm water. Pumps are often used in concert with underground storage or holding basins, which are discussed as an adaptation strategy in this report.

While pumps are an effective means of management that helps delay and deter runoff, they are costly to operate in terms of carbon emissions and are energy intensive.[104] Often rainwater runoff contains pollutants when entering the storage location; therefore filtration devices must be used to remove sediment.[105] This runoff water can be used for grey-water systems, irrigation or for fire prevention.[106]

Advantages[107]

- ✓ Reduces storm water runoff
- ✓ Flexible and modular system

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102 City-Data. (n.d.). *Atlantic City, NJ : Beach and Dunes.* Retrieved April 30, 2011

103 Roaf, Susan (ed). (2010). Transforming Markets in the Built Environment: Adapting to Climate Change. *Architectural Science Review.* Volume 53. Number 1.

104 Smith, P.N. (2001). *Hydraulic Engineering Circular No. 24 Highway Stormwater Pump Design. U.S. Department of Transportation* (U.S. DOT) Federal Highway Administration National Highway Institute.

105 City of Chatanooga (n.d.). *Stormwater Best Management Practices Rock Filter Dam*. Chatanooga, TN: Retrieved April 30, 2011.

106 Ibid.

107 Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds., (2008). *Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change,* IPCC Secretariat

✓ Reuses collected rainwater

Disadvantages[108]

- x Pumps require energy to operate
- x Requires continuous maintenance
- x Basins, sumps and catchment systems have limited storage capacity

Synergies and conflicts with sustainable design principles

>Pumps conflict with sustainable design guidelines, as they can be energy intensive to operate. PANYNJ sustainable design guidelines require the reduction of energy use over a baseline. Energy consumption of this equipment contributes to increased carbon emissions. Pumps could conflict with this requirement, however efficient pump systems and renewable energy sources could help to reduce the impact that pumps have.

Relevance to PANYNJ

⇒The PANYNJ has a wide variety of infrastructure types. The benefit of sumps, pumps and catchment systems is that it is a flexible solution to storm water and flooding and could be used for each of the infrastructure types PANYNJ owns. It can be used in combination with above or below ground storage tanks as a temporary, quick fix solution. Sumps and pumps are used in conjunction with protective adaptive strategies and would be relevant to many coastal PANYNJ facilities. In the case study below, the use of sumps and pumps in concert with water reuse strategies would be a relevant comprehensive strategy for PANYNJ infrastructure. This would take advantage of synergies with their sustainable design guidelines for water reuse. According to the PANYNJ, the City of Newark currently operates a storm water pumping facility adjacent to Newark Airport. This facility lowers the water elevation in the drainage canal in advance of a storm allowing the upstream drainage systems to function properly in spite of high water levels in Newark Bay.

Case study

» Marmaray Project (Istanbul, Turkey)

The Marmaray Project in Turkey is a commuter rail tunnel system that is located along the coast of Turkey and travels under the Istanbul Strait.[109] The tunnel did not only need to be protected from rising sea levels from climate change, but from disasters such as tsunamis associated with earthquakes. Three of the transit stations are located underground and there is risk of leaks and flooding from storm surge.[110] The design of the project included several integrated strategies including sumps and pumps that reuse water for tunnel washing and fire-

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[108] United Nations Division of Technology, Industry and Economics *Rainwater Harvesting And Utilisation - An Environmentally Sound Approach for Sustainable Urban Water Management: An Introductory Guide for Decision-Makers*. Retrieved April 30, 2011

[109] Marmaray Project website. *Marmaray Rail Tube Tunnel and Commuter Rail Mass Transit System in Istanbul*. Retrieved on April 30, 2011

[110] Idib.

fighting, temporary raised barriers at transit entrances and flood gates.[111] As Marmaray was constructed relatively recently, it utilizes proven and effective strategies from its predecessors in preparing for potential issues including storm surge and sea level rise.

Key challenges

Flooding related to severe storm surges and sea level rise

Primary strategy

- Sumps and pumps

Additional applicable strategies

- Entrance barriers
- Floodgates

g. Enhanced maintenance

Many of the adaptation strategies cited in this report take significant planning and resources. Enhanced maintenance is an umbrella category that includes numerous ways of incrementally and immediately improving the resiliency of existing infrastructure not originally designed to withstand the predicted impacts of climate change. These strategies are mostly focused on reducing the deterioration rate of existing infrastructure that is exposed to climate change impacts.[112] These types of strategies are low cost in comparison to other large capital projects and can be deployed within existing operations structures.[113] The below examples are a non-exhaustive list of ways that agencies are using maintenance strategies to build in resilience to existing infrastructure.

- ***Epoxy sealants***
  Close cracks or holes in infrastructure that could leak or leave materials exposed to corrosion. [114]
- ***Materials replacement***
  Improved material types that resist corrosion are water resistant or allow for better filtration, from exposure to storm surge and increased precipitation.[115]
- ***Drain mapping and improved maintenance***

[111] Horgan, D. Flood (2007, July) Part 1: Linking Two Continents: The Marmary Project- Flood Protection: A Comparison. *PB Network* Issue 65.
[112] Auld, H., MacIver D. and Klaassen, J. (2007) Adaptation Options for Infrastructure Under Changing Climate Conditions. Occasional Paper 10. Environment Canada, Adaptation and Impacts Research Division. Toronto, Canada
[113] Grimes, G.A.and Barkan C.P.L. (2006) Cost-Effectiveness of Railway Infrastructure Renewal Maintenance . Journal of Transportation Engineering. American Society of Civil Engineers.
[114]Deyle, R.E., Bailey,K.C., and Matheny, A.(2007). Adaptive Response Planning to Sea Level Rise in Florida and Implications for Comprehensive and Public-Facilities Planning. Florida Planning and Development Lab Florida State University Department of Urban and Regional Planning.
115 Ibid.

Improve knowledge of location and repair state of drains, pipes and ventilation gates. Implement improved maintenance program to more frequently clean and monitor drain infrastructure. In addition to its adaptive benefits of creating a more resilient drainage system, this strategy has been employed to monitor and seal pipe leaks to reduce water use and in turn, reduce energy used for pumping.[116]

Advantages[117]

✓ Incremental change with immediate resilience benefits

✓ Relatively less capital intensive

✓ Considered a "no regrets action" that improves operations while simultaneously addressing resilience. No regrets actions are defined as actions that provide benefits regardless of the level of impacts of climate change.[118]

Disadvantages[119]

x Does not address long-term planning issues as these strategies may only be effective up to a certain level or climate change impact

x Requires planning for the assignment of labor and resources

Synergies and conflicts with sustainable design principles

> This strategy has a synergy with sustainable design guidelines that focus on integrated maintenance, durability and design flexibility as it helps improve the life of the structures and reduces the need for large capital projects.

Relevance to PANYNJ

⇒ Infrastructure deteriorates with age.[120] Considering the PANYNJ has a significant amount of infrastructure; it is reasonable to believe, like all other infrastructure, that they undergo perpetual wear and tear. Performing continuous maintenance on these infrastructures will mitigate the cause for capital-intensive retrofits and new construction.[121] The PATH transit system could benefit from a joint study with the MTA similar to the Drain London project.

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[116] Institute for Sustainable Communities Climate Leadership Academy. (2010) Promising Practices in Adaptation and Resilience: A Resource Guide for Local Leaders v1.0.

[117] Miller, C. (2010). Extensive Green Roofs. Whole Building Design Guide a Program of the National Institute of Building Sciences.

[118] Auld, H., MacIver D. and Klaassen, J. (2007) Adaptation Options for Infrastructure Under Changing Climate Conditions. Occasional Paper 10. Environment Canada, Adaptation and Impacts Research Division. Toronto, Canada

[119] U.S. DOE Energy Efficiency and Renewable Energy Federal Energy Management Program. (2004). *Federal Technology Alert Green Roofs.*

[120] Durango, P., and Madanat, S. (2002). Optimal Maintenance and Repair Policies in Infrastructure Management Under Certain Facility Deterioration Rates: An Adaptive Control Approach. *Transportation Research Part A Volume 36.*

[121] Ibid.

Case study
» London Underground – Drain London Project (UK) [122]

The London Underground was built directly underneath the River Thames as well as other bodies of water. There have been several separate efforts aiming to protect the London Underground from flooding and leaking. Drain London was developed as a drainage mapping and risk assessment program to manage the continuing operations of London's extensive network of pumps and drains. The London Drain project is a good example of a cross-agency solution that integrates risk assessments, strategic planning, improved maintenance standards and advanced modeling to provide short-term management of climate change impacts.

Key challenges
Flooding induced by increased precipitation

Primary strategy
- Drain mapping and enhanced maintenance

Additional strategies in London climate adaptation plan
- Raised entrances
- Floodgates
- Thames barrier
- Pumps and sumps

Additional applicable case studies in this report

- Maryland Roadways (use of new paving materials that were water resistant and some that were pervious for better infiltration). See page 37.

h. Wetland protection, restoration and manmade wetlands

Wetlands are a living, natural shoreline features that includes vegetation and wildlife. They are transition areas between land and water, providing a buffer against storm surge and flooding.[123] The type of soil, vegetation, level of water and wildlife of wetlands varies greatly between regions, but they are present on every continent except Antarctica.[124]

Advantages[125]

- ✓ Create habitat for wildlife and organisms that live in tidal areas
- ✓ Wetlands filter water and reduce pollutants

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122 Greater London Authority. *Drain London .* Retrieved April 30, 2011 from Greater London Authority Environment, Water

123 U.S. EPA Office of Water. (2004). *U.S. EPA Wetlands Overview.*

124 Ibid.

125 National Oceanic and Atmospheric Administration (NOAA). (2010). *Adapting to Climate Change: A Planning Guide for State Coastal Managers*.

✓ Sequester carbon

✓ Provide recreational open space

✓ Reduce heat island effect

✓ Less costly than structural shore protections

✓ Absorb storm surge and flooding

✓ In the case of the Bluebelt Program, property values increased because of proximity to green space and recreation that this strategy provides[126]

Disadvantages

x As seen in the Bluebelt Program case study, constructing new wetlands or restoring existing wetlands in urban areas requires that large tracts of land be purchased or set aside and removed from use for development. This can be politically and financially prohibitive.

x They require close monitoring, management and protection while they are being built or rebuilt[127]

Synergies and conflicts with sustainable design principles

>There are many synergies between wetland protection and PANYNJ sustainable design guidelines. The infrastructure design guidelines cite the protection of wetlands as a sustainable sites consideration, so it is clear that PANYNJ could benefit from the synergies. Development of wetlands on previously developed or contaminated land requires significant planning and caution so as not to contaminate waterways further.

Relevance to PANYNJ

⇒Wetland protection is very relevant to PANYNJ because of the location of existing infrastructure, especially the John F. Kennedy Airport, located near the Jamaica Bay Wetlands. Jamaica Bay restoration projects are ongoing and have been supported by PANYNJ.[128] By maintain and working to protect these wetlands, flooding and inundation at the airport could be minimized, as mentioned wetlands act as a buffer between water and the land.

Case study

» Galveston Bay Wetland Restoration (TX)

A number of areas in Galveston Bay have been progressively losing wetland acres to erosion, development and other pressures. Projects to rebuild and protect the Bay wetlands are ongoing.[129] This project includes restoration of a number of different areas within Galveston

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[126] London Climate Change Partnership. (2006). *Adapting to Climate Change: Lessons for London*. Greater London Authority, London.

[127] U.S. EPA Office of Water. (2004). *U.S. EPA Wetlands Overview.*

[128] Baron, Lisa, P. Weppler, J. Mcdonald. Hudson Raritan Estuary Comprehensive Restoration Plan. Public Meeting. May 20, 2010

[129] Galveston Bay Foundation. (*Conservation-Wetland Restoration.* Retrieved on April 30, 2011

Bay. It is a good example of the application of a multitude of strategies including more traditional levees, addition of sediment and native vegetation[130] and the innovative reef block system, made from living oysters that become a natural blockade to prevent erosion.[131] The combination of wetlands restoration, barriers and natural stormwater management strategies is a good example of how to implement a synergistic combination of accommodation strategies.

Key challenges

Storm surges, sea level rise

Primary strategy

- Wetland restoration

Additional applicable strategies

- Dredging to restore wetlands
- Levees
- Living oyster reefs

Case study:

» Bluebelt Program for Stormwater Management (Staten Island, NY)

Localized stormwater issues for Staten Island frequently occur due to poor drainage and large amounts of impermeable surfaces. The Bluebelt program has improved Staten Island's ecosystems through this watershed-based stormwater and septic overflow control system that combines infrastructure planning with wetland restoration. As stated by the NYC Department of Environmental Protection, this program has saved them an estimated $80 million in comparison with building conventional storm sewer systems to treat them same problem. In addition, notably, the program is designed to address current problems of storm water management but also was designed to address the full built out potential of Staten Island based on current zoning. [132]

Key challenges

Flooding and sewer overflow due to storm surge and increased precipitation

Primary strategy

- Purchased land to become designated wetland

Additional applicable strategies

- Created stormwater detention ponds
- Enhanced stream flow and ponds
- Culvert upgrades and improvements

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130 Idib.

131 ReefBLK℠ (n.d.). *ReefBLK™ Oyster Reed Block System.* Retrieved April 30, 2011

132 New York City Department of Environmental Protection (NYC DEP). (2007). *The Staten Island Bluebelt: A Natural Solution to Storm Water Management.*

i. Underground stormwater storage tanks and basins

There are many different types and designs for structural stormwater infrastructure but the general intention of the strategy is to collect, store, divert, infiltrate, treat and potentially reuse stormwater runoff from impervious surfaces.[133] Urban areas typically lack of green space and the emergence of stormwater runoff as a key source of pollution have led to the frequent use of underground detention in cities.[134]

Underground options are specifically offered as a comparison to examples of natural or aboveground storm water management strategies that are discussed later in the report. However, they are complementary and can be used with natural stormwater strategies, catchment systems and green roofs.

Advantages[135]

✓ Reduces rate and amount of storm water runoff

✓ Allows for development of land by moving storm water collection below ground

✓ Easy installation using prefabricated modular systems

✓ Increased public safety in comparison to surface catchment and ponds

Disadvantages

x Requires integrating landscape designs to allow access for system maintenance. [136]
x Detention without infiltration does not allow for groundwater recharge and may deplete local watersheds[137]
x If not developed with a comprehensive watershed analysis, can be insufficient in slowing peak runoff[138]
x Maintenance can be challenging as debris can often clog openings[139]
x Higher cost compared to surface treatment of stormwater[140]

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[133] City of Portland, OR Bureau of Environmental Services. . *Stormwater Solutions Handbook. Taking it Underground*. Retrieved April 30, 2011
[134] Finlay, S. (2000). *Software for the Hydraulic Design of Underground Stormwater Detention Tanks.* Applied Modeling of Urban Water Systems, Computational Hydraulics International , no. 8
[135] City of Portland, OR Bureau of Environmental Services. (n.d.). *Stormwater Solutions Handbook. Taking it Underground*. Retrieved April 30, 2011
[136] Ibid.
[137] Committee on Reducing Stormwater Discharge Contributions to Water Pollution (2008). *Urban Stormwater Management in the United States.* National Research Council:
The National Academies Press:
[138] Ibid.
The National Academies Press.
[139] Lake Superior Duluth Streams. . *Stormwater Underground Storage.* Duluth, Minnesota: Retrieved April 30, 2011.

Synergies and Conflicts with Sustainable Design Principles

> Many synergies exist with Port Authorities sustainable design guidelines, as the PANYNJ requires that projects implement Best Management Practices in stormwater management. Underground storage tanks can be used to address issues of stormwater capture on brownfields where infiltration is not possible due to contamination.[141] In addition there are synergies with the capture and reuse of stormwater for irrigation. Conflicts arise in the area of energy use as underground storage tanks can utilize pumps and filters that require energy to operate.

Relevance to PANYNJ

⇒Similarly to the above natural stormwater management techniques, this strategy is relevant to managing stormwater and possible flooding at all PANYNJ buildings and infrastructure. This strategy is recommended in the sustainable design guidelines and can be used to satisfy New Jersey and New York stormwater permitting requirements.

Case study

» Brisbane International Airport (AU)[142]

In January 2011, Queensland suffered its worst storm-related flood since 1893. Despite this, the coastal airport handled the surges and flooding so well, that residents used the facility for shelter. Built in 1988 using SLR and flood projection contingency in the design, the airport was able to continue service throughout the crisis as the infrastructure was elevated above sea level beyond convention and catchment systems and basins had been established. These elements coupled with modular pumps, that were available at the time of the flood, successfully prevented floodwaters from harming the airport.[143]

Brisbane Airport[144]

[140] Ibid.
[140] Ibid.
[141] U.S EPA Brownfield Program. (2008). *Design Principles for Stormwater Management on Compacted, Contaminated Soils in Dense Urban Areas*
[142] Australian Associated Press. (2011) Brisbane Airport to Stay Open Amid Queensland Flood Crisis. *Herald Sun*.
[143] Walton, J. (2011). Brisbane Airport Open Overnight, but Road Closures are Worsening. Australian Business Traveller.
[144]Van Oord. (2008). Aerial Image of Brisbane Airport, Australia . Retrieved from Van Oord Newsroom:

The combination of land elevation and runoff management interventions has made Brisbane airport an unqualified success in its resistance of flooding.

Key challenges

Flooding and storm surge from increased precipitation and SLR

Primary strategy

- Underground basins and catchment systems

Additional applicable strategies

- Elevation
- Modular Pumps
- Channels and culverts

Flooding in Brisbane in 2011[145]

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j. Natural stormwater management (bioswales, channels and culverts, infiltration)

Natural stormwater management is characterized by structural or non-structural landscape elements designed to slow the rate of runoff while also removing silt and pollution from surface runoff water.[146] Vegetation, soil and other natural features are

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145 Davies, Ed. "Over 90 Missing in Australia as Floods Inundate Brisbane | Reuters." *Reuters.com*. Reuters, 11 Jan. 2011. Retrieved May 10, 2011.

146 City of Chicago Water Management *Green Design Drainage Swales*. Chicago, Illinois: Retrieved April 30, 2011

used in place of hard solutions like cement basins[147] and examples include swales or bioswales[148], channels, culverts[149], rain gardens, tree plantings and porous pavement that allows infiltration. [150]

Advantages[151]

- ✓ Reduces storm water runoff rate and amount
- ✓ Reduces the pollutant load in runoff through natural filtration
- ✓ Reduces erosion of land and sedimentation of waterways caused by runoff
- ✓ Natural swales require less maintenance than storm drains and piping
- ✓ Reduces heat island effect
- ✓ Provides habitat for wildlife and native vegetation[152]

Disadvantages

- x Use of natural filtration on severely contaminated brownfield sites is not always advisable if contamination still exists[153]
- x Requires some monitoring[154] and some projects can be expensive[155]
- x Usually most effective when implemented as part of a comprehensive solution so that structural overflow systems can be put into place if natural systems are overwhelmed. [156]

Synergies and Conflicts with Sustainable Design Principles

>Many synergies exist between the PANYNJ sustainable design guidelines and the natural stormwater management strategies including, helping to protect and maintain absorbent landscapes by maintaining water collection and drainage, mitigating heat island effect, implementing stormwater Best Management Practice strategies, and

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147 National Oceanic and Atmospheric Administration (NOAA)(2010) *Adapting to Climate Change: A Planning Guide for State Coastal Managers*. Silver Spring, Maryland

148 Bioswales are drainage swales that are planted with native vegetation.

149 University of Minnesota Extension. (1998*). Cross-Drainage Culverts Forest Management Practices Fact Sheet Managing Water Series # 10*. Retrieved April 30, 2011

150 City of Portland, OR Bureau of Environmental Services. . *Stormwater Solutions Handbook. Taking it Underground*. Retrieved April 30, 2011

151 Ibid.

152 Jurries, D. (2003). *BIOFILTERS (Bioswales, Vegetative Buffers, & Constructed Wetlands) For Storm Water Discharge Pollution Removal. Guidance for using Bioswales, Vegetative Buffers, and Constructed Wetlands for reducing, minimizing, or eliminating pollutant discharges to surface waters*. Oregon DEQ

153 U.S EPA Brownfield Program. (2008). *Design Principles for Stormwater Management on Compacted, Contaminated Soils in Dense Urban Areas.*

154 Ibid.

155 University of Minnesota Extension. (1998*). Cross-Drainage Culverts Forest Management Practices Fact Sheet Managing Water Series # 10*. Retrieved April 30, 2011

156 City of Portland, OR Bureau of Environmental Services. *Stormwater Solutions Handbook. Taking it Underground*. Retrieved April 30, 2011

sustainable landscape maintenance. Conversely, the only possible conflict of the sustainable design guidelines with natural stormwater management is the ability to maximize use of known contaminated land because water filtration through unknown contaminants can undesirably re-direct contaminants into habitats and other waterways.[157]

Relevance to PANYNJ

⇒ As cited previously in the report, PANYNJ facilities and infrastructures will be exposed to flooding from increased precipitation and sea level rise caused by climate change impacts. Flooding from storm events already currently affects infrastructure in the PANYNJ district. Natural stormwater management strategies can be deployed to reduce the potential of flooding and inundation. In addition, given that PANYNJ design guidelines already recommend these strategies, the opportunity for cost and implementation synergies are great.

Case study

» Maryland roadways (Edmonston, Maryland)

Many low-lying cities in Maryland along the Anacostia have problems with flooding that lead to sewer overflow and untreated stormwater runoff polluting the Anacostia waterway. The Anacostia is a river that spans mostly urban areas and has been polluted from runoff from roads and highways.[158] The city of Edmonston used federal stimulus dollars set aside for green infrastructure to implement a sustainable stormwater solution along their roadways.[159] Green infrastructure is an integrated approach to managing stormwater that uses both natural and structural systems to infiltrate, capture, treat and reuse stormwater.[160] The project goals included protecting the Anacostia River from polluted runoff, reducing flooding impact, encouraging green economic development, slowing traffic and creating an enhanced environment for pedestrians.[161] The rehabilitation project was complicated by existing urban utility infrastructure but ultimately was successful; the project just won a Green Highways Partnership award for going beyond compliance in stormwater management.[162]

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[157] U.S EPA Brownfield Program. (2008). *Design Principles for Stormwater Management on Compacted, Contaminated Soils in Dense Urban Areas.*

[158] Town of Edmonston, Maryland. (2010, July). *Greening of Decatur Street: Edmonston, MD: Green Street Design Options and Benefits Analysis.* Low Impact Development Center Beltsville, MD.

[159] Rein, Lisa. (2009). Prince George's Town Aims to Pave a 'Greener' Path. The Washington Post Washington, D.C..

[160] National Oceanic and Atmospheric Administration (NOAA)(2010) *Adapting to Climate Change: A Planning Guide for State Coastal Managers*. Silver Spring, Maryland

[161] Town of Edmonston, Maryland. (2010, July). *Greening of Decatur Street: Edmonston, MD: Green Street Design Options and Benefits Analysis.* Low Impact Development Center Beltsville, MD.

[162] Town of Edmonston, Maryland. . *Green Highways Partnership* Retrieved April 30, 2011

Low Impact Development Center image of proposed solution[163]

Key challenges

Flooding from increased precipitation

Primary strategies

- Porous pavement and brick replace blacktop
- Rain gardens in median
- Drought-resistant tree canopy to shade sidewalk and filter rainwater
- Reduce width of street and replace sides with moisture absorbing plants

k. Green Roofs

Green roofs refer to a roof structure that is partially or completely covered with growing medium, vegetation, and planted over a waterproof membrane.[164]Green roofs are designed to mitigate storm water runoff and reduce the heat island effects associated with non-albedo rooftops.[165] Rainwater is partially absorbed by the growing medium (1 gallon of water a sq. ft. for each 4in deep medium), which delays and decreases the amount of peak stormwater runoff for the site.[166][167] There are two types of green roofs: extensive and intensive. Extensive green roofs are typically less than 6 inches and typically contain small shrubbery and grasses.[168] Intensive green roofs are much deeper

[163] Low Impact Development Center *Town of Edmonston, Maryland LID Green Street*. Retrieved April 30, 2011
[164] Miller, C. (2010). *Extensive Green Roofs.* Whole Building Design Guide a Program of the National Institute of Building Sciences.
[165] Fischetti, M. (2008). How Do Green Roofs Work?. *Scientific American*.
[166] Moisse, K. (2010). Over the Top: Data Show "Green" Roofs Could Cool Urban Heat Islands and Boost Water Conservation. *Scientific American*.
[167] Berghage, R. et al. (2009, February). Green Roofs for Stormwater Runoff Control. U.S. EPA
[168] Miller, C. (2010). *Extensive Green Roofs.* Whole Building Design Guide a Program of the National Institute of Building Sciences

and can withstand heavier structures, vegetation (i.e. trees), and occupants.[169] Green roofs help mitigate heat island effect by decreasing surface air temperatures, this decreases the heat load on buildings, requiring less energy use for cooling. According to a 2006 study for NYC's Regional Heat Island Initiative, green roofs can cool surrounding area temperatures by an average of 16.4 degrees Celsius per unit area.[170]

Advantages[171]

- ✔ Controls storm water runoff
- ✔ Improves water quality
- ✔ Mitigates urban heat-island effects
- ✔ Provides an additional layer of insulation on the roof, which increases the energy efficiency of a building.

Disadvantages[172]

- x impacted by high winds because the membrane is not fastened to the roof
- x High upfront costs
- x Difficult to detect leaks in waterproof material unless a leak detection system is installed.
- x Requires ongoing maintenance
- x Can only be installed on flat roofs

Synergies and conflicts with sustainable design principles

> Green roofs are synergistic with sustainable design guidelines as they help reduce heat island effect in urban settings. Green roofs also increase the amount of green spaces and vegetation, helping to reduce storm water runoff and mitigating the need for energy-intensive pump systems to process the runoff. The PANYNJ sustainable design guidelines require the consideration of open space and appropriate vegetation. Lastly, through the reduction of heat island effect green roofs can reduced the cooling load on a building, reducing energy usage, which is a sustainable design goal of the PANYNJ.[173]

Relevance to PANYNJ

⇒The PANYNJ owns 45 million sq. ft. of building space in New York and New Jersey. [174] It is likely that several buildings in PANYNJ's portfolio are able to support a green roof (dependent on roof load specifications and roof style). Such retrofits could significantly reduce surrounding surface-temperature heat island effects and reduce

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169 Ibid.

170 Moisse, K. (2010). Over the Top: Data Show "Green" Roofs Could Cool Urban Heat Islands and Boost Water Conservation. *Scientific American*.

171 Miller, C. (2010). *Extensive Green Roofs.* Whole Building Design Guide a Program of the National Institute of Building Sciences

172 U.S. DOE Energy Efficiency and Renewable Energy Federal Energy Management Program. (2004). *Federal Technology Alert Green Roofs*.

173 Miller, C. (2010). *Extensive Green Roofs.* Whole Building Design Guide a Program of the National Institute of Building Sciences

174 Port Authority of New York & New Jersey. . *About - Real Estate & Development.* Retrieved April 30, 2011

storm water runoff from the buildings. By reducing the heat-island effect near PANYNJ's buildings, a reduced cooling load would be required, ultimately reducing energy costs. In addition, all new building developments could be considered for green roof installation.

Case study

» Chicago Green Building for Adaptation (IL) [175]

Chicago, is impacted by increasing temperatures and precipitation as a result of climate change. The new Rancho Verde complex, a recently constructed, 12-acre eco-industrial park made from a brownfield, sought to reduce heat island effect while managing storm water runoff in a sustainable way. One element of Rancho Verde's sustainable design was a green roof.

Rancho Verde site green roof[1]

This technique has effectively helped manage the facility's storm water runoff and has reduced the amount of energy required to cool the building. This LEED Platinum facility illustrates how various sustainability strategies have multiple benefits with systemic effects.

Key challenges

Increased precipitation and increased temperatures

Primary strategy

- Green roof

Additional applicable strategies

- Natural stormwater management (bioswales, rain garden)
- Underground stormwater storage tanks

l. Elevated Buildings

Freeboard building elevation is an elevation strategy that lifts the buildings lower floor above the predicted flood level.[176] It is currently used to fulfill the requirements for the National Flood Insurance Plan (NFIP) and is indicated as a

[175] Christy Webber Landscapes. (2009). *Regional Green Building Case Study.* Retrieved from Illinois Chapter USGBC

[176] Massachusetts Office of Coastal Zone Management . *StormSmart Coasts - Using Freeboard to Elevate Structures above Predicted Floodwaters*. Retrieved April 30, 2011

potential adaptation strategy for SLR.[177] This strategy is proven to work in coastal zones for residential and small buildings within predicted FEMA flood zones, but insurance policies are not yet designed to incorporate SLR.[178]

Advantages[179]

✔ Protects buildings within flood zones from water damage

✔ Reduces the relevant flood insurance premiums or risk, of losses due to floods.

✔ This strategy allows structures to be built upon an encroaching shoreline or in a vulnerable area, with low risk of flooding

Disadvantages[180]

No disadvantages were found.

Synergies and conflicts with sustainable design principles

>Elevation of buildings allows for the development of buildings within the flood zone and if designed with sensitivity, within wetland areas.[181] Earthwork strategies cited in the Port Authorities sustainable design guidelines can be implemented to raise the building using soil from the existing site, additionally brownfield sites could be utilized for elevated buildings.

Relevance to PANYNJ

⇒Since freeboards are currently only suitable for residential and small coastal buildings, this strategy is not applicable to large high-rise buildings, but could be considered as an option for smaller, coastal PANYNJ buildings within FEMA flood plains for reduced insurance premiums.[182] PANYNJ has issued climate change impact evaluation guidance for all new capital projects. This evaluation guidance directs staff that designs shall consider an 18" increase over the current FEMA 100-year flood level plus one-foot criteria (Current FEMA 100 year flood level plus 2.5').[183]

Case Study:

[177]U.S. FEMA (2010). Freeboard National Flood Insurance Policy Index. Retrieved April 30, 2011
[178] Batten, B. K. et al. (2008). *Evaluation of Sea Level Rise for FEMA Flood Insurance Studies: Magnitude and Time Frames of Relevance.* ASCE
[179] Coulbourne, W.L. (2010) Foundation Designs Required for Sustainability in Coastal Flood Zones. 2010 American Society of Civil Engineers Structures Congress.
[180] Shaw, W. *Raise Your Home, Lower Your Monthly Payments. Protect buildings and reduce monthly expenses with freeboard*. Massachusetts Office of Coastal Zone Management. Retrieved April 30, 2011
[181] U.S. FEMA (2009) *Design and Construction in Coastal A Zones.*
[182] Shaw, W. *Raise Your Home, Lower Your Monthly Payments. Protect buildings and reduce monthly expenses with freeboard*. Massachusetts Office of Coastal Zone Management. Retrieved April 30, 2011
[183] Port Authority of New York and New Jersey Engineering Department. (2010) Sustainable Infrastructure Guidelines.

»Maryland building performance standards[184]

Maryland has a proactive climate change plan. Their building performance standards include building codes that are designed to resist sea level rise and storm surge from increased precipitation. Maryland has taken a whole-ecosystem approach to sea level rise vulnerability and is one of the leading examples of coastal building adaptation.

Key challenges

Flooding from increased precipitation and inundation from sea level rise

Primary strategy

- Elevate buildings

Additional applicable strategies

- Deep pile or column foundations
- Flood and debris resistant materials
- Wind-resistant envelope

Maryland freeboard building standard[185]

m. Floating structures (bridges and buildings)

This strategy includes infrastructure or buildings that are designed to float on the water continuously or only under flooding conditions to accommodate for frequent

[184] Maryland Commission on Climate Change Adaptation and Response Working Group (2008, July) *Climate Change Chapter 5: Comprehensive Strategy for Reducing Maryland's Vulnerability to Climate Change.* Retrieved from Maryland Department of the Environment.

[185185] Maryland Commission on Climate Change Adaptation and Response Working Group (2008, July) *Climate Change Chapter 5: Comprehensive Strategy for Reducing Maryland's Vulnerability to Climate Change.* Retrieved from Maryland Department of the Environment.

flooding or sea level rise. Structural and civil engineers define the largest of these structures as Very Large Floating Structures (VLFS).[186] Two basic types exist, the semi- submersible-type and the pontoon-type.[187] This adaptation strategy has recently been considered as an effective strategy for bridge engineers to consider when planning and designing bridges for rising sea levels.[188] Floating buildings for residential and commercial use also can accommodate large changes in sea levels due to sea level rise, tides or storm surges.[189]

Advantages

✔ Flexible nature of the infrastructure accommodates varying degrees of sea level rise for continuous adaptation to changing climate impacts [190]

✔ Protects against seismic activity due to base isolation [191]

✔ Floating bridges have a shorter executive term and are less costly than conventional bridges[192]

Disadvantages

x High winds have damaged floating bridges in the past.[193]

x Only applies to new developments.

Synergies and conflicts with sustainable design principles

> Floating structures have no synergies with sustainable design principles outside of the integrated planning and design guidelines that are relevant to all infrastructure planning. One potential conflict to be aware of is the effect of floating structures that are sited on or near ecologically sensitive wetlands, swamps or other buffer zones. Siting and design of floating infrastructure should be sensitive to protecting these areas.

Relevance to PANYNJ

⇒For new bridge construction that the PANYNJ considers in the future, floating bridges could be a viable solution for new construction as floating infrastructure creates new spaces for structures offshore that will respond to changing sea level

[186] Watanabe, E. and Utsunomiya, T. (2003), Analysis and design of floating bridges. *Progress in Structural Engineering and Materials*, Vol 5: 127–144
[187] Ibid..
[188] Ibid.
[189] London Climate Change Partnership. (2006). *Adapting to Climate Change: Lessons for London*. Greater London Authority, London.
[190] Watanabe, E. and Utsunomiya, T. (2003), Analysis and design of floating bridges. *Progress in Structural Engineering and Materials*, Vol 5: 127–144
[191] Ibid.
[192] Seif, M. and Inoue, Y.(1998) Dynamic Analysis of Floating Bridges. *Marine Structures* Volume 11, Issues 1-2. p.29-46.
[193]Washington State Department of Transportation and Bucher, Willis & Ratliff Corporation. *(2000). Hood Canal Bridge East-Half Replacement Closure Mitigation Plan — Preferred Options*..

rise. The Battery Park City ferry terminal is an example of local floating infrastructure.

Case study

» Netherlands Floating Infrastructure [194]

Frequent flooding occurs due to the low-lying geography of the Netherlands. Much of the coastal and river-adjacent land is frequently flooded, so they have begun to successfully build structures that accommodate this reality. In 2005 they completed a floating greenhouse that floated atop a water storage area, creating synergies between the need for stormwater retention and development.[195] The greenhouse was floated atop of pontoon like structures. Following this, a full housing development of 34 amphibious and 14 purely floating houses was developed on the Maas River.[196] The house structure is similar with a hollow basement filled with foam, the house floats in up to 5.5m of water.[197]

Key challenges

Flooding due to increased precipitation and SLR

Primary strategies

- Floating buildings

Amphibious housing in Netherlands[198]

n. Waterway deepening, dredging and sediment traps

Dredging is an excavation activity done in shallow seas or fresh water areas with the purpose of gathering up bottom sediments that are impeding access to the waterway.[199] As

[194] London Climate Change Partnership. (2006,). *Adapting to Climate Change: Lessons for London*. Greater London Authority, London.
[195] Ibid.
[196] Ibid.
[197] Ibid.
[198] Ibid.

sea level rises, one potential effect will be increased erosion depositing more sediment into navigable waters. This may require channels to be deepened to counter act the rising water induced flooding[200] along the surrounding coastal land and ports. [201] Dredging activities are conducted to maintain existing channels, berths, and are often used to keep waterways navigable.[202] It is also used as a source to replenish sand on some public beaches, where too much sand has been lost because of coastal erosion.[203]

Advantages

- ✔ Prevents flooding by increasing channel depth and capacity[204]
- ✔ Improves passage into ports, allows for larger vessels to pass through[205]
- ✔ Allows larger energy efficient cargo ships to use channel and keeps ports competitive[206]

Disadvantages

- x Creates disturbances in aquatic ecosystems and harms wildlife[207]
- x Increases risk of erosion of coastline[208]
- x Expensive and requires on-going maintenance[209]

Synergies and Conflicts with Sustainable Design Principles

> Waterway deepening, dredging and sediment trap projects conflicts with the sustainable design guidelines to Protect the Ecological Health of Wetlands and Floodplains because oftentimes deepening and dredging projects can alter the ecological landscape and habitat.

Relevance to PANYNJ

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199 Haydel, J.F. and McAnally, W. H. (2002, November) *Port Sedimentation Solutions for the Tennessee-Tombigbee Waterway in Mississippi Report 1: Preliminary Evaluation*. Mississippi Department of Transportation.

200 U.S. Geological Survey (USGS). (1992). *Water-Resources Investigations Report 90-4041 POTENTIAL EFFECTS OF DREDGING THE SOUTH FORK OBION RIVER ON GROUND-WATER LEVELS NEAR SIDONIA, WEAKLEY COUNTY, TENNESSEE*. Nashville, TN

201 Korean Ministry of Land Transport and Maritime Affairs. (2010). *Dredging in the Four Major Rivers Prevents Flood Damages*. Retrieved April 30, 2011

202 International Institute for Sustainable Seaports Global Environment & Technology Foundation and the Port of Portland. (2010) *Environmental Initiatives at Seaports Worldwide: A Snapshot of Best Practices.* Portland, Oregon.

203 Auckland Council Civil Defense Emergency Management (n.d.). *Natural Hazards Beach Erosion and Flooding* . Auckland, NZ: Retrieved April 30, 2011

204 US Army Corp of Engineers. (2009). *Delaware River Main Stem and Channel Deepening Project Environmental Assessment* Philadelphia, PA

205 Ibid.

206 Columbia River Channel Coalition. *Channel Deepening*. Portland, OR: Retrieved April 30, 2011

207 Sharp, J.A. et al. (2010). *Sediment Management Alternatives for the Port of Bienville*. Mississippi Department of Transportation.

208 West Virginia Conservation Agency. *Statewide Flood Plan Appendix H Dredging and Stream Channel Restoration.* p.231 Retrieved April 30, 2011

209 Ibid.

⇒Many PANYNJ facilities and infrastructures lie along or adjacent to bodies of water including but not limited to the Hudson River, East River, Upper New York Bay, and Newark Bay that are susceptible to flooding hazards from storm surge events. Waterway deepening, dredging and sediment trap strategies are deployed to reduce the potential of flooding. [210] Further, the PANYNJ currently has a consultant performing hydrographic surveys at navigable waterways to accommodate the increasing volume of deep-hulled vessels. [211] Additionally, PANYNJ has conducted harbor-dredging projects to prepare port terminals for deep draft vessels.[212]

Case Study:

» Port Canaveral Port Authority (FL)[213]

In 2004 Port Canaveral was affected by three land-falling hurricanes that resulted in operational interruptions stemming from the build up of sediment at the harbor entrance channel which limited cruise ship and essential cargo access. The port had to be dredged by the Army Corps of Engineers before it could resume operations and the port implemented a study to design a strategy to prevent such interruption in the future. In 2007 the South Jetty Deposition Basin, a sediment trap, was constructed to intercept sand shoaling prior to its ability to build up and act as a barrier to navigation in the channel. This is one example of an implemented and tested strategy for port resiliency that also addresses business performance needs of the port. The sediment trap has withstood two hurricane events including in 2009 when it effectively held back 100,000 cubic yards of sediment from being deposited in the harbor and port activities were not interrupted. The collected sediment was then used for beach nourishment.[214]

Key challenges

Storm surges

Primary strategies

- Sediment trap
- Seafloor dredging

Additional applicable strategies

- Dunes and beach nourishment

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[210] US Army Corp of Engineers. (2009). *Delaware River Main Stem and Channel Deepening Project Environmental Assessment* Philadelphia, PA

[211] S. T. Hudson Engineers. *The Port Authority of NY & NJ Hydrographic Surveys at Numerous Facilities.* Retrieved April 30, 2011

[212] Port Views (2008). *Port of New York and New Jersey Newsletter* Vol. 7, No. 1 Spring 2008. Retrieved May 9, 2011.

[213] Bodge, Kevin et al. (2009). *Port Canaveral South Jetty Deposition Basin Entrance Channel Sediment Trap.* Port Canaveral Port Authority. Canaveral, Florida.

[214] Ibid.

RETREAT STRATEGIES

As defined earlier in this report, retreat is a last resort strategy that includes development and zoning reformations or adjusted land use in coastal zone, or the managed withdrawal from coastal areas. This would be considered an operational or structural approach, depending on the specific strategy used. Analysis of retreat strategies was outside the scope of this project. However, below, managed retreat is discussed and two case studies presented as examples.

o. Move infrastructure (managed retreat)

Managed retreat is the planned abandonment of threatened areas near shorelines that moves buildings, infrastructure and people away from rising water and prevents inundation.[215] It can include planned abandonment or moving existing structures to higher ground or further away from encroaching water triggered by established thresholds to instigate the movement.[216] These thresholds can be tied with strict building codes that specify appropriate structure types, buy-back and relocation programs to compensate property owners, and land repurposing and redevelopment planning efforts that consider climate change risks.[217]

Advantages[218][219]

- ✔ Minimizes impacts by relocating buildings and infrastructure to safer ground
- ✔ Depending on type of infrastructure or building, it could be less expensive than building barriers or armoring
- ✔ Allows for restoration of wetlands and other natural buffers to storm surge and sea level rise
- ✔ Allows for redevelopment for pre-existing habitat and wildlife regeneration of waterside sites can provide an opportunity to recreate habitat lost from previous development.[220]

Disadvantages[221]

[215]NYSERDA ClimAID Team (2010). *Responding to Climate Change in New York State* the Synthesis Report of *Integrated Assessment for Effective Climate Change Adaptation Strategies in New York State*. Albany, NY

[216] Tam, Laura . (2009). Strategies for Managing Sea Level Rise. *Urbanist* . Retrieved from: San Francisco Planning and Urban Research Association (SPUR)

[217] Suffolk County Department of Planning. (2003). *Land Acquisition Programs: A Summary of Authorizing Legislation and Program Requirements Suffolk County, New York.* Hauppauge, New York.

[218] Tam, Laura . (2009). Strategies for Managing Sea Level Rise. *Urbanist* . Retrieved from: San Francisco Planning and Urban Research Association (SPUR)

[219] van Kappel, B. (2002). *Managed Realignment of Coastal Flood Defenses: A Comparison between England and Germany.* Flood Hazard Research Centre Middlesex University.

[220] Thames Estuary Partnership Biodiversity Action Group. (2010). *Tidal Thames Habitat Action Plan*. p. 11. London, UK.

[221] Tam, Laura . (2009). Strategies for Managing Sea Level Rise. *Urbanist* . Retrieved from: San Francisco Planning and Urban Research Association (SPUR)

- x Shoreline communities are oftentimes already disadvantaged and lack the adaptive capacity to relocate
- x Retreat may require costs beyond anticipated relocation or property costs if site remediation is required
- x Time consuming, involves legal and equity issues, and not all property owners are willing sellers.[222]

Synergies and Conflicts with Sustainable Design Principles

>No synergies exist with sustainable design principles.

Relevance to PANYNJ

⇒Managed retreat is recognized as requiring extensive regional planning and financial resources. It was beyond the scope of this effort to determine the applicability of retreat strategies for PANYNJ . PANYNJ provided input to the New York State Climate Change Action Council and the New York State Sea Level Rise Task Force[223]. Relocation is recognized in the New York State Climate Action Plan as an option for adaptation in coastal zones.[224] In public comments to the NYS Sea Level Rise Task Force, PANYNJ stated, "the Port Authority would argue that relocating urban infrastructure in New York City would be prohibitively expensive, cause huge social disruption, and may not be technically feasible."[225]

Case study

» NJ Department of Environmental Protection Green Acres Program-Blue Acres Funding Program [226]

New Jersey Coastal Blue Acres program acquires coastal lands damaged or prone to damages by storms to provide a buffer for other lands. The New Jersey's Green Acres Program, began in 1961 as a result of a bond referendum aimed at doubling New Jersey's open space and recreational lands. [227] Coastal Blue Acres (CBA) was created with the passage of the Green Acres, Farmland, Historic Preservation and Blue Acres Bond Act of 1995 as part of the Green Acres program for the acquisition of land that has been severely damaged by storms, or is threatened by future storms, or serves as a buffer to protect other land from storm damage.[228] In 2007, The Green Acres, Farmland, Blue Acres, and Historic Preservation Bond Act was passed that authorized $12 million for the acquisition of lands along the floodways and tributaries of the Delaware River, Passaic River or Raritan River by the government of the state of New Jersey for recreation and conservation. An additional $24 million was approved by

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[222] Suffolk County Department of Planning. (2003). *Land Acquisition Programs: A Summary of Authorizing Legislation and Program Requirements Suffolk County, New York.* Hauppauge, New York.
[223] Air Quality and Adaptation Planning. Port Authority of New York and New Jersey. Retrieved May 9, 2011
[224] New York State Climate Action Council (2010). *New York State Climate Action Plan Interim Report Chapter 11: Adapting to Climate Change.* Albany, NY.
[225]Zeppie, C. *New York State Sea Level Rise Task Force Report: Port Authority of New York and New Jersey's Comments.* Port Authority of New York and New Jersey. Retrieved May 9, 2011
[226] New Jersey Department of Environmental Protection (NJDEP). (2011). *Green Acres Program.* Trenton, NJ.
227 The Nature Conservancy. (2011, February 28). *Green Acres Program Marks its 50th Anniversary*. Trenton, NJ.
[228] National Oceanic and Atmospheric Administration (NOAA) (n.d.). *Ocean and Coastal Resource Management Land Acquisition Case Studies*. Retrieved April 30, 2011

voters in the Green Acres, Water Supply and Floodplain Protection, and Farmland and Historic Preservation Bond Act of 2009 due to recent and ongoing flooding throughout New Jersey that inspired all levels of government to maximize federal and state grants for the buyout of flood prone properties to help get people out of harm's way and create open space.[229] Properties (including structures) that have been damaged by, or may be prone to incurring damage caused by, storms or storm-related flooding, or that may buffer or protect other lands from such damage, are eligible for acquisition. Green Acres has created a special category of funding to assist towns and counties in acquiring flood prone lands. All land acquisitions through the Blue Acres program must be from willing sellers and land owners can submit an application to the state to sell their land via a form available on their website.[230]

Key challenges

Storm surges

Primary strategy

- Land Acquisition

Proposed section of the Malibu Beach Wildlife Management Area (WMA) near Ocean City, NJ along the Atlantic Coast to be restored and converted into migratory bird stopover habitat . Tile floors mark the area where an old bar and tavern once existed on the site. Adjacent beaches are critical feeding and resting areas for migratory, breeding, and wintering shorebirds and the area is prone to coastal flooding.[231]

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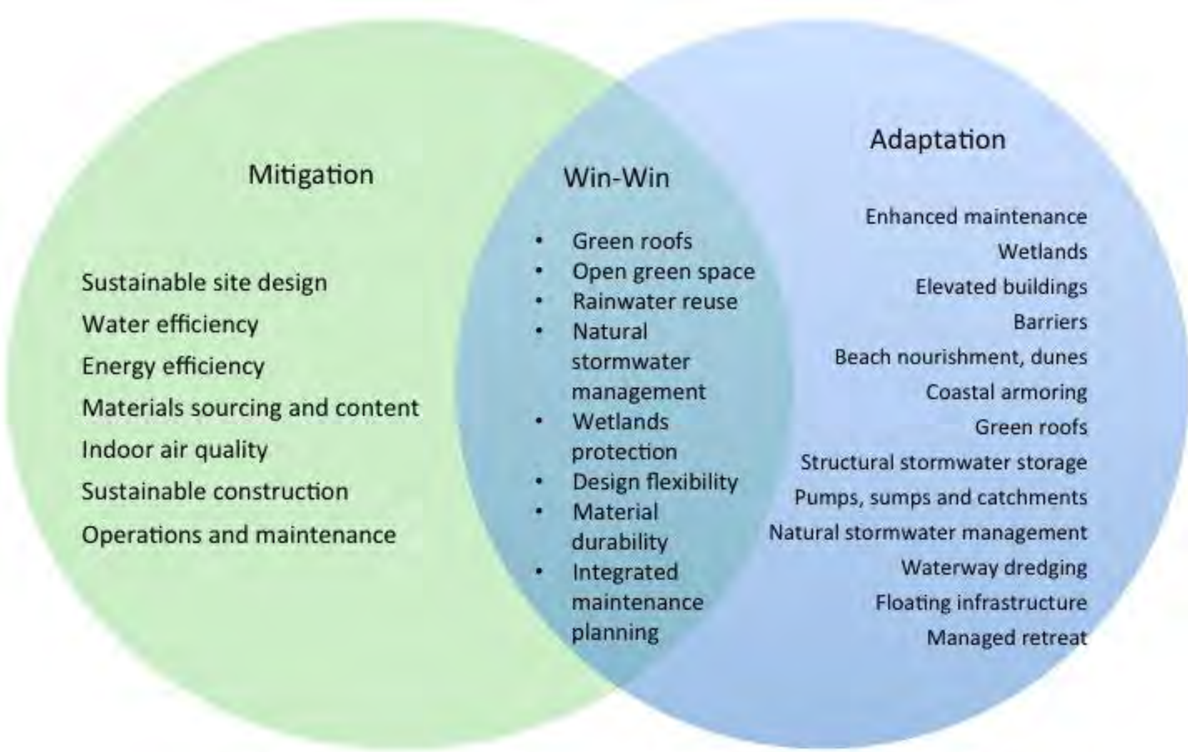
[229]New Jersey Department of Environmental Protection (NJDEP). (2011) *Green Acres Program Project Descriptions Grants and Loans to Local Governments and Nonprofit Organizations for Open Space Acquisition and Park Development Recommended for Funding to the Garden State Preservation Trust.* p. 5 Trenton, NJ.
[230] New Jersey Department of Environmental Protection (NJDEP). (2010). *New Jersey State Blue Acres Offer Application*. Trenton, NJ
[231] Conserve Wildlife Foundation of New Jersey. *Malibu Beach Maritime Forest Restoration Project*. Retrieved April 30, 2011

V. ADAPTATION STRATEGIES & SUSTAINABLE DESIGN



Adapted from "Toronto's Climate Change Agenda". Institute for Sustainable Communities. 2010. Promising Practices Adaptation & Resilience: A Resource Guide for Local Leaders. Pg 38. http://www.iscvt.org/who_we_are/publications/Adaptation_Resource_Guide.pdf.

Climate change mitigation is defined by the PANYN through its relation to design as, "reducing the adverse environmental impacts of the design, construction, operation, maintenance and occupancy" of operations. [232] Mitigation and climate change adaptation are not isolated concepts; rather, they are distinct but overlapping approaches to addressing the impacts of climate change. The relationship between the two is clear, by reducing emissions, we limit climate change impacts to a level in which we are capable of adapting to.[233] As defined earlier, adaptation in the context of this report is a response that is focused on building resilience to climate change impacts into infrastructure. Mitigation is defined as activities that reduce greenhouse gas emissions in order to minimize the severity of climate change impacts.[234] In the context of infrastructure adaption to SLR and increased precipitation, mitigation and adaptation have important areas of overlap and conflict that this report seeks to highlight.

[232] Port Authority of New York and New Jersey Engineering Department. (2007) Sustainable Design Project Manual.
[233] Institute for Sustainable Communities Climate Leadership Academy. (2010). *Promising Practices in Adaptation and Resilience: A Resource Guide for Local Leaders v1.0.*
[234] Pew Center on Climate Change. (2006). *Climate Change 101: Understanding and Responding to Global Climate Change.* Washington, D.C.

There are many benefits to taking advantage of these synergies and PANYNJ already has the framework for implementing mitigation activity. As such, they are in a good position to identify these synergies early on in adaptation planning. The report and attached matrix are meant to be an analysis of the intersection of the reviewed adaptation strategies and the Port Authorities existing sustainable design guidelines.

As previously stated, the goals of the sustainable design guidelines for both buildings and infrastructure are to reduce impacts on the environment, optimize project design, extend the lifecycle of projects and provide a cost savings in operational costs.[235] Both sets of guidelines are organized to address sites, water, energy, materials, construction, operations and maintenance and in addition, the building guidelines address indoor air quality.

The sites section of both sets of guidelines applies to the project site and surrounding habitat. This section addresses the location of the site, brownfields, transportation, open space, heat island effect, and stormwater, among other site development factors. This area has many overlaps with adaptation strategies that address both building and infrastructure protection and accommodation. The key synergies include strategies for reducing flooding from increased precipitation and sustainable design guidelines that address stormwater and wetlands. Green roofs, underground storage tanks, pumps, sumps and catchment systems and natural stormwater management strategies are a key set of integrated strategy that mitigate heat island, reducing energy use for cooling, reduce flooding through infiltration, allows for water reuse and reduces pollutants. However, some of these strategies need to be carefully considered on sites that are brownfields or contain capped contamination, as infiltration could need to be restricted.[236] Other conflicts should be considered when working with wetland adaptation strategies, permanent barriers, beach nourishment and coastal armoring all have potential negative effects on wetlands. [237]

The water efficiency section addresses the efficient use of water, the reuse of wastewater and requires stormwater management best practices and/or a water management plan. This section has similar synergies with the adaptation strategies as the site section. The adaptation strategies named above help to form an integrated waste and storm water management approach that can reduce potable water use.

Energy efficiency measures include energy reduction requirements over a baseline, commissioning activities and energy monitoring activities. The key conflict in this section that needs to be recognized is the pumps and sumps and underground storage tank adaptation strategies that utilize electrically driven pumps and filters to manage stormwater. Any adaptation strategies that require additional energy use should be analyzed to understand the tradeoff between additional protection and increased emissions.

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[235] Port Authority of New York and New Jersey (PANYNJ) Engineering Department. (2010). *Sustainable Infrastructure Guidelines*. New York, NY..

[236] U.S EPA Brownfield Program. (2008). *Design Principles for Stormwater Management on Compacted, Contaminated Soils in Dense Urban Areas.*

[237] Tam, Laura . (2009). Strategies for Managing Sea Level Rise. *Urbanist* . Retrieved from: San Francisco Planning and Urban Research Association (SPUR)

The guidelines for materials focus on the origin and content of materials as well as the general approach to materials management. The guidelines for the content of materials and maintenance and durability could be applied to any built adaptive strategies that require structural materials. The more important synergies are between the guidelines for design flexibility and the adaptive strategies. The PANYNJ building guidelines describes design flexibility as actions that "will facilitate future building modification, adaptive, reuse, expansion and/or disassembly" describes design flexibility."238 This type of flexibility and long-term planning is key to all built adaptation strategies as they need to be responsive to changing climate impacts and this guideline could be applied to all infrastructure adaptation design.

Construction guidelines address the effects of the process of construction on the surrounding community and habitat. These guidelines have synergies with adaptive strategies because the goal of construction strategies is to protect the resiliency of the surrounding community and natural systems. Some adaptive strategies like beach nourishment have potential negative impacts on the surrounding habitat. Using the PANYNJ guidelines for sustainable construction, it is possible to mitigate these negative affects by minimizing pollution.

> ***""We often see these two important topics [adaptation and mitigation] compete for resources. Often, mitigation wins out because the results are associated with money savings (e.g., energy efficiency). Adaptation is also a more difficult issue to address since it involves planning on a long-term horizon and the risks are not always easily identifiable. They relate in the fact that the more we emit, the higher the likelihood and severity of impacts."***
>
> – Kristin Lemaster, environmental engineer

The indoor air quality section contains guidelines that address daylight, occupant comfort and air quality. There are few overlaps between addressing indoor air quality in buildings and adaptations strategies. The one overlapping concept is that of thermal comfort. Green roofs and can reduce heat island effect, which in turn could reduce heat loads on the building. This can help to provide a more comfortable atmosphere for occupants.

Maintenance and operations sections contain guidelines for implementing continuing operations solutions that maintain the sustainability of the buildings and infrastructure. There are adaptation strategy overlaps in the area of enhanced maintenance strategies. These strategies are meant to be incremental changes that improve the resiliency of infrastructure. They are best implemented in the type of integrated, cross-departmental plan that the maintenance and operations design guidelines call for.

Retreat strategies are included in the matrix to illustrate the fact that these strategies do not have any synergies with sustainable design guidelines. Retreat strategies aim to minimize development and limit building in at risk areas, or move existing structures, and therefore do not use sustainable design strategies.

See appendix for matrix.

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[238] Port Authority of New York and New Jersey Engineering Department. (2007). *Sustainable Design Project Manual.*

VI. CONCLUSION

The critical infrastructure managed by PANYNJ is subject to the predicted impacts from climate change-accelerated SLR and increased precipitation. The strategies described in this report outline many of the possible adaptation strategies for managing the risks that SLR, intensified storm surges and increased precipitation pose to urban coastal infrastructure. Globally, many adaptation efforts have not yet been fully realized. This report illustrates several early successes that showcase some of the most effective and advanced techniques for managing these risks. These strategies require additional extensive analysis and further study by the PANYNJ to determine further their applicability to PANYNJ district infrastructure. The case studies presented highlighted some lessons learned but the continued monitoring of their success or failure is important to improving on any strategies planned or implemented by the PANYNJ.

"We believe that our responses to climate change must be based on science, and we are relying on the best scientific projections available to us. But at the same time, there is uncertainty about the rate and extent of climate change that we will face. To address this uncertainty we are seeking responses that provide flexibility and allow us to take an adaptive management approach. We are also prioritizing responses that provide immediate benefits and "no regrets"."

– Aaron Koch, Policy Advisor, Mayor's Office of Long-term Planning and Sustainability

The report also draws attention to the importance of a scientifically rigorous, integrated and flexible climate change response plan. The importance of having accurate scientific climate change predictions as the foundation of adaptation planning is exhibited throughout this report. The advantages of the integration of mitigation and adaptation strategies are shown in the analysis of the intersection between the two. The benefit of a fully integrated climate change response plan that addresses both mitigation and adaptation initiatives is clear. The integration of these concepts will fully realize the advantages of the overlaps and minimize the disadvantages of the conflicts. Built in flexibility in climate change planning is key given the uncertain nature of the rate and impact of climate change. All of the case studies included show how a flexible adaptation plan can, itself, adapt as needed. For example, adaptation strategies like coastal armoring and elevated infrastructure require monitoring and mid-course corrections in response to the latest climate change impact predictions, as adjustments to these strategies will be needed to maintain their success. This continually iterative process of monitoring and adjusting is vital to the long-term success of protect and accommodate interventions.

The continued monitoring of adaptation lessons learned, the further exploration of emerging and existing adaptation strategies, and the development of an integrated adaptation and mitigation response plan will place the PANYNJ in a position to effectively address the predicted impacts of climate change.

VII. BIBLIOGRAPHY

Abdullah, T. (2011, March 30). Chief Environmental Engineer for NYCT MTA. (E. Bourdeau, Interviewer)

Atkins, C. (2011, January 27) *Assessing the Need for Adaptation: The Port of Los Angeles/RAND Corporation.* Port of Los Angeles. Los Angeles, CA: *Retrieved* from American Association of Ports Authorities: http://aapa.files.cms-plus.com/SeminarPresentations/2011Seminars/11ClimateChange/11ClimateChange_Atkins_Carter.pdf

Auckland Council Civil Defense Emergency Management (n.d.). *Natural Hazards Beach Erosion and Flooding*. Auckland, NZ: Retrieved April 30, 2011 from Auckland Council: http://www.arc.govt.nz/council/civil-defence-emergency-management/natural-hazards/beach-erosion-and-flooding.cfm

Auld, H., MacIver D. and Klaassen, J. (2007) *Adaptation Options for Infrastructure Under Changing Climate Conditions.*
Occasional Paper 10. Environment Canada, Adaptation and Impacts Research Division. Toronto, Canada: Retrieved from Environment Canada: http://www.ec.gc.ca/Publications/71CA9FFD-DFE4-4EC2-BC36-8DC89BFCC885/OccasionalPaper10English.pdf

Australian Associated Press**.** (2011, January 12). Brisbane Airport to Stay Open Amid Queensland Flood Crisis. *Herald Sun*. Retrieved from Herald Sun Melbourne & Victoria News*:* http://www.heraldsun.com.au/news/national/brisbane-airport-to-stay-open-amid-queensland-flood-crisis/story-e6frf7l6-1225985961912

Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds., (2008). *Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change,* IPCC Secretariat, Geneva, 210 pp. Retrieved from Intergovernmental Panel on Climate Change: http://www.ipcc.ch/pdf/technical-papers/climate-change-water-en.pdf

Barber, D. (n.d.). *Beach Nourishment Basics.* Retrieved April 30, 2011 Bryn Mawr College Department of Geology: http://www.brynmawr.edu/geology/geomorph/beachnourishmentinfo.html

Baron, Lisa, P. Weppler, J. Mcdonald. *Hudson Raritan Estuary Comprehensive Restoration Plan.* Public Meeting. May 20, 2010. Retrieved May 9, 2011 from http://www.harborestuary.org/watersweshare/pdfs/HRECRP/PublicMtg-JBWR052010.pdf

Batten, B. K. et al. (2008). *Evaluation of Sea Level Rise for FEMA Flood Insurance Studies: Magnitude and Time-Frames of Relevance.* Conference Proceeding Paper Solutions to Coastal

Disasters Congress 2008. Retrieved from America Society of Civil Engineers: http://cedb.asce.org/cgi/WWWdisplay.cgi?162794

Berghage, R. et al. (2009, February). Green Roofs for Stormwater Runoff Control. U.S. EPA Retrieved from U.S. EPA publications: http://www.epa.gov/nrmrl/pubs/600r09026/600r09026.pdf

Bird, E. (Ed.). (2010). *Encyclopedia of the World's Coastal Landforms* (1 ed.). New York, NY: Springer. p.128

Black, Richard. (2011, April 8). *BBC News - New York Set to Be Big Loser as Sea Levels Rise*. BBC - Homepage. Retrieved May 2, 2011. http://www.bbc.co.uk/news/science-environment-13011073.

Bodge, Kevin et al. (2009, August 28). *Port Canaveral South Jetty Deposition Basin Entrance Channel Sediment Trap.* Port Canaveral Port Authority. Canaveral, Florida: Retrieved from American Association of Port Authorities Files: http://aapa.files.cms-plus.com/PDFs/FacilitiesEngAwards/2009/Canaveral_FE_Award_09.pdf

Carey, W., Maurmeyer, E., and Pratt, T. (2004). *Striking a Balance A Guide to Coastal Dynamics and Beach Management in Delaware* Second Ed. Retrieved from Delaware Department of Natural
Resources and Environmental Control (DNREC), Division of Soil and Water: Conservation: http://www.swc.dnrec.delaware.gov/SiteCollectionDocuments/Soil/Shoreline/StrikeBalance.pdf

Christy Webber Landscapes. (2009, March 11). *Regional Green Building Case Study.* Retrieved from Illinois Chapter USGBC: http://www.usgbc-illinois.org/wp-content/uploads/2009/09/CWL09.pdf.

City of Chatanooga (n.d.). *Stormwater Best Management Practices Rock Filter Dam*. Chatanooga, TN: Retrieved April 30, 2011 from City of Chattanooga BMP: http://www.chattanooga.gov/BMP4-07.pdf

City of Chicago Water Management (n.d.). *Green Design Drainage Swales*. Chicago, Illinois: Retrieved April 30, 2011 City of Chicago: http://www.cityofchicago.org/city/en/depts/water/supp_info/conservation/green_design/drainage_swales.html

City of Portland, OR Bureau of Environmental Services. (n.d.). *Stormwater Solutions Handbook. Taking it Underground*. Retrieved April 30, 2011 from the City of Portland Bureau of Environmental Services: http://www.portlandonline.com/bes/index.cfm?c=43110

City-Data. (n.d.). *Atlantic City, NJ : Beach and Dunes.* Retrieved April 30, 2011 from City-Data Atlantic City, NJ : http://www.city-data.com/picfilesc/picc45767.php

Climate Change and a Global City: An assessment of the Metropolitan East Coast (MEC) Region Coastal Zone Sector Report: Sea Level Rise and Coastal Hazards(June 8, 2000) Retrieved April 30, 2011 from: http://metroeast_climate.ciesin.columbia.edu/reports/coasts.pdf

Columbia River Channel Coalition. *Channel Deepening*. Portland, OR: Retrieved April 30, 2011 from Columbia River Channel Coalition: http://www.channelcoalition.com/

Committee on Reducing Stormwater Discharge Contributions to Water Pollution (2008, October). *Urban Stormwater Management in the United States.* National Research Council: The National Academies Press: Washington, D.C.. Retrieved from North Central Texas Council of Governments: http://www.nctcog.org/envir/SEEclean/stormwater/nrc_stormwaterreport.pdf

Conserve Wildlife Foundation of New Jersey. (n.d.). *Malibu Beach Maritime Forest Restoration Project*. Retrieved April 30, 2011 from Conserve Wildlife Foundation of New Jersey: http://www.conservewildlifenj.org/protecting/habitat/restoration/malibu/

Cooper, M.J.P. et al. (2005). *FUTURE SEA LEVEL RISE AND THE NEW JERSEY COAST Assessing Potential Impacts and Opportunities*. Retrieved May 1, 2011 from: http://www.environmentnewjersey.org/uploads/sR/9N/sR9N-sL9cXyA7pGI_ODVlw/Future_Sea_Level_Rise.pdf

Coulbourne, W.L. (2010) Foundation Designs Required for Sustainability in Coastal Flood Zones. 2010 American Society of Civil Engineers Structures Congress. Retrieved from Auburn Department of Engineering: ftp://ftp.eng.auburn.edu/pub/hza0002/ASCE%202010/data/papers/207.pdf

Davies, Ed. (2011)"Over 90 Missing in Australia as Floods Inundate Brisbane" Reuters. *Reuters.com*. 11 Jan. 2011. Retrieved May 10, 2011 from: http://www.reuters.com/article/2011/01/11/us-australia-floods-idUSTRE6BU09620110111

Delaware Department of Natural Resources and Environmental Control Public Affairs. (2008, December 30). News from the Delaware Department of Natural Resources and Environmental Control Vol. 38, No. 568 Retrieved April 30, 2011 from State of Delaware Department of Natural Resources and Environmental Control: http://www.dnrec.delaware.gov/News/Pages/ProtectCoastalAreasByNotPlacingOldChristmasTreesonSandDunes%3BOldTreesCanBeRecycled.aspx

Deyle, R.E., Bailey,K.C., and Matheny, A. (2007, September 1). *Adaptive Response Planning to Sea Level Rise in Florida and Implications for Comprehensive and Public-Facilities Planning.* Florida Planning and Development Lab Florida State University Department of Urban and Regional Planning. Retrieved from Florida Department of Community Affairs Publications: http://www.dca.state.fl.us/fdcp/dcp/publications/Files/AdaptiveResponsePlanningSeaLevelRise.pdf

Douglas, J. (2011, March 15) *Deployment of Floodwall At St. Paul Downtown Airport Underway*. Retrieved from Minnesota National Guard In the News: http://www.minnesotanationalguard.org/press_room/e-zine/articles/index.php?item=3139

Durango, P., and Madanat, S. (2002). Optimal Maintenance and Repair Policies in Infrastructure Management Under Certain Facility Deterioration Rates: An Adaptive Control Approach. *Transportation Research Part A Volume 36.* Berkeley, California. Retrieved from University of California Transportation Center Papers: http://www.uctc.net/papers/558.pdf

Environmental Agency (n.d.). *Thames Barrier Closures*. Retrieved April 30, 2011, from UK The Environmental Agency: http://www.grdp.org/research/library/publications/41065.aspx

Environmental Agency (n.d.). *Thames Barrier-At Home and Leisure: Flood*. Retrieved April 30, 2011, From UK The Environmental Agency: http://www.environment-agency.gov.uk/homeandleisure/floods/38353.aspx

Few, R., Brown, K. and Tompkins, E.L. (2004, October) *Scaling Adaptation: Climate Change Response and Coastal Management in the UK.* Working Paper 60. Tyndall Centre for Climate Change Research. Norwich, UK: Retrieved from SafeCoast: http://www.safecoast.org/editor/databank/File/scalingadaptationUK.pdf

Finlay, S. (2000). *Software for the Hydraulic Design of Underground Stormwater Detention Tanks.* Applied Modeling of Urban Water Systems, Computational Hydraulics International , no. 8, pp. 203-224; Retrieved from CSA Illumina: http://md1.csa.com/partners/viewrecord.php?requester=gs&collection=TRD&recid=200161001453CE&q=Applied+Modeling+of+Urban+Water+Systems%2C+Computational+Hydraulics+International+finlay&uid=790677094&setcookie=yes

Flood Control America. (2009). *Featured Project IFCW™-Holman Field, St. Paul, MN.* Retrieved April 30, 2011 from Flood Control America Projects: http://www.floodcontrolam.com/projects.php

Glick, P., Clough, J., and Nunley, N.. (2008, May) Sea Level Rise and Coastal Habitats of the Chesapeake Bay. National Wildlife Federation. Reston, VA: Retrieved from National Wildlife Federation Global Warming Chesapeake Bay and Global Warming: http://www.nwf.org/Global-Warming/Effects-on-Wildlife-and-Habitat/Estuaries-and-Coastal-Wetlands/~/media/PDFs/Global%20Warming/Reports/FullSeaLevelRiseandCoastalHabitats_ChesapeakeRegion.ashx.

Grant, D. (n.d.). *Beach Renourishment: Are All The Dollars Making Cents?* Retrieved April 30, 2011 Brookdale Community College: http://ux.brookdalecc.edu/staff/sandyhook/dgrant/field/dollars.htm

Grimes, G.A.and Barkan C.P.L. (2006, August) Cost-Effectiveness of Railway Infrastructure Renewal Maintenance . *Journal of Transportation Engineering*. American Society of Civil Engineers. Retrieved from Illinois Center for Transportation: http://ict.illinois.edu/railroad/CEE/pdf/Grimes%20&%20Barkan%202006.pdf

Fischetti, M. (2008, April 30). How Do Green Roofs Work?. *Scientific American*. Retrieved from Scientific American: http://www.scientificamerican.com/article.cfm?id=living-cover.

Galveston Bay Foundation. (n.d.). *Conservation-Wetland Restoration.* Retrieved on April 30, 2011 from the Galveston Bay Foundation: http://www.galvbay.org/conservation_wetlands.html

The Geography Site (2008, January 28). *Sand Dunes*. Retrieved April 30, 2011 from The Geography Site: http://www.geography-site.co.uk/pages/physical/coastal/dunes.html

Greater London Authority (n.d.). *Drain London .* Retrieved April 30, 2011 from Greater London Authority Environment, Water: http://www.london.gov.uk/drain-london

Greater London Authority (2010, February)*The Draft Climate Change Adaptation Strategy for London- Public Consultation Draft.* London, England: Retrieved from the Greater London Authority: http://legacy.london.gov.uk/mayor/priorities/docs/Climate_change_adaptation_080210.pdf

Herrington , T.O., (n.d.). *New Jersey Sea Grant College Program Manual for Coastal Hazard Mitigation.* Retrieved April 30, 2011 at NJ DEP Coastal Management: http://www.state.nj.us/dep/cmp/coastal_hazard_manual.pdf

Haydel, J.F. and McAnally, W. H. (2002, November) *Port Sedimentation Solutions for the Tennessee-Tombigbee Waterway in Mississippi Report 1: Preliminary Evaluation*. Mississippi Department of Transportation. Retrieved from Mississippi Department of Transportation Highways Divisions Reports: http://www.gomdot.com/Divisions/Highways/Resources/Research/pdf/Reports/InterimFinal/SS117.pdf

Horgan, D. Flood (2007, July) Part 1: Linking Two Continents: The Marmary Project- Flood Protection: A Comparison. *PB Network* Issue 65. Retrieved from Parsons Brinckerhoff PB Network Research Library: http://www.pbworld.com/news_events/publications/network/issue_65/pdf/050.pdf

Horton, R. and O'Grady, M. et.al. (2009, February 17). CLIMATE RISK INFORMATION. NEW YORK CITY PANEL ON CLIMATE CHANGE. New York, New York. Retrieved from: http://www.nyc.gov/html/om/pdf/2009/NPCC_CRI.pdf

Institute for Sustainable Communities Climate Leadership Academy. (2010, September) *Promising Practices in Adaptation and Resilience: A Resource Guide for Local Leaders v1.0.* Retrieved from Institute for Sustainable Communities Publications: http://www.iscvt.org/who_we_are/publications/Adaptation_Resource_Guide.pdf

International Institute for Sustainable Seaports Global Environment & Technology Foundation and the Port of Portland. (2010, April 1) *Environmental Initiatives at Seaports Worldwide: A Snapshot of Best Practices.* Portland, Oregon: Retrieved from Portland Bureau of Planning and Sustainability: http://www.portlandonline.com/bps/index.cfm?a=296244&c=53715

IPCC (1990). *First Assessment Report Climate Change: The IPCC Response Strategies - Chapter 5 Coastal Zone Management.* [Core Writing Team Working Group III] IPCC, Geneva, Switzerland.

Retrieved from Intergovernmental Panel on Climate Change: http://www.ipcc.ch/publications_and_data/publications_ipcc_first_assessment_1990_wg3.shtml

IPCC (2007). *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, p.30 Retrieved from Intergovernmental Panel on Climate Change: http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml

IPCC, (2007). *Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Retrieved from Intergovernmental Panel on Climate Change: http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf

Jurries, D. (2003, January). *BIOFILTERS (Bioswales, Vegetative Buffers, & Constructed Wetlands) For Storm Water Discharge Pollution Removal. Guidance for using Bioswales, Vegetative Buffers, and Constructed Wetlands for reducing, minimizing, or eliminating pollutant discharges to surface waters*. Retrieved from Oregon Department of Environmental Quality: http://www.deq.state.or.us/wq/stormwater/docs/nwr/biofilters.pdf

Koch, A. (2011, April 25). Policy Advisor at the Mayor's Office of Long-Term Planning, NYC. (S. Zoegall, Interviewer)

Korean Ministry of Land Transport and Maritime Affairs. (2010, August 20). *Dredging in the Four Major Rivers Prevents Flood Damages*. Retrieved April 30, 2011 from Korea News: http://www.korea.net/detail.do?guid=49269

Lake Superior Duluth Streams. (n.d.). *Stormwater Underground Storage.* Duluth, Minnesota: Retrieved April 30, 2011 from Lake Superior Duluth Streams: http://www.lakesuperiorstreams.org/stormwater/toolkit/underground.html

Leatherman, S. (n.d.). *New Jersey*. Retrieved April 30, 2011 from Dr. Beach: http://www.drbeach.org/NewJersey.htm

Lemaster, K. (2011, March 22). CDM. (E. Bourdeau, Interviewer)

London Climate Change Partnership. (2006, July). *Adapting to Climate Change: Lessons for London*. Greater London Authority, London. Retrieved from South Florida Regional Planning Council: http://www.sfrpc.com/Climate%20Change/9.pdf

Low Impact Development Center (n.d.). *Town of Edmonston, Maryland LID Green Street.* Retrieved April 30, 2011 from Low Impact Development Center Recent Projects: http://www.lowimpactdevelopment.org/projects_recent.htm#Recent14

Marmaray Project website. (n.d.). *Marmaray Rail Tube Tunnel and Commuter Rail Mass Transit System in Istanbul* . Retrieved on April 30, 2011 from Marmaray Project website: http://www.marmaray.com/

Maryland Commission on Climate Change Adaptation and Response Working Group (2008, July) *Climate Change Chapter 5: Comprehensive Strategy for Reducing Maryland's Vulnerability to Climate Change.* Retrieved from Maryland Department of the Environment: http://www.mde.state.md.us/assets/document/Air/ClimateChange/Chapter5.pdf

Massachusetts Office of Coastal Zone Management (n.d.). *StormSmart Coasts - Using Freeboard to Elevate Structures above Predicted Floodwaters*. Retrieved April 30, 2011 from Massachusetts Office of Coastal Zone Management: http://www.mass.gov/czm/stormsmart/regulations/freeboard.htm

Mayor Bloomberg Launches Task Force to Adapt Critical Infrastructure to Environmental Effects of Climate Change. (2008, August 12). NYC.gov. New York City, Retrieved May 2, 2011: http://www.nyc.gov/portal/site/nycgov/menuitem.c0935b9a57bb4ef3daf2f1c701c789a0/index.jsp?pageID=mayor_press_release.

Miller, C. (2010 June 11). *Extensive Green Roofs.* Whole Building Design Guide a Program of the National Institute of Building Sciences. Retrieved from Whole Building Design Guide Extensive Green Roofs: http://www.wbdg.org/resources/greenroofs.php.

Miller, T.E. et al. (2009, June 17) Climate and Coastal Dune Vegetation: Disturbance, Recovery, and Succession. *Plant Ecology-An International Journal*. Springer. New York, NY:. Retrieved at Florida State University Department of Biological Science: http://www.bio.fsu.edu/~miller/HOMEPAGE/docs/MillerGornishBuckley09.pdf

Moisse, K. (2010, February 2). Over the Top: Data Show "Green" Roofs Could Cool Urban Heat Islands and Boost Water Conservation. *Scientific American*. Retrieved from Scientific American: http://www.scientificamerican.com/article.cfm?id=green-roof-climate-change-mitigation.

National Flood Forum (2009) Blue Pages Master Document. Posted: July 2009 Retrieved : April 30, 2011 www.severnsidesolutions.co.uk/floodforum/files/Blue%20Pages%20Master%20Document%20July%2009.pdf

National Infrastructure Advisory Council. (2009, September 8). *Critical Infrastructure Resilience Final Report and Recommendations*. Washington, D.C.. Retrieved from U.S. Department of Homeland Security: http://www.dhs.gov/xlibrary/assets/niac/niac_critical_infrastructure_resilience.pdf

National Oceanic and Atmospheric Administration (NOAA)(2010) *Adapting to Climate Change: A Planning Guide for State Coastal Managers*. Silver Spring, Maryland: Retrieved from NOAA Office of Ocean and Coastal Resource Management: http://coastalmanagement.noaa.gov/climate/adaptation.html

National Oceanic and Atmospheric Administration (NOAA) (n.d.). *Ocean and Coastal Resource Management Land Acquisition Case Studies*. Retrieved April 30, 2011 from NOAA: http://coastalmanagement.noaa.gov/initiatives/shoreline_ppr_acquisition.html#2

The Nature Conservancy. (2011, February 28). *Green Acres Program Marks its 50th Anniversary*. Trenton, NJ: Retrieved from The Nature Conservancy Newsroom: http://www.nature.org/newsfeatures/media/pressreleases/green-acres-program-marks-50th-anniversary.xml

New Jersey Department of Environmental Protection (NJDEP). (2009, October 15). *Coastal Engineering-Beach Nourishment.* Retrieved April 30, 2011 NYDEP: http://www.state.nj.us/dep/shoreprotection/nourishment.htm

New Jersey Department of Environmental Protection (NJDEP). (2011, April 28). *Green Acres Program.* Trenton, NJ: Retrieved April 30, 2011 from NJDEP: http://www.state.nj.us/dep/greenacres/index.html

New Jersey Department of Environmental Protection (NJDEP). (2011, April 1) *Green Acres Program Project Descriptions Grants and Loans to Local Governments and Nonprofit Organizations for Open Space Acquisition and Park Development Recommended for Funding to the Garden State Preservation Trust.* p. 5 Trenton, NJ: Retrieved from NJDEP: http://www.state.nj.us/dep/greenacres/pdf/lnp.press.package.4_1_11.pdf

New Jersey Department of Environmental Protection (NJDEP). (2010, July 26). *New Jersey State Blue Acres Offer Application*. Retrieved from NJDEP: http://www.state.nj.us/dep/greenacres/pdf/blue_acres_app.pdf

New York City Department of Environmental Protection (NYC DEP). (2007, March 20). *The Staten Island Bluebelt: A Natural Solution to Storm Water Management.* Retrieved April 30, 2011 from NYC DEP: http://www.nyc.gov/html/dep/html/dep_projects/bluebelt.shtml

New York State Climate Action Council (2010, November). *New York State Climate Action Plan Interim Report Chapter 11: Adapting to Climate Change.* Albany, NY: Retrieved from NYC Climate Change: http://www.nyclimatechange.us/ewebeditpro/items/O109F24144.pdf

New York State Department of Environmental Conservation (NYS DEC) (n.d.). *Dam Safety, Coastal & Flood Protection*. Retrieved April 30, 2011, from NYS DEC: http://www.dec.ny.gov/lands/311.html

Nordstrom, K.F., Jackson, N.L., and Rafferty, P.(2010,) *Mitigating the Effects of Bulkheads on the Bay Shore of Fire Island National Seashore*. Shipman et al. (eds). Puget Sound Shorelines and the Impacts of Armoring—Proceedings of a State of the Science Workshop, May 2009: U.S. Geological Survey Scientific Investigations Report 2010-5254, p. 57-64. Retrieved from USGS Publications Warehouse: http://pubs.usgs.gov/sir/2010/5254/pdf/sir20105254_chap6.pdf

NYSERDA ClimAID Team (2010) *Responding to Climate Change in New York State* the Synthesis Report of *Integrated Assessment for Effective Climate Change Adaptation Strategies in New York State*. Albany, NY: Retrieved from New York State Energy Research Development Authority: http://www.nyserda.org/programs/Environment/EMEP/clim-aid-synthesis-draft.pdf

O'Connell, J.F.(2010) *Shoreline armoring impacts and management along the shores of Massachusetts and Kauai, Hawaii* , in Shipman, H. et al. (eds). 2010, Puget Sound Shorelines and the Impacts of Armoring—Proceedings of a State of the Science Workshop, May 2009: U.S. Geological Survey Scientific Investigations Report 2010-5254, p. 65-76. Retrieved from USGS Publications Warehouse:http://pubs.usgs.gov/sir/2010/5254/pdf/sir20105254_chap7.pdf

PIANC InCom Working Group 06 (1993). Problems Created by Saltwater Infiltration. *PTC1 report of WG 6 Iissue*. Brussels, Belgium: Retrieved from General Secretariat of PIANC Technical Reports: http://www.pianc.org/edits/articleshop.php?id=1000061

Paxton, T.P. (n.d.). *Monmouth County Planning Board's Eco-Tups: Coastal Dunes.* Retrieved April 30, 2011 from Monmouth County Planning Board, Environmental Planning Section Monmouth, NJ: http://www.visitmonmouth.com/page.aspx?ID=2969

Pew Center on Climate Change. (2006, October 12). *Climate Change 101: Understanding and Responding to Global Climate Change.* Washington, D.C.: Retrieved from Pew Center on Climate Change Reports: http://www.pewclimate.org/docUploads/Climate101-FULL_121406_065519.pdf

Port Authority of New York and New Jersey (PANYNJ) Engineering Department. (2007, August 15) *Sustainable Design Project Manual*. New York, NY.. Retrieved from PANYNJ: http://www.panynj.gov/about/pdf/Sustainable-Design-Project-Manual.pdf

Port Authority of New York and New Jersey (PANYNJ) Engineering Department. (2010, August 19) *Sustainable Infrastructure Guidelines*. New York, NY..

Port Authority of New York & New Jersey. (n.d.). *About - Overview of Facilities and Services.* Retrieved April 30, 2011 from The Port Authority of New York & New Jersey: http://www.panynj.gov/about/facilities-services.html

Port Authority of New York & New Jersey. (n.d.). *About - Real Estate & Development.* Retrieved April 30, 2011 from The Port Authority of New York & New Jersey: http://www.panynj.gov/real-estate-development/about-real-estate-development.html.

Port Authority of New York & New Jersey. (n.d.). *Air Quality and Adaptation Planning*. Port Retrieved May 9, 2011 from: http://www.panynj.gov/about/air-quality-adaptation-planning.html

Port Views (2008). *Port of New York and New Jersey Newsletter* Vol. 7, No. 1 Spring 2008. Retrieved May 9, 2011 from: http://www.panynj.gov/port/portviews/pv_fa_vol7_no1_6.html

Port Canaveral. (n.d.). *Photo Tours.* Canaveral, FL Retrieved April 30, 2011 from Port Canaveral: http://www.portcanaveral.com/cruising/phototour.php

Purcell, A. (2011, April 26). AICP, LEED AP Supervisor, Environmental Programs, PANYNJ Aviation Department. (H. Tovar, Interviewer)

ReefBLK℠ (n.d.). *ReefBLK℠ Oyster Reed Block System.* Retrieved April 30, 2011 from ReefBLK℠: http://www.reefblk.com/

Rein, Lisa. (2009, July 23). Prince George's Town Aims to Pave a 'Greener' Path. The Washington Post Washington, D.C.: Retrieved from The Washington Post: <http://www.washingtonpost.com/wp-dyn/content/article/2009/07/22/AR2009072203470.html>.

Reyes, M. (2004, December 9). *Congestion Management Game for LaGuardia Airport* 1.231. Final Report . Retrieved from MIT Airport Systems Planning, Design, and Management: http://ardent.mit.edu/airports/ASP_exercises/ASP%20Reyes%20report%20LGA.pdf

Richard Stockton College of NJ New Jersey Beach Profile Network. (n.d.). *Monmouth County*. Retrieved April 30, 2011 from Richard Stockton College of NJ: http://www.gannet.stockton.edu/crc/monmouth1.htm

Roaf, Susan (ed). (2010). Transforming Markets in the Built Environment: Adapting to Climate Change. *Architectural Science Review.* Volume 53. Number 1. Retrieved from Google Books: http://books.google.com/books?id=KpKzCIlHAm8C&pg=PA115&dq=disadvantages+of+rainwater+pumps+climate+change&hl=en&ei=A8irTZmrO6Hw0gGArKn5CA&sa=X&oi=book_result&ct=result&resnum=1&ved=0CEEQ6AEwAA#v=onepage&q&f=false.

Rosenzweig, C. and Solecki, W. (2010), *Chapter 1: New York City adaptation in context*. Annals of the New York Academy of Sciences,1196: 19–28. Accessed at: http://onlinelibrary.wiley.com/doi/10.1111/j.1749-6632.2009.05308.x/abstract

Rosenzweig, C. Dr. (2011, March 9(Senior Research Scientist at the Goddard Institute for Space Studies at Columbia University. (C. Resler, S. Knapp-Mills, and E. Bourdeau Interviewers)

Rouverand, E. (2011, April 4). Senior Architect, LEED AP Head of Sustainable Design at ADPI (S. Knapp-Mills, Interviewer)

Rutgers University Institute of Marine and Coastal Science (n.d.). *Ocean City Fill image* Retrieved April 30, 2011 from Rutgers University Institute of Marine and Coastal Science: http://marine.rutgers.edu/geomorph/oceancityfill.jpg

S. T. Hudson Engineers. (n.d.). *The Port Authority of NY & NJ Hydrographic Surveys at Numerous Facilities.* Retrieved April 30, 2011 from S. T. Hudson Engineers Hydrographic Surveys: http://www.sthe.com/portfolio/hydrographic-surveys.html

Schell, C. (2010, September 28). *New Jersey ~ Adapting to Climate Change.* Retrieved from North Jersey Transportation Planning Authority: http://www.njtpa.org/Plan/Element/Climate/documents/NJTPACWG92810final.ppt

Seif, M. and Inoue, Y.(1998, January) Dynamic Analysis of Floating Bridges. *Marine Structures* Volume 11, Issues 1-2. p.29-46. Retrieved from ScienceDirect: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V41-3TN44DT-2&_user=10&_coverDate=01%2F01%2F1998&_rdoc=1&_fmt=high&_orig=gateway&_origin=gateway&_sort=d&_docanchor=&view=c&_searchStrId=1736732015&_rerunOrigin=google&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=0ad49e8756bd3443d34ab7bf00494349&searchtype=a

Sharp, J.A. et al. (2010, February 8). *Sediment Management Alternatives for the Port of Bienville*. Mississippi Department of Transportation. Retrieved from Mississippi State Geosystems Research Institute:
http://www.gri.msstate.edu/publications/docs/2010/02/7186Sedimentation_Solutions_for_the_Port_of_Bienville_2010.02.08.pdf

Shaw, W. (n.d.). *Raise Your Home, Lower Your Monthly Payments. Protect buildings and reduce monthly expenses with freeboard*. Massachusetts Office of Coastal Zone Management. Retrieved April 30, 2011, from the Massachusetts Office of Coastal Zone Management:
http://www.mass.gov/czm/stormsmart/

Smith, P.N. (2001, February). *Hydraulic Engineering Circular No. 24 Highway Stormwater Pump Design. U.S. Department of Transportation* (U.S. DOT) Federal Highway Administration National Highway Institute. Retrieved from U.S. DOT On-line Publications:
http://isddc.dot.gov/OLPFiles/FHWA/010594.pdf.

Stamski, R. (2005, June) *COASTAL EROSION AND ARMORING IN SOUTHERN MONTEREY BAY A Technical Report in Support of the Monterey Bay National Marine Sanctuary Coastal Armoring Action Plan* v1.1. Monterey,California: Retrieved from Monterey Bay National Marine Sanctuary Resource Management Issues: Coastal Armoring:
http://montereybay.noaa.gov/resourcepro/resmanissues/pdf/061305erosion.pdf

Stutz, B. (2009, September 10). New York City Girds Itself for Heat and Rising Seas. *Yale Environment 360*. Yale School of Forestry & Environmental Studies. New Haven, CT: Retrieved from *Yale Environment 360*
http://e360.yale.edu/feature/new_york_city_girds_itself_for_heat_and_rising_seas/2187/

Suffolk County Department of Planning. (2003, July) *Land Acquisition Programs: A Summary of Authorizing Legislation and Program Requirements Suffolk County, New York.* Hauppauge, New York: Retrieved from Suffolk County New York:
http://www.co.suffolk.ny.us/upload/planning/pdfs/landacq_all.pdf

Tam, Laura . (2009, Nov/Dec). Strategies for Managing Sea Level Rise. *Urbanist* . Retrieved from San Francisco Planning and Urban Research Association (SPUR):
http://www.spur.org/publications/library/report/strategiesformanagingsealevelrise_110109

Tempe Town Lake on the Rio Salado. (n.d). *Inflatable Dams*. Retrieved April 30, 2011, from the City of Tempe, Arizona: http://www.tempe.gov/lake/lakehistory/dams.htm

Tempe Town Lake on the Rio Salado. (n.d). *Town Lake Water.* Retrieved May 2, 2011, from the City of Tempe, Arizona: http://www.tempe.gov/lake/water/

Tempe Town Lake Dam Bursts, Flooding River Bed . (2010, July 21) CBS News. Associated Press, Retrieved May 2, 2011 from:
http://www.cbsnews.com/stories/2010/07/21/national/main6698274.shtml

Thames Estuary Partnership Biodiversity Action Group. (2010, May 10). *Tidal Thames Habitat Action Plan*. p. 11. London, UK. Retrieved from Thames Estuary Partnership: http://www.thamesweb.com/tep-docs/cat_view/82-project-documents.html

Tompkins, E.L et. al (2009, July). *An Inventory of Adaptation to Climate Change in the UK: Challenges and Findings.* Working Paper 135. Tyndall Centre for Climate Change Research. Norwich, UK: Retrieved from University of Leeds: http://leeds.academia.edu/EmmaTompkins/Papers/107833/An_Inventory_of_Adaptation_to_climate_change

Town of Edmonston, Maryland. (2010, July). *Greening of Decatur Street: Edmonston, MD: Green Street Design Options and Benefits Analysis.* Low Impact Development Center Beltsville, MD: Retrieved April 30, 2011 from Town of Edmonston, Maryland Going Green: http://edmonstonmd.gov/GoingGreen.html

Town of Edmonston, Maryland. (n.d.). *Green Highways Partnership* Retrieved April 30, 2011 from Town of Edmonston, Green Highways Forum: http://edmonstonmd.gov/GreenHighwaysForum.html

United Nations Division of Technology, Industry and Economics (n.d.). *Rainwater Harvesting And Utilisation - An Environmentally Sound Approach for Sustainable Urban Water Management: An Introductory Guide for Decision-Makers* . Retrieved April 30, 2011 from UN Environmental Programme: http://www.unep.or.jp/ietc/publications/urban/urbanenv-2/7.asp

University of Minnesota Extension. (1998*). Cross-Drainage Culverts Forest Management Practices Fact Sheet Managing Water Series # 10*. Retrieved April 30, 2011 from University of Minnesota Extension: http://www.extension.umn.edu/distribution/naturalresources/dd6979.html

U.S. Army Corp of Engineers. (2007). *Shore Protection Assessment: Beach Nourishment-How Beach Nourishment Works.* Vicksburg, MS: Retrieved from ASBPA: http://www.asbpa.org/publications/fact_sheets/HowBeachNourishmentWorksPrimerASBPA.pdf

US Army Corp of Engineers. (2009, April). *Delaware River Main Stem and Channel Deepening Project Environmental Assessment* Philadelphia, PA: Retrieved from US Army Corp of Engineers Philadelphia District.: http://www.nap.usace.army.mil/cenap-pl/MainChannel_EA_3Apr09.pdf

U.S. DOE Energy Efficiency and Renewable Energy Federal Energy Management Program. (2004, September). *Federal Technology Alert Green Roofs*. Retrieved from National Renewable Energy Laboratory: http://www.nrel.gov/docs/fy04osti/36060.pdf

US Department of Transportation (USDOT) Climate Change Center. (2008). T*he Potential Impacts of Global Sea Level Rise on Transportation Infrastructure*. USDOT Climate Change Center. Retrieved May 10, 2011 from: http://climate.dot.gov/impacts-adaptations/sea_level_rise.html

U.S. EPA Office of Water. (2004, December). *EPA Wetlands Overview*. Retrieved from the U.S. EPA Office of Water: http://water.epa.gov/lawsregs/guidance/wetlands/definitions.cfm

U.S EPA Brownfield Program. (2008, April). *Design Principles for Stormwater Management on Compacted, Contaminated Soils in Dense Urban Areas.* Retrieved from the California Environmental Protection Agency: http://www.waterboards.ca.gov/losangeles/water_issues/programs/stormwater/municipal/ventura_ms4/CommentLetters/attachBIA/Attachment%205.%20EPA%20Bioretention%20Brownfields.pdf

U.S. FEMA (2009, January) *Design and Construction in Coastal A Zones* Retrieved from State of Rhode Island Emergency Management Agency: http://www.riema.ri.gov/documents/FEMA/FloodRelated/757_apd_2_coastalazones-1.pdf

U.S. FEMA (n.d.). *Levee System Information for Stakeholders*. Retrieved April 30, 2011 from U.S. FEMA: http://www.fema.gov/plan/prevent/fhm/lv_intro.shtm

U.S. FEMA (2010, August 11). Freeboard National Flood Insurance Policy Index. Retrieved April 30, 2011 from U.S. FEMA: http://www.fema.gov/plan/prevent/floodplain/nfipkeywords/freeboard.shtm

U.S. Geological Survey (USGS). (1992). *Water-Resources Investigations Report 90-4041 POTENTIAL EFFECTS OF DREDGING THE SOUTH FORK OBION RIVER ON GROUND-WATER LEVELS NEAR SIDONIA, WEAKLEY COUNTY, TENNESSEE*. Nashville, TN: Retrieved from USGS *Water-Resources Investigations:* http://pubs.usgs.gov/wri/wri90-4041/pdf/wrir_90-4041_a.pdf

van Kappel, B. (2002, March 4). *Managed Realignment of Coastal Flood Defenses: A Comparison between England and Germany.* Flood Hazard Research Centre Middlesex University. Retrieved from SafeCoast: http://www.safecoast.org/editor/databank/File/managed%20realignment.pdf

Van Oord. (2008). Aerial Image of Brisbane Airport, Australia . Retrieved from Van Oord Newsroom: http://www.vanoord.com/gb-en/our_newsroom/archive_news_releases/news_archive_2008/contract_brisbane_airport,_australia/index.php

Waikato Regional Council New Zealand Government. (n.d.). Dune *Erosion.* Retrieved April 30, 2011 from Waikato Regional Council New Zealand Government Environment: http://www.waikatoregion.govt.nz/Environmental-information/Regional-hazards-and-emergency-management/Coastal-hazards/Dune-erosion/

Walton, J. (2011, January 12). *Brisbane Airport Open Overnight, but Road Closures are Worsening*. Australian Business Traveller. Retrieved from Australian Business Traveller: http://www.ausbt.com.au/brisbane-airport-open-overnight-but-road-closures-are-worsening.

Ward, W.T. (2006) Coastal Dunes and Strand Plains in Southeast Queensland: Sequence and Chronology Abstract.
Australian Journal of Earth Sciences: An International Geoscience Journal of the Geological Society of Australia. Volume 53, Issue 2. Taylor & Francis. London, UK: Retrieved from Informaworld:
http://www.informaworld.com/smpp/content~db=all~content=a748039360~frm=titlelink?words=coastal,sand,dunes

Washington State Department of Transportation and Bucher, Willis & Ratliff Corporation. *(February 2000). Hood Canal Bridge East-Half Replacement Closure Mitigation Plan — Preferred Options*. (Core Writing Team: Soderquist, Amos, Wilson and Pawlak). Retrieved from Washington State Department of Transportation:
http://www.wsdot.wa.gov/NR/rdonlyres/B2244DE6-6FA8-4B8C-83AF-55872C2463E8/4531/HCBClosure.PDF

Watanabe, E. and Utsunomiya, T. (2003, July/September), Analysis and design of floating bridges. *Progress in Structural Engineering and Materials*, Vol 5: 127–144. Retrieved from Wiley Online Library: http://onlinelibrary.wiley.com/doi/10.1002/pse.151/abstract

West Virginia Conservation Agency. (n.d.). *Statewide Flood Plan Appendix H Dredging and Stream Channel Restoration.* p.231 Retrieved April 30, 2011 from West Virginia Conservation Agency:
http://www.wvca.us/flood/pdf/14_Appendix_H_Dredging_and_Stream_Channel_Restoration.pdf

Wilkins, J. (2011). Sustainability Program Manager, MassPort. (S. Knapp-Mills, Interviewer)

WGBH Science Unit and Production Group, I. (n.d.). *Dam Basics*. Retrieved April 30, 2011, from PBS Online: http://www.pbs.org/wgbh/buildingbig/dam/basics.html#emb

Zeppie, C. *New York State Sea Level Rise Task Force Report: Port Authority of New York and New Jersey's Comments.* Port Authority of New York and New Jersey. Retrieved May 9, 2011 from: http://www.panynj.gov/about/pdf/PANYNJ-Comments-Sea-Level-Rise-TF.pdf

Zimmerman, R., 2002: Global Climate Change and Transportation Infrastructure: Lessons from the New York Area. In *The Potential Impacts of Climate Change on Transportation: Workshop Summary*, U.S. Dept. of Transportation, Workshop, 1-2 October. Retrieved April 30, 2011 from: http://climate.volpe.dot.gov/workshop1002/.

VIII. APPENDIX

a. Matrix of sustainable design guidelines and adaptation strategies

See below matrix, zoom in to 300% for easier viewing.

Adaptation Strategies

Appendix a. Matrix of Sustainable Design Guidelines and Adaptation Strategies

KEY: ✔ = Complementary strategies

✖ = Conflicting strategy

? = Dependent on context

	Protect					Accommodate											Retreat	
						Enhanced maintenance												
	Barriers (including underground cut off walls)	Flexible structural barriers-modular, inflatable	Elevated infrastructure	Beach nourishment, fill and dunes	Coastal armoring	Equipment replacement	Drain mapping, and maintenance	Materials-water proof, water resistant	Epoxy Sealants	Greenroof	Wetland protection, restoration and man-made wetlands, riparian buffer zones	Underground storage tanks, on-site basins (pumps can be included in tanks)	Pumps, sumps and catchment systems	Natural stormwater management (bioswales, channels and culverts, infiltration)	Waterway deepening/dredging / sediment traps	Floating infrastructure	Move infrastructure	Changes in development planning and land use
Infrastructure Design Guidelines																		
SUSTAINABLE SITES																		
IS-1 Utilize an Integrated Team Approach	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔		
IS-2 Prepare a Site Assessment	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	Retreat strategies are not applicable to sustainable design guidelines as they are focused on limiting building and development in at risk areas	
IS-3 Maximize Use of Previously Developed Sites	✔	✔	✔			✔					?	✔		?				
IS-4 Maximize Use of Known Contaminated Sites	✔	✔	✔								?	✔		✖				
IS-5 Protect the Ecological Health of Wetlands and Floodplains	✖	?	?	✖	✖		✔				✔	✔		✔	✖	?		
IS-6 Protect and Maintain Absorbent Landscapes	✖	✔	✔	?	✖					✔		?		✔				
IS-7 Utilize Pervious Pavement							✔					✔		✔				
IS-8 Utilize Appropriate Vegetation				✔						✔	✔			✔				
IS-9 Use Turfgrass Appropriately										✔				✔				
IS-10 Amend and Reuse Existing Soils			✔	✔								✔		✔				
IS-11 Balance Earthwork	✔		✔	✔	?									✔				
IS-12 Coordinate Utility Work						✔	✔					✔	✔	✔				
IS-13 Utilize Trenchless Technology						?	✔					✔	✔	✔				
IS-14 Mitigate Heat Island Effect										✔	✔			✔				
IS-15 Minimize Light Pollution																		
IS-16 Optimize Public Environments – Bicycles and Pedestrians																		
IS-17 Optimize Traffic Safety																		
IS-18 Optimize Roadway Alignment Selection														✔				
IS-19 Expand or Enhance Intermodal Connectivity																		
IS-20 Use Transportation System Management																		
IS-21 Use Transportation Technologies																		
WATER SECTION																		
IW-1 Implement Stormwater Best Management Practice Strategies							✔			✔	✔	✔	✔	✔				
IW-2 Implement Rainwater Neutrality										✔	✔	✔	✔	✔				
IW-3 Reduce Use of Potable Water for Irrigation										✔		✔	✔					
IW-4 Utilize End Use Metering – Water																		
ENERGY SECTION																		
IE-1 Optimize Energy Performance	?					✔				✔		✖	✖					
IE-2 Commission Electrical and Mechanical Systems						✔												
IE-3 Utilize End Use Metering – Energy						✔												
IE-4 Use On-Site Renewable Energy																		
IE-5 Protect Ozone Layer																		
IE-6 Provide Alternative Fueling Stations																		
MATERIALS SECTION																		
IM-1 Use Recycled Materials	✔	✔	✔		✔							✔				✔		
IM-2 Use Local / Regional Materials	✔	✔	✔	✔	✔				✔	✔		✔		✔				
IM-3 Reuse Materials	✔			?					✔			✔						
IM-4 Use Durable Materials	✔	✔	✔		✔			✔	✔			✔				✔		
IM-5 Use Sustainably Harvested Wood																		
IM-6 Minimize Use of Toxic and / or Hazardous Materials						✔			?									
IM-7 Enhance Pavement Lifecycle							✔	✔										
IM-8 Preventative Pavement Maintenance								✔					?					
IM-9 Utilize Warm-Mix Asphalt Technology																		
CONSTRUCTION SECTION																		
IC-1 Minimize Pollution from Construction Activity	✔	✔		✔	✔						✔	✔	✔	✔		✔		
IC-2 Protect Existing Natural Systems	?	✔	?	?	?						✔			✔				
IC-3 Utilize Transportation Management During Construction																		
IC-4 Utilize Green Construction Equipment	✔	✔	✔	✔	✔						✔	✔	✔	✔	✔	✔		
IC-5 Reduce Noise and Vibration During Construction	?	?	?		?										?	?		
IC-6 Implement Construction Waste Management	?	✔	✔		✔					✔	✔	✔	✔	✔		✔		
IC-7 Implement Integrated Pest Management During Construction	✔	✔	✔		✔					✔	✔	✔	✔	✔		✔		
OPERATIONS AND MAINTENANCE SECTION																		
IO-1 Implement Sustainable Landscape Maintenance	?									✔	✔		✔	✔				
IO-2 Maintain Soil Quality	?			?			✔			✔				✔				
Building Design Guidelines																		
SITE ENVIRONMENTAL QUALITIES																		
SEQ-1 Site Selection			✖								✔							
SEQ-2 Support Urban Development																		
SEQ-3 Brownfield Redevelopment	✔	✔	✔		?						?	✔		✖				
SEQ-4 Expanded Public Transit																		
SEQ-5 Bicycle Access																		
SEQ-6 Alternative Fuel Vehicles																		
SEQ-7 Reduced Parking Disturbance																		
SEQ-8 Reduced Site Disturbance		✔									✔	✔		✔				
SEQ-9 Reduced Development Footprint										✔	✔	✔		✔				
SEQ-10 Storm Water Use							✔			✔		✔	✔	✔				
SEQ-11 Heat Island Effect Mitigation Site			?											✔				
SEQ-12 Heat Island Effect Mitigation Roof										✔								
SEQ-13 Light Pollution Reduction																		
WATER ENVIRONMENTAL QUALITIES																		
WEQ-1 Water Management Plan							✔			✔		✔	✔	✔				
WEQ-2 Wastewater Reuse										✔		✔		✔				
WEQ-3 Water Use Efficiency																		
WEQ-4 Landscape Hydrology										✔				✔				
MATERIAL ENVIRONMENTAL QUALITIES																		
MEQ-1 Material Management Plan and Recycling						✔												
MEQ-2 Building Re-Use																		
MEQ-3 Resource Reuse																		
MEQ-4 Materials with Recycled Content																		
MEQ-5 Material Proximity																		
MEQ-6 Agricultural Materials																		
MEQ-7 Wood Certification																		
MEQ-8 Maintenance and Durability	✔					✔	✔	✔	✔	✔		✔						
MEQ-9 Wood Preservatives																		
MEQ-10 Design Flexibility	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔		
ENERGY ENVIRONMENTAL QUALITIES																		
EEQ-1 Comprehensive Energy Management Plan						✔												
EEQ-2 Building Systems Commissioning						✔							✔					
EEQ-3 Optimize Energy Performance						✔				✔		✖	✖					
EEQ-4 Ozone Layer Protection/Greenhouse Gas Reduction																		
EEQ-5 Renewable Energy Transition																		
EEQ-6 Energy Systems Control and Maintenance																		
EEQ-7 End User Metering																		
EEQ-8 Additional Commissioning						✔							✔					
CONSTRUCTION ENVIRONMENTAL QUALITIES																		
CEQ-1 Construction Environment											✔							
CEQ-2 Construction Storm Water Runoff/Pollution Prevention											✔							
CEQ-3 Construction Waste Management																		
CEQ-4 Construction IAQ Management Plan																		
INDOOR ENVIRONMENTAL QUALITIES																		
IEQ-1 IAQ Performance																		
IEQ-2 Daylight & Views																		
IEQ-3 Air Quality Monitoring																		
IEQ-4 Ventilation Effectiveness																		
IEQ-5 Reduce Contaminants from Materials																		
IEQ-6 Chemical & Particulate Control																		
IEQ-7 Thermal Comfort										✔				✔				
IEQ-8 Pest Control																		
IEQ-9 Personal Control																		
IEQ-10 Acoustics																		
IEQ-11 Lighting Quality																		
MAINTENANCE & OPERATION ENVIRONMENTAL QUALITIES																		
MOEQ-1 Maintenance & Operations Program						✔	✔	✔	✔									
MOEQ-2 Recycling Program																		
MOEQ-3 Training Program						✔	✔	✔	✔									

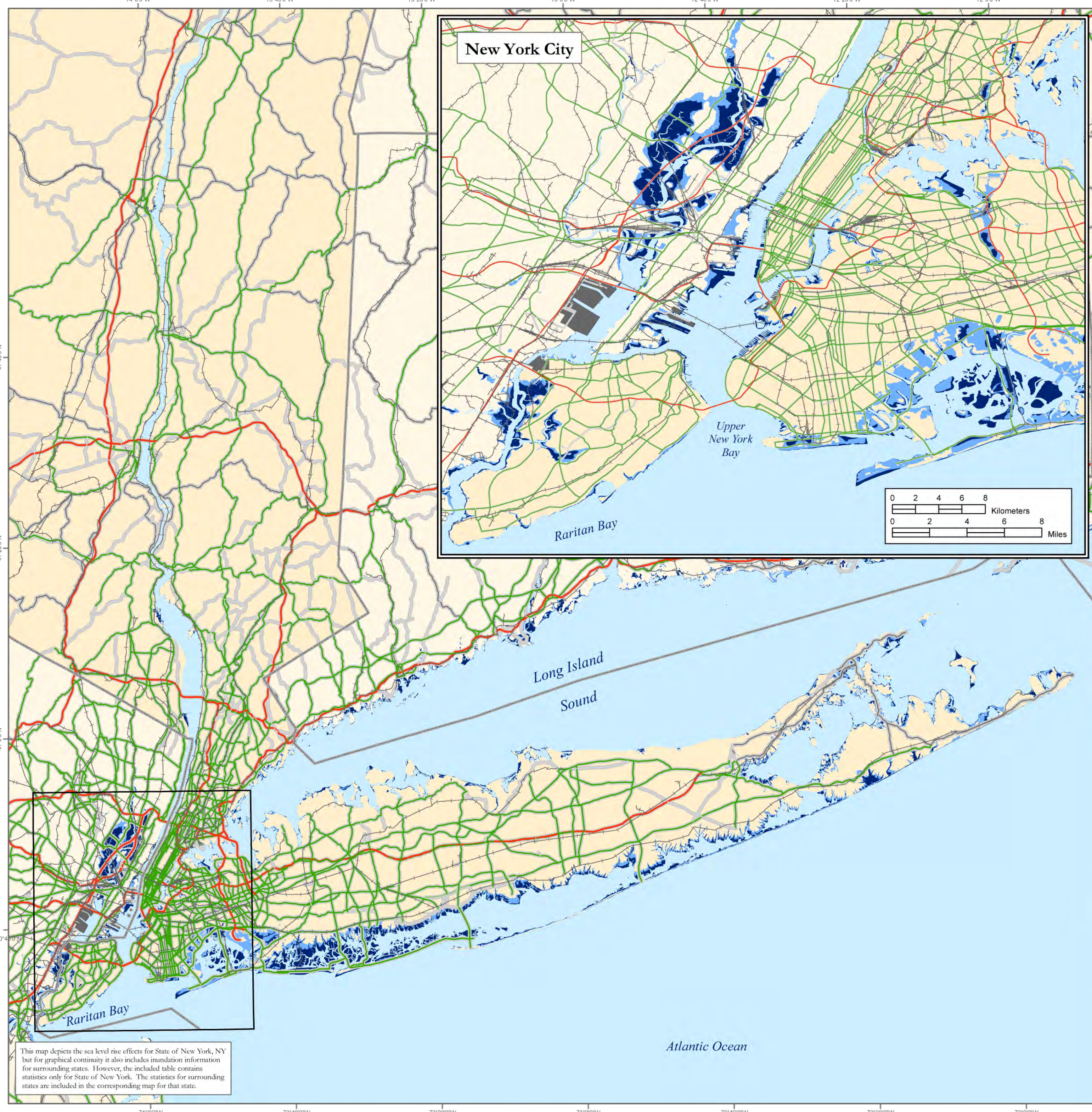
b. Maps of New Jersey and New York projected eustatic sea level rise impacts

See below maps.

Eustatic Sea
Level Rise: 59 cm

State of New York

Regularly Inundated Areas, At-Risk Areas and Affected Transportation Infrastructure



- Regularly Inundated Area
- At-Risk Area
- Airport Runway
- Ports Property Area
- Interstate Highway
- Non-Interstate Principal Arterial
- Minor Arterial
- NHS (indicated by background)
- Railroad

Potentially Impacted Transportation Network		
Type	Inundated	At-Risk
Roads (km)		
Interstate Highways	2.9	12.0
Non-Interstate Principal Arterials	49.2	110.0
Minor Arterials	1.8	19.5
National Highway System Features	44.7	101.9
Other Transportation Types (km)		
Railroads	53.1	72.6
Potentially Impacted Land Area (acres)		
Total Impacted Area	69,031	62,289
Airport Property Area	445	3,202
Airport Runway Area	76	462
Ports Property Area	72	38

Notes:
The methodologies and source data used to generate these maps are discussed in *The Potential Impacts of Global Sea Level Rise onTransportation Infrastructure: Study Goals, Methodologies, and Recommendations.* This report also lists summary statistics for the transportation infrastructure affected according to this analysis. These maps are presented as an *estimate* of areas that, without protection, may regularly be inundated or may be at-risk of periodic inundation due to storm surge, under the methodologies used in this study. These maps are not intended for navigational or engineering purposes, and are meant to provide a rough idea of the areas and transportation facilities that might be affected under the scenarios and methodologies used in this study.

***Eustatic** sea level rise refers to the change in sea level created by any volumetric increase in the oceans worldwide, primarily due to thermal expansion and ice melt.

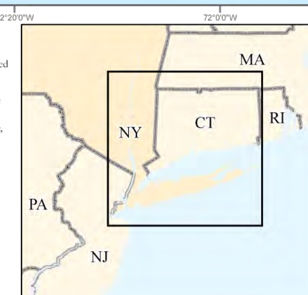
Sources:
Interstates, Non-Interstate Principal Arterials, Minor Arterials, and NHS - National Highway Planning Network.
Rails - Federal Railroad Administration.
Ports - Digitized from Digital Orthophoto Quadrangles clipped to the mean high water line.
Airport Property and Runways - Tele Atlas.

Coordinate System: UTM 18 N - North American Datum 1983

1:530,000

0 5 10 15 20 25 30 Kilometers

0 5 10 15 20 25 30 Miles

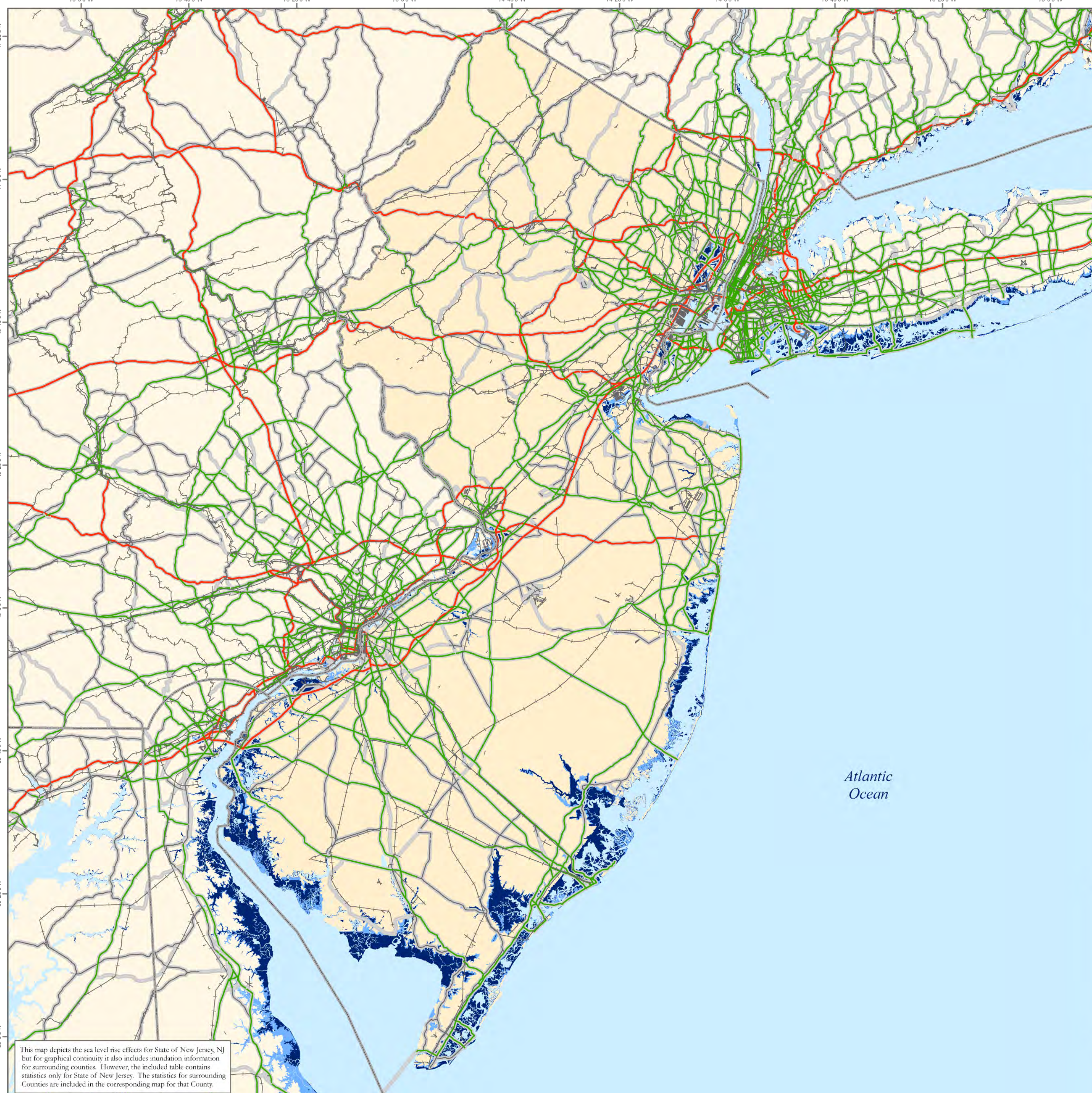


ICF20080606CJH999 - 59 cm

Eustatic Sea
Level Rise: 59 cm

State of New Jersey

Regularly Inundated Areas, At-Risk Areas and Affected Transportation Infrastructure



- Regularly Inundated Area
- At-Risk Area
- Airport Runway
- Ports Property Area
- Interstate Highway
- Non-Interstate Principal Arterial
- Minor Arterial
- NHS (indicated by background)
- Railroad

N

Potentially Impacted Transportation Network

Type	Inundated	At-Risk
Roads (km)		
Interstate Highways	14.8	11.5
Non-Interstate Principal Arterials	67.6	87.2
Minor Arterials	14.2	16.1
National Highway System Features	58.1	62.4
Other Transportation Types (km)		
Railroads	109.8	123.6
Potentially Impacted Land Area (acres)		
Total Impacted Area	216,773	108,630
Airport Property Area	228	583
Airport Runway Area	18	54
Ports Property Area	203	141

Notes:
The methodologies and source data used to generate these maps are discussed in *The Potential Impacts of Global Sea Level Rise onTransportation Infrastructure: Study Goals, Methodologies, and Recommendations.* This report also lists summary statistics for the transportation infrastructure affected according to this analysis. These maps are presented as an *estimate* of areas that, without protection, may regularly be inundated or may be at-risk of periodic inundation due to storm surge, under the methodologies used in this study. These maps are not intended for navigational or engineering purposes, and are meant to provide a rough idea of the areas and transportation facilities that might be affected under the scenarios and methodologies used in this study.

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Rails - Federal Railroad Administration.
Ports - Digitized from Digital Orthophoto Quadrangles clipped to the mean high water line.
Airport Property and Runways - Tele Atlas.

Coordinate System: UTM 18 N - North American Datum 1983

1:700,000

0 5 10 15 20 25 30 35 40 Kilometers

0 5 10 15 20 25 30 35 40 45 Miles

ICF20080606CJH999 - 59 cm

c. Timeline of NY/NJ current regional climate planning efforts

- **Spring 2007 NYC initiates PlaNYC2030**[239]

- **August 2007 NYS Sea Level Task Force**[240]
  Multi-stakeholder group composed of state agencies, local governments, not-for-profit groups and private citizens that includes the PANYNJ, appointed and created by the New York State Legislature, to assess impacts to the state's coastlines from rising seas and recommend protective and adaptive measures.

- **August 2007 PANYNJ Sustainable Design Project Manual-Buildings**
  Using LEED NC 2.1 as a model, applies to New Construction & Substantial Renovation or Reconstruction of buildings greater than or equal to 20,000 GSF

- **March 2008 PANYNJ Sustainability Policy**
  Sets several goals including to reduce GHG emissions by 80% by 2050 from a 2006 baseline and to adapt facilities to reduce climate change risks

- **August 2008 Formation of the NYC Panel on Climate Change (NPCC) and NYC Climate Change Adaptation Task Force**
  The panel was created as one part of the PlaNYC initiative and is modeled on the Intergovernmental Panel on Climate Change (IPCC) to advise the Mayor of NYC and the New York City Climate Change Adaptation Task Force (the "Task Force") on issues related to climate change and adaptation as it relates to infrastructure based on sound science and a thorough understanding of climate change, its potential impacts, and adaptation.[241] The panel includes leading climate change and impact scientists, academics, and private sector practitioners.[242] The panel is charged with: developing a unified set of climate change projections for New York City; creating a set of tools to help task force members identify at-risk infrastructure and develop adaptation strategies; write draft protection levels to guide the design of new infrastructure; and to issue a technical report on the localized effects of climate change on New York City-similar to the IPCC's landmark 2007 report on global climate change.[243] The Climate

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239 PlaNYC 2030 Website Accessed at: http://www.nyc.gov/html/planyc2030/html/theplan/the-plan.shtml

240 NYS DEC Authorizing Legislation - Sea Level Rise Task Force LAWS OF NEW YORK, 2007 CHAPTER 613 Accessed at: http://www.dec.ny.gov/energy/45895.html

241 Rosenzweig, C. and Solecki, W. (2010), Chapter 1: New York City adaptation in context. Annals of the New York Academy of Sciences, 1196: 19–28. doi: 10.1111/j.1749-6632.2009.05308.x Accessed at: http://onlinelibrary.wiley.com/doi/10.1111/j.1749-6632.2009.05308.x/abstract

242 NYC Panel on Climate Change (NPCC) Climate Risk Information Report February 2009 http://www.nyc.gov/html/om/pdf/2009/NPCC_CRI.pdf

243 **PR- 308-08 August 12, 2008 MAYOR BLOOMBERG LAUNCHES TASK FORCE TO ADAPT CRITICAL INFRASTRUCTURE TO ENVIRONMENTAL EFFECTS OF CLIMATE CHANGE** Accessed at: http://www.nyc.gov/portal/site/nycgov/menuitem.c0935b9a57bb4ef3daf2f1c701c789a0/index.jsp?pageID

Change Adaptation Task Force is charged with: creating an inventory of existing infrastructure that may be at-risk from the effects of climate change; developing adaptation plans to secure at risk assets based on NYC-specific climate change projections; and drafting design guidelines that take into account anticipated climate change impacts for new infrastructure.[244]

- **February 2009 NYC Panel on Climate Change (NPCC) Climate Risk Information Report[245]**
  Produced for the Task Force, provides climate change projections for New York City and identifies some of the potential risks to the City's critical infrastructure posed by climate change including Increased structural damage & impaired operations from sea level rise and related impacts.

- **August 2009 NY Executive Order No. 24 creates New York Climate Action Council (ClimAID)[246]**
  New York Climate Action Council (ClimAID)[247] with a directive to prepare a draft Climate Action Plan and setting a goal to reduce greenhouse gas emissions in New York State by 80 percent by 2050 from a 1990 baseline.

- **August 2010 PANYNJ Sustainable Infrastructure Guidelines**
  Similar to PANYNJ Sustainable Design Project Manual except for infrastructure

- **November 2010 NYSERDA climAID NY State Climate Action Plan Interim Report Released**
  The Report details expected increases in sea level related to increased Greenhouse Gas (GHG) emissions but goes beyond a focus on mitigating GHG releases to include adaptation measures that minimize and prepare for the effects of anticipated climate change. [248] The Climate Action Plan focuses on developing cutting edge information on vulnerability and to facilitate the creation of adaptation strategies. [249]

- **December 2010 NYS Sea Level Task Force Releases Report**

=mayor_press_release&catID=1194&doc_name=http%3A%2F%2Fwww.nyc.gov%2Fhtml%2Fom%2Fhtml%2F2008b%2Fpr308-08.html&cc=unused1978&rc=1194&ndi=1

[244] **PR- 308-08 August 12, 2008 MAYOR BLOOMBERG LAUNCHES TASK FORCE TO ADAPT CRITICAL INFRASTRUCTURE TO ENVIRONMENTAL EFFECTS OF CLIMATE CHANGE** Accessed at: http://www.nyc.gov/portal/site/nycgov/menuitem.c0935b9a57bb4ef3daf2f1c701c789a0/index.jsp?pageID=mayor_press_release&catID=1194&doc_name=http%3A%2F%2Fwww.nyc.gov%2Fhtml%2Fom%2Fhtml%2F2008b%2Fpr308-08.html&cc=unused1978&rc=1194&ndi=1

[245] NYC Panel on Climate Change (NPCC) Climate Risk Information Report February 2009 http://www.nyc.gov/html/om/pdf/2009/NPCC_CRI.pdf

246 NY Executive Order 24 Establishing the New York Climate Action Council http://www.nyclimatechange.us/ewebeditpro/items/O109F24028.pdf

247 NY Executive Order 24 Establishing the New York Climate Action Council http://www.nyclimatechange.us/ewebeditpro/items/O109F24028.pdf

[248]New York State Climate Action Plan Interim Report - November 9, 2010 NY State Climate Action Council Website Accessed at: http://nyclimatechange.us/InterimReport.cfm

[249]New York State Climate Action Plan Interim Report - November 9, 2010 Appendix H ClimAID Report Summary http://www.nyclimatechange.us/ewebeditpro/items/O109F24043.pdf

Applying the best available science to evaluate ways to protect NY states remaing coastal ecosystems and increase coastal community resilience in the face of sea level rise. Finds that more than 62 percent of New York's population lives in marine coastal counties. That over the long term, cumulative environmental and economic costs associated with structural protection measures, such as seawalls, dikes, and beach nourishment, may be more expensive and less effective than non-structural measures, such as elevation of at-risk structures and planned relocation away from the coastal shoreline, especially in less urbanized areas. Solutions for urban areas, however, may require a mixed approach of structural and non-structural solutions. Recommends that within 2-5 years an executive order should provide direction to all relevant state agencies (including the PANYNJ) to factor current and anticipated impacts of sea level rise into all relevant aspects of decision making. Implementation involves changes to regulation and agency guidance. [250]

d. Additional abbreviated case studies

Below are additional case studies of interest to PANYNJ that did require full analysis, as they are not comparable or not applicable to the PANYNJ. They do represent interesting applications of adaptation strategies.

Case Studies

» MOSE Barrier (Venice, Italy)

Venice is built in a lagoon that can be easily flooded. The MOSE Barrier is a precaution against climate change as it allows for a temporary barrier to storm surges at each of the lagoon inlets. It was approved in 2003 and is currently under construction. Completion is expected in 2014.

Key challenges

Flooding, SLR of the Adriatic, storm surges.

Strategy

- **Barrier (permanent)** MOSE (Experimental Electromechanical Module) Barrier

Source

Bright Hub
http://www.brighthub.com/engineering/civil/articles/56319.aspx

» Norfolk SLR (Norfolk, VA)

Norfolk was built on a marsh that had been filled in for development. After years of wear, the fill is settling and compacting, bringing back the marsh-like conditions. The land in the area is also sinking and tidal flooding is a recurring impact. An integrated set of protective and

[250] New York State Sea Level Rise Task Force Report to the Legislature December 31, 2010 http://www.dec.ny.gov/docs/administration_pdf/slrtffinalrep.pdf

accommodating strategies was applied. Modular strategies coupled with long-term capital projects address Norfolk's SLR issues.

Key challenges

Flooding, SLR.

Strategies

- Inflatable dams
- Storm surge floodgates
- Increasing road heights
- Readjust storm drain angles
- Allow parks to become wetlands

Source

http://www.nytimes.com/2010/11/26/science/earth/26norfolk.html?_r=1

» Stormwater Management and Road Tunnel (SMART) (Kuala Lumpur, Malaysia)

Kuala Lumpur has frequent flash floods. SMART was built to divert these floods as well as to help ease heavy traffic jams that are common in the densely populated city. A double-deck motorway was built that can be closed off to cars in the event of flooding to allow for water to be diverted. There are three levels of operation. Level one allows both decks to be open during dry times. As rainfall and risk of flood increases the lower level will be used for diverting floodwaters and only the upper level will be open to cars. In heavy storms, the entire tunnel is closed to traffic and the capacity to divert up to 3 million cubic meters of water is utilized. Kuala Lumpur is innovative in their approach to stormwater management by understanding their daily transportation needs and combining them with the requirements to protect the city from flooding. This approach is both economical and strategically effective.

Key challenges

Flooding from storm surge and increased precipitation, traffic jams

Strategies

- Pumps and sumps
- Stormwater storage

Sources

http://www.raeng.org.uk/news/publications/list/reports/Engineering_the_future_2011.pdf
http://www.tunnels.mottmac.com/projects/?mode=region&id=2047

» The Sigma Plan for Flooding (Antwerp, Belgium)

Land near the Scheldt Estuary is prone to flooding. An integrated plan using protect, accommodate and retreat strategies was developed. This is a long-term development project to protect residents and develop a multifunctional estuarine water system.

Key challenges

Flooding.

Strategies

- Created controlled inundation areas
- Dike heightening program
- Managed retreat using land use changes from agriculture to estuary habitat

Source

London Climate Change Partnership
http://www.sfrpc.com/Climate Change/9.pdf

» Florida Lee County Climate Change Resiliency Strategy (CCRS) (Lee County, Florida)

As a coastal region, the county needs to prepare for potential impacts of SLR and the resulting storm surge, as a result of climate change. Protect, accommodate and retreat strategies have been implemented in an adaptation plan.

Key challenges

SLR, storm surges.

Strategies:

- Coastal armoring, beach nourishment
- Managed retreat (planned relocation)
- Elevation of infrastructure

Source

Lee County Dept. of Sustainability
http://www.lee-county.com/gov/dept/sustainability/Documents/Committee/2010/August 18/DRAFT Lee County Climate Change Resiliency Strategy CCRS 201.pdf