Flood Risk Reduction Strategies for Vulnerable Coastal Populations along Hackensack River, Hudson River, Arthur Kill, Barnegat Bay and Delaware Bay

Qizhong (George) Guo, Ph.D., P.E., D. WRE
Professor and Principal Investigator
Rutgers, The State University of New Jersey
School of Engineering
Department of Civil and Environmental Engineering
Phone: 848-445-2983; Email: Qguo@Rutgers.edu

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Outline

1. Study Background, Geographic Areas and Team
2. Flood Risk Reduction Strategy Development Framework
3. Green, Adaptive and Innovative Flood Risk Reduction Measures
4. Area-Specific Strategies
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1. Study Background, Geographic Areas and Team

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Flood Risk Reduction Strategies for Vulnerable Coastal Populations:
A Study Initiated and Sponsored by New Jersey Governor’s Office for Sandy Recovery and Rebuilding (GORR) & New Jersey Department of Environmental Protection (NJDEP)

Six New Jersey colleges and universities have collaborated with the state to evaluate flood mitigation strategies.

The studies focus on areas of the state heavily impacted by Superstorm Sandy that may be vulnerable to future flooding.

The university flood mitigation analyses are part of an overall effort by the Christie Administration to make the state more resilient in the post-Sandy era.

The State will incorporate the findings from these studies into its work with the Army Corps of Engineers under the Federal Government on its comprehensive study of the Coastal North Atlantic Region.
Six (6) NJ Universities and Colleges Involved:

1. Rutgers, The State University of NJ
2. Stevens Institute of Technology
3. New Jersey Institute of Technology
4. Monmouth University
5. Montclair State University
6. Stockton College

Studied Areas along Five (5) NJ Coastal Waters:

1.) Hackensack River (Little Ferry, Moonachie)
2.) Hudson River (Hoboken, Jersey City)
3.) Arthur Kill (Elizabeth, Linden, Rahway, Carteret, Woodbridge)
4.) Barnegat Bay (Point Pleasant, Brick, Toms River, Seaside Heights, Stafford, Little Egg Harbor)
5.) Delaware Bay (Commercial, Downe, Greenwich, Maurice River)
Rutgers Project Team

**Principal Investigator:** George Guo

**Hackensack River**
Rutgers University: Robert Miskewitz, Manoj Raavi, Carolyn Loudermilk
Montclair State University (Subcontractor): Meiyin Wu, Josh Galster, Clement Alo, Robert Prezant, Jason Beury
Monmouth University (Collaborator): Tony Macdonald, Jim Nickels

**Hudson River**
Robert Miskewitz, Eleni Athanasopoulou, Kaveh Gharyeh, Jun Zhao

**Arthur Kill**
Bertrand Byrne, Jie Gong, Raghav Krishnamoorthy, Henry Mayer

**Barnegat Bay**
Yunjie Li, Michael J. Kennish, Norbert P. Psuty, Richard G. Lathrop Jr., Jim Trimble

**Delaware Bay**
David Bushek, Richard G. Lathrop Jr., Junghoon Kim, Bertrand Byrne, Jim Trimble
Outline

1. Study Background, Geographic Areas and Team

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3. Green, Adaptive and Innovative Flood Risk Reduction Measures

4. Area-Specific Strategies
FRAMEWORK
for Coastal Flood Risk Reduction Strategy Development

THREAT
- Threat Sources
  - Rainfall
  - Coastal Storm
  - Riverine Flow
  - Sea Level Rise
  - Climate Change
- Threat Levels
  - Rainfall: 0.25', 1', 2', 5', 10', 25-yr
  - Tide: Semidiurnal, High, Spring High, Extreme High, Mean Higher High
  - Coastal Storm: 10-, 50-, 100-yr
  - Sea Level Rise: yr 2050, yr 2100
  - Combined Effects

VULNERABILITY
- Inundation
  - Area
  - Depth
  - Duration
- Land Use
  - Residential (General & Vulnerable Populations)
  - Institutional
  - Recreational
  - Agricultural
  - Commercial/Industrial
  - Healthcare/Emergency
  - Ecological
  - Cultural
- Infrastructure
  - Water (Drainage, Potable, and Waste)
  - Solid Waste
  - Energy
  - Transportation
  - Communications

RISK REDUCTION
- Spatial Scales
  - Lot/Block/Neighborhood
  - Municipal
  - Cross-Municipal/Regional
- Measures: Type
  - Maintenance vs. Construction
  - Mobile/Adaptable vs. Fixed
  - Green/Nature-based vs. Grey
  - Non-structural (Policy, Regulation, etc.) vs. Structural
  - Micro-grid vs. Large-grid Powered
  - Innovative vs. Conventional
- Measures: Function
  - Rainfall Interception
  - Storage
  - Conveyance
  - Upstream Flow Reduction
  - Diversion
  - Deceleration
  - Tide Barrier
  - Pumping
  - Surge Barrier
  - Mobile Barrier
  - Elevation
  - Avoidance

ASSESSMENT
- Costs
- Benefits
- Environmental Impacts
- Waterfront Accessibility
- Synergy
Consideration of All Three Sources of Flood Water:

(1) Rainwater
(2) Riverine Water
(3) Ocean Water
Types of Measures Considered:

(1) Maintenance/repair vs. new construction
(2) Mobile/adaptable vs. fixed
(3) Green/nature-based vs. grey
(4) Non-structural (policy, regulation, etc.) vs. structural
(5) Micro-grid vs. large-grid powered
(6) Innovative vs. conventional
(7) Preventative vs. protective
(8) Retroactive vs. anticipatory
(9) Short-term vs. long-term
Flood Risk Reduction Measures’ Functions for Coastal City
# Flood Risk Reduction Measures and Their Functions

<table>
<thead>
<tr>
<th>Rainfall Interception</th>
<th>Storage</th>
<th>Conveyance</th>
<th>Upstream Flow Reduction</th>
<th>Diversion</th>
<th>Flow Deceleration</th>
<th>Tide Barrier</th>
<th>Pumping</th>
<th>Surge Barrier</th>
<th>Mobile Flood Barrier</th>
<th>Elevation</th>
<th>Avoidance</th>
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<tr>
<td>Increase Vegetation</td>
<td>Retention</td>
<td>Sewer</td>
<td>Dam</td>
<td>New Sewer</td>
<td>Vegetated Swale</td>
<td>Flap Gate</td>
<td>Pumping Station</td>
<td>New Levee</td>
<td>Movable Flood Wall</td>
<td>Elevate Building</td>
<td>Buyout</td>
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<tr>
<td>Green Roof</td>
<td>Detention</td>
<td>Channel</td>
<td>Watershed Management</td>
<td>Bypass Force Main*</td>
<td>Artificial Wetlands</td>
<td>Sluice Gate</td>
<td>Emergency Power</td>
<td>Seawall</td>
<td>Flood Gate</td>
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<td>Evacuation</td>
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<tr>
<td>Biowale</td>
<td>Infiltration</td>
<td>Dredging</td>
<td>Headwall</td>
<td>Wind Pump</td>
<td>Rain Pump*</td>
<td>Elevating Levee</td>
<td>Temporary Seawall</td>
<td>Inflatable Barrier</td>
<td>Risk</td>
<td>Education</td>
<td></td>
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<tr>
<td>Vegetated Filter Strip</td>
<td>Expansion</td>
<td>Combined Sewer Separation</td>
<td>RAIN PUMP*</td>
<td>New Dunes</td>
<td>Current PUMP*</td>
<td>Beach Nourishment</td>
<td>Artificial Wetlands</td>
<td>Sheet BULKHEAD</td>
<td>Concrete BULKHEAD</td>
<td>Risk</td>
<td>Education</td>
</tr>
<tr>
<td>Porous Paving</td>
<td>Constructed Wetlands</td>
<td>Culvert Size</td>
<td>WAVE PUMP*</td>
<td>Current PUMP*</td>
<td>Repair Levee</td>
<td>Vegetated Levee</td>
<td>Breakwater</td>
<td>In-Water Barrier</td>
<td>Restored Wetlands</td>
<td>Living Shoreline</td>
<td>Floating Barrier</td>
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<tr>
<td>Rain Garden</td>
<td>Lake Expansion</td>
<td>Debris Removal</td>
<td>SHEETING</td>
<td>SHEETING</td>
<td>CONCRETE BULKHEAD</td>
<td>Concrete BULKHEAD</td>
<td>Concrete BULKHEAD</td>
<td>New Levee</td>
<td>FLAP GATE*</td>
<td>CAUSEWAY WITH OPERABLE FLOOD GATE*</td>
<td></td>
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<tr>
<td>Planter Box</td>
<td>De-Snagging</td>
<td>Debris</td>
<td></td>
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<tr>
<td>Rain Barrel</td>
<td>Straightening</td>
<td>Sewer Flushing</td>
<td>Sheet BULKHEAD</td>
<td>Sheet BULKHEAD</td>
<td>Concrete BULKHEAD</td>
<td>Concrete BULKHEAD</td>
<td>Concrete BULKHEAD</td>
<td>New Levee</td>
<td>FLAP GATE*</td>
<td>CAUSEWAY WITH OPERABLE FLOOD GATE*</td>
<td></td>
</tr>
<tr>
<td>Soil Amendment</td>
<td>Vertical Wall</td>
<td>Repair Levee</td>
<td>VEGETATED LEVEE</td>
<td>BREAKWATER</td>
<td>IN-WATER LEVEE</td>
<td>Restored Wetlands</td>
<td>Living Shoreline</td>
<td>FLOATING BARRIER</td>
<td>EXTENDABLE FLOOD PANEL*</td>
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</tbody>
</table>

*Newly proposed
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1. Study Background, Geographic Areas and Team

2. Flood Risk Reduction Strategy Development Framework

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4. Area-Specific Strategies
NEW TECH 1: Stormwater Green Infrastructure
(to intercept rainwater)
A software was created to estimate the costs and optimize the placement of stormwater green infrastructure in terms of the costs.
Three Maximum Potentials for Implementing Stormwater Green Infrastructure

**Potential 1:** Green infrastructure elements are implemented where possible in the whole town.

**Potential 2:** Green infrastructure elements are implemented only in the area which is under 100-year flood zone.

**Potential 3:** Green infrastructure elements are implemented where most suitable. A GIS suitability model is generated in ArcGIS. Three criteria are selected for the suitability model: soil type, land cover, and tree canopy. These criteria are ranked based upon their suitability for implementing green infrastructure.
Potential 1:
Green infrastructure elements are implemented where possible in the whole town.
Potential 2: Green infrastructure elements are implemented only in the area which is under 100-year flood zone.
Potential 2: Green infrastructure elements are implemented only in the area which is under 100-year flood zone.
Potential 3: Green infrastructure elements are implemented where most suitable.
Potential 3: Green infrastructure elements are implemented where most suitable.
NEW TECH 2: Stormwater Bypass Force Mains
(to improve storm drainage capacity)
NEW TECH 3: Green Water Pumps – Rainwater-Driven
(no external energy needed)
NEW TECH 3: Green Water Pumps – Wave-Driven
(no external energy needed)
NEW TECH 3: Green Water Pumps – Wind-Driven
(no external energy needed)
NEW TECH 4: Extendable Flood Panels – Type 1
NEW TECH 4: Extendable Flood Panels – Type 1 (operation)

Movable Flood Panel Positions at Different Water Protection Levels

(a) Protection Level 1 (e.g. 10_Yr)
(b) Protection Level 2 (e.g. 50_Yr)
(c) Protection Level 3 (e.g. 100_Yr)

Type 1
NEW TECH 4: Extendable Flood Panels – Type 2

Movable Flood Panel

Rotational Axis
Anchor Bolt
Base Plate
Surface of Dock/Shipyard, etc.

Rotational Panel 1
Movable Panel 2
Anchor Bars

Water Side

Type 2
NEW TECH 4: Extendable Flood Panels – Type 2

Movable Flood Panel Positions at Different Water Protection Levels

(a) Protection Level 1 (e.g. 10_Yr)
(b) Protection Level 2 (e.g. 50_Yr)
(c) Protection Level 3 (e.g. 100_Yr)

Type 2
Illustrative Sketch of Flood Protection Levels
NEW TECH 5: Regional Causeway over Saltmarsh with Operable Flood Gates
(allow wetlands to migrate upland as sea level rises)

(Photo Source: The Times-Picayune)
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Studied Areas along Five (5) NJ Coastal Waters (from north to south):

1.) **Hackensack River** (Little Ferry, Moonachie)
2.) **Hudson River** (Hoboken, Jersey City)
3.) **Arthur Kill** (Elizabeth, Linden, Rahway, Carteret, Woodbridge)
4.) **Barnegat Bay** (Point Pleasant, Brick, Toms River, Seaside Heights, Stafford, Little Egg Harbor)
5.) **Delaware Bay** (Commercial, Downe, Greenwich, Maurice River)
Study Area 1: Hackensack River (Little Ferry, Moonachie)
Little Ferry, Moonachie along Hackensack River
Image showing water control structures in Little Ferry
Image showing water control structures in Moonachie
Losen Slote tide gate
(Trash Racks at Intake Structure)
Losen Slote tide gate
(equipped with high volume pumps)
Inundation depths (in feet) in Little Ferry and Moonachie under (a) 10-year coastal flood, (b) 50-year coastal flood, (c) 100-year coastal flood, and (d) 500-year coastal flood

(Source: FEMA Map Service Center)
Flooding is a regular concern in both of these communities and although the storm surge from Hurricane Sandy highlighted their vulnerability to an extreme event, smaller more frequent events regularly occur and impact residents, commerce and the area’s transportation infrastructure.

The study of this area addressed improvements to the stormwater drainage system for storm events that are limited to a storm surge that reaches the vertical extent of the protective berms surrounding the area.

The existing berms (the soft edges) are expected to be only able to protect the coastal storm of the recurrence interval less than 10 years.
Study Area 1: Hackensack River (Little Ferry, Moonachie)

At the municipal scale, the recommendations from this study include:

1. Cleaning and dredging of open trenches present in Moonachie.
2. Implementation of green infrastructure to reduce the source contribution of runoff.
3. Mapping and simulation of existing drainage systems.
4. Maintenance and upgrade to the existing tide gate structures.
5. Creation of new surface storages in Little Ferry and Moonachie.
6. Expansion of existing storm water detention capabilities of Willow Lake in Little Ferry.
At the block and lot scale, the recommendations include:

1. Proper maintenance of the existing stormwater drainage system. Periodic cleaning and maintenance of storm grates, etc.
2. Installation of check valves at the outlet of all storm water pipes to impede tidal waters.
3. Redesigning of open trenches as vegetated swales to increase infiltration. Expansion and conversion of open trenches to wetlands or bioretention structures.
4. Reduction of impervious surface at Route 46 corridor.
5. Raising of important transportation infrastructure.
6. Implementation of stormwater green or blue infrastructure projects.
Five projects at specific locations are recommended as well:

1. Expansion of open ditches in Moonachie and Little Ferry and Carlstadt towns.
2. Implementation of green infrastructure strategies along Moonachie Road.
4. Rehabilitation of Trenches on State Street.
5. Tree removal from drainage system.
Headwall in Moonachie with three drainage pipes of unknown origin. Ditches are also filled with sediment.
Existing drainage system details for Moonachie
(red-open trenches, blue-gravity mains)
The location of the proposed drainage basins (in blue) that could be used to reduce flooding in Moonachie and Little Ferry (town borders in red).
Study Area 2: Hudson River
(Hoboken and Jersey City)
Jersey City & Hoboken along Hudson River
Storm Surge Threat
10-Year Coastal Storm: Jersey City & Hoboken, NJ

(Source: FEMA Map Service Center)
50-Year Coastal Storm:
Jersey City & Hoboken, NJ

(Source: FEMA Map Service Center)
100-Year Coastal Storm: Jersey City & Hoboken, NJ

(Source: FEMA Map Service Center)
# Water Elevations Accordingly to Level of Threats, Along the Coastline of Hudson River Study Area

<table>
<thead>
<tr>
<th>Level of Threat</th>
<th>Water Elevations (NAVD88)</th>
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</thead>
<tbody>
<tr>
<td>10 - Year Storm</td>
<td>8.5 feet</td>
</tr>
<tr>
<td>50 - Year Storm</td>
<td>11.3 feet</td>
</tr>
<tr>
<td>100 – Year Storm</td>
<td>12.3 feet</td>
</tr>
<tr>
<td>100 – Year Storm + 2050 SLR</td>
<td>13.6 feet</td>
</tr>
<tr>
<td>100 – Year Storm + 2100 SLR</td>
<td>15.4 feet</td>
</tr>
<tr>
<td>2050 Sea Level Rise</td>
<td>1.3 feet</td>
</tr>
<tr>
<td>2100 Sea Level Rise</td>
<td>3.1 feet</td>
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</tbody>
</table>
Most of the frequent floods that Hoboken and Jersey City have to face are due to the backpressure that restricts flow out of the combined sewers.

During periods of heavy rainfall, sanitary wastewater and storm water can overflow the conveyance system and discharge directly to surface water bodies. Each CSO outfall is protected from coastal surge via a flap gate.
Flap Gate at Morris Marina, Jersey City, NJ
Recommended **Regional Flood Mitigation Measures**

**Measure 1: Flood Wall**
Floodwall Schematic showing Bulkhead and Extensions
Recommended **Regional Flood Mitigation Measures**

**Measure 2: Gates at Open Tidal Canals**

In the study area, there are two open canals, the Long Slip in Hoboken and the Morris Marina in Jersey City. Both of these canals represent an entrance for storm surge from the Hudson River.

The surge barriers are recommended at entrance of these two canals. This measure should be implemented in connection with the measure of the floodwall.
Hoboken: Recommended Measures at Municipal Scale

Surge Threat: Flood Barrier to Protect Hoboken alone
Hoboken: Recommended Measures at Municipal Scale

**Stormwater Threat:**
Measure 1 - Surface Storage at Long Slip Canal
Hoboken: Recommended Measures at Municipal Scale

**Stormwater Threat:**
**Measure 2 – Sewer Separation**

It is recommended that the combined sewer system be separated into stormwater and wastewater conveyance systems that will allow for better management of stormwater since more options are available to handle the storage and disposal of stormwater than there are for sewage.
Hoboken: Recommended Measures at Municipal Scale

**Stormwater Threat:**
Measure 3 – Green Infrastructure for Runoff Reduction

The area of Hoboken is highly impervious without many parks or open spaces. Green infrastructures like porous pavements, swales, green gardens, and green roofs, can be implemented. It is proposed that the storm water inputs to the drainage system should be reduced for this study area. The feasibility of implementing green infrastructure to absorb a portion of the surface water runoff has been assessed for this study.
Jersey City: Recommended Measures at Municipal Scale

**Surge Threat**: Addressed through the regional floodwall
Jersey City: Recommended at **Municipal** Scale

**Stormwater Threat:**

**Measure 1: Green Belt**

consists of open areas under the elevated roadway of US Rt. 78 and adjacent areas
Jersey City: Recommended at Municipal Scale

**Stormwater Threat:**
Measure 2: Surface Storage at Morris Marina
Jersey City: Recommended Measures at Municipal Scale

**Stormwater Threat:**
**Measure 3: Sewer Separation**

It is recommended that the combined sewer system be separated into stormwater and wastewater conveyance systems that will allow for better management of stormwater since more options are available to handle the storage and disposal of stormwater than there are for sewage.

**Stormwater Threat:**
**Measure 4: Green Infrastructure for Runoff Reduction (city-wide)**

The feasibility of implementing green infrastructure to absorb a portion of the surface water runoff has been assessed for the area of Jersey City.
Jersey City: Recommended Measures at **Block/Lot Scale**

The flood mitigation strategies on this scale are primarily engineering practices that will make sure that existing stormwater infrastructure is functioning and enhance its effectiveness by reducing the stress upon it.

The raising of some parts of Route 440 was investigated in the area of Jersey City. Small scale flooding in this area often occurs in low-lying intersections or roadways. These areas could be raised and infiltration galleries installed beneath them to provide temporary storage.
Study Area 3: Arthur Kill
(Elizabeth, Linden, Rahway, Carteret and Woodbridge)
Study Area

3: Arthur Kill
(Elizabeth, Linden, Rahway, Carteret and Woodbridge)
Recommended **Regional** Flood Mitigation Measures

It is recommended that a **floodwall** be installed along the Arthur Kill from the City of Elizabeth to the Township of Woodbridge (approximately 15 miles) varying in height from 8 to 10 feet.

It is envisioned that the floodwall will be adaptable such that its height can be readily increased to deal with future sea level rise.

The floodwall will need to be combined with in-water closure devices at all tributaries of the Arthur Kill, most notably the Elizabeth River, Rahway River and Woodbridge River along with all the small creeks that will interrupt the floodwall.
Proposed Regional Seawall along the Arthur Kill
City of Linden
Proposed Measures at Municipal Scale
(e.g., City of Linden)

(1) The City of Linden is vulnerable to coastal flooding from the Arthur Kill on its eastern side and inland along the Rahway River and its tributaries such as Marshes Creek. Installation of a new floodwall along the banks of the river with in-water channel closure devices at the confluence of the Rahway River and the Arthur Kill and at the confluences of the smaller Arthur Kill tributaries Piles and Morses Creek will mitigate both the coastal and riverine flooding threat faced by the community. It is envisioned that the floodwall will be adaptable such that its height can be readily increased to deal with future sea level rise.

(2) The City also experiences local flooding due to inadequate conveyance capacity in downstream stormwater channels caused by excessive sedimentation in Orchard Brook, Peach Orchard and Morses Creek where these channels were widened to form reservoirs in the past. It is also likely that since these waterways are tidally impacted conveyance in these channels are restricted when precipitation occurs during elevated tidal periods. It is recommended that the channels be de-silted on a regular basis to ensure that downstream conveyance is maximized thereby reducing localized flooding.

(3) Tremley Point where low lying portions of this community are flooded regularly due to inadequate conveyance in Marshes Creek coupled with restricted flow during elevated tidal periods. It is suggested that flooding can be mitigated in this community by improving conveyance in Marshes Creek by, removing the bottleneck where the creek passes under a railroad track, straightening the creek where it meanders adjacent to the community and by installing a sluice gate that can be operated as needed to control the inflow of coastal floods.

(4) Green infrastructure mitigation measures be implemented to reduce the amount of stormwater runoff generated
Tremley Point in City of Linden adjacent to Marshes Creek
Marshes Creek Adjoining Tremley Point in City of Linden
Marshes Creek Adjoining Tremley Point in City of Linden
(Crossing under NJ Turnpike and Railway Track)
Marshes Creek Adjoining Tremley Point in City of Linden
(Downstream of Railway Track)
Possible Buyout Parcels in Woodbridge Township
Study Area 4: Barnegat Bay
(Point Pleasant, Brick, Toms River, Seaside Heights, Stafford, Little Egg Harbor)
PLACEMENT OF FLOOD DEFENSE MEASURES:

Surge Defense Barriers
PLACEMENT OF SURGE DEFENSE MEASURES:

Bulkhead, Concrete Floodwall, Levee, etc.
PLACEMENT OF SURGE DEFENSE MEASURES:

Sluice Gate/In-Water Barrier, Flood Gate, Culvert Flap Gate
PLACEMENT OF FLOOD DEFENSE MEASURES:

Stormwater Pump Stations
Study Area 5: Delaware Bay
(Commercial, Downe, Greenwich, Maurice River in Cumberland County)
Recommended **Regional** Flood Mitigation Measures:

1. Regional Causeway System across saltmarsh adjacent to upland with operable flood gates
Recommended **Regional** Flood Mitigation Measures:

2. Floodwater Pump

(Windmill tower, www.ironmanwindmill.com)
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THANK YOU!
ANY QUESTIONS?