Resiliency: Opportunities for Improved Planning and Design to Manage Coastal Risks

Paul Tschirky, PhD, PEng, D.CE
Peter de Haven, PE

November 13, 2018
Agenda

• Coastal Risks

• Coastal Resiliency and Adaptation
  – Definition
  – Approaches
  – Examples
Why Resilience and Adaptation?
"Two of the greatest challenges facing the nation are recognizing the magnitude of risk posed by flooding and motivating the public and decision-makers to make the investments and difficult policy decisions required to reduce flood risk."

Flood Risk Management Priorities
Coastal Risks

- Hurricanes and Tropical Storms
- Storm Surge and Waves
- Sea-Level Rise
- Rainfall (changes in intensity and distribution)
- Growth in coastal population

UNDERSTAND, QUANTIFY, AND ASSESS RISKS
iss056e162819 (Sept. 14, 2018) --- Hurricane Florence is pictured from the International Space Station as a category 1 storm as it was making landfall near Wrightsville Beach, North Carolina.
Risk - Storms

Hurricanes

NOAA Historical Hurricane Tracks 1851-2016
Centered on Carolina Beach, NC

Estimated return period in years for hurricanes passing within 50 nautical miles of various locations on the U.S. Coast
Risk - Storms

Rain events

Warmer temperatures result in the ability of the atmosphere to hold more moisture

Possibly higher intensity storms or changing distribution

After Harvey NOAA revising Houston’s 100-year 24-hour rainfall from 12-14 inches to 15-18 inches (in the range of old 500-year estimates).
Risk - Rising Seas

Sea Level Rise

- Science of sea level rise is continuously evolving
- Many forecasts available
- Future projections are highly variable
- Based upon models, assumptions, vigorous debate
- **BUT** no doubt sea level is rising
In 2010, NC CRC Science Panel recommends 39” by 2100 for planning purposes (15-55” range likely)
Sea Level Rise

With 1.5 m sea level rise
What are the effects of sea level rise?

- Increased damage from coastal storms
- Storm water/municipal drainage no longer works during high tide
- Increasing frequency of flood events
- Inundated roads (nuisance flooding)
- Salt-water intrusion
  - Rivers and lenses of fresh groundwater becoming more saline
  - Re-location of municipal drinking wells
- Plant, tree, and habitat mortality
- Lowland fields no longer suitable for agriculture
## Coastline Population by State: 1960 to 2008

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>179,323,175</td>
<td>203,211,926</td>
<td>226,545,805</td>
<td>248,709,873</td>
<td>281,421,906</td>
<td>304,059,724</td>
<td>124,736,549</td>
</tr>
<tr>
<td>Atlantic</td>
<td>26,665,037</td>
<td>30,449,628</td>
<td>31,943,197</td>
<td>35,231,154</td>
<td>39,215,349</td>
<td>41,584,799</td>
<td>14,919,762</td>
</tr>
<tr>
<td>Gulf of Mexico</td>
<td>5,562,984</td>
<td>6,936,997</td>
<td>9,149,249</td>
<td>10,723,973</td>
<td>12,557,407</td>
<td>13,920,664</td>
<td>8,357,680</td>
</tr>
<tr>
<td>Pacific</td>
<td>15,220,210</td>
<td>19,328,790</td>
<td>22,495,109</td>
<td>27,093,528</td>
<td>30,351,636</td>
<td>31,918,370</td>
<td>16,698,160</td>
</tr>
<tr>
<td>Maine</td>
<td>439,851</td>
<td>464,883</td>
<td>548,040</td>
<td>623,198</td>
<td>682,814</td>
<td>713,357</td>
<td>273,506</td>
</tr>
<tr>
<td>Massachusetts</td>
<td>2,597,027</td>
<td>2,862,290</td>
<td>2,932,393</td>
<td>3,095,930</td>
<td>3,317,771</td>
<td>3,414,730</td>
<td>817,703</td>
</tr>
<tr>
<td>Rhode Island</td>
<td>859,488</td>
<td>946,725</td>
<td>947,154</td>
<td>1,003,464</td>
<td>1,048,319</td>
<td>1,050,788</td>
<td>191,300</td>
</tr>
<tr>
<td>Connecticut</td>
<td>1,588,514</td>
<td>1,882,926</td>
<td>1,935,906</td>
<td>2,030,017</td>
<td>2,120,734</td>
<td>2,170,444</td>
<td>581,930</td>
</tr>
<tr>
<td>New York</td>
<td>10,557,830</td>
<td>11,341,996</td>
<td>10,544,051</td>
<td>10,806,642</td>
<td>11,685,650</td>
<td>12,181,502</td>
<td>1,623,672</td>
</tr>
<tr>
<td>New Jersey</td>
<td>3,290,028</td>
<td>3,750,347</td>
<td>3,831,213</td>
<td>4,005,994</td>
<td>4,367,129</td>
<td>4,479,494</td>
<td>1,189,466</td>
</tr>
<tr>
<td>Delaware</td>
<td>446,292</td>
<td>548,104</td>
<td>594,338</td>
<td>666,168</td>
<td>783,600</td>
<td>873,092</td>
<td>426,800</td>
</tr>
<tr>
<td>Maryland</td>
<td>2,026,229</td>
<td>2,294,049</td>
<td>2,399,856</td>
<td>2,582,753</td>
<td>2,761,143</td>
<td>2,911,538</td>
<td>885,309</td>
</tr>
<tr>
<td>Virginia</td>
<td>1,325,584</td>
<td>1,683,387</td>
<td>1,967,609</td>
<td>2,487,459</td>
<td>2,827,481</td>
<td>3,050,717</td>
<td>1,725,133</td>
</tr>
<tr>
<td>North Carolina</td>
<td>441,605</td>
<td>477,404</td>
<td>563,609</td>
<td>679,075</td>
<td>792,902</td>
<td>909,106</td>
<td>467,501</td>
</tr>
<tr>
<td>South Carolina</td>
<td>403,667</td>
<td>441,785</td>
<td>532,498</td>
<td>621,683</td>
<td>742,274</td>
<td>877,921</td>
<td>474,254</td>
</tr>
<tr>
<td>Georgia</td>
<td>267,305</td>
<td>281,108</td>
<td>326,382</td>
<td>386,415</td>
<td>439,154</td>
<td>475,764</td>
<td>208,459</td>
</tr>
<tr>
<td>Florida</td>
<td>3,835,751</td>
<td>5,388,107</td>
<td>7,664,458</td>
<td>10,066,203</td>
<td>12,285,697</td>
<td>13,871,629</td>
<td>10,035,878</td>
</tr>
<tr>
<td>Alabama</td>
<td>363,389</td>
<td>376,690</td>
<td>443,536</td>
<td>476,923</td>
<td>540,258</td>
<td>580,748</td>
<td>217,359</td>
</tr>
<tr>
<td>Mississippi</td>
<td>189,050</td>
<td>239,944</td>
<td>300,217</td>
<td>312,368</td>
<td>363,988</td>
<td>349,294</td>
<td>160,244</td>
</tr>
<tr>
<td>Louisiana</td>
<td>1,192,074</td>
<td>1,385,438</td>
<td>1,575,797</td>
<td>1,550,498</td>
<td>1,610,435</td>
<td>1,426,150</td>
<td>234,076</td>
</tr>
<tr>
<td>Texas</td>
<td>2,305,308</td>
<td>2,882,491</td>
<td>3,795,011</td>
<td>4,314,492</td>
<td>5,126,048</td>
<td>5,871,839</td>
<td>3,566,531</td>
</tr>
<tr>
<td>California</td>
<td>12,254,192</td>
<td>15,649,052</td>
<td>18,008,000</td>
<td>21,748,651</td>
<td>24,135,820</td>
<td>25,161,295</td>
<td>12,907,103</td>
</tr>
<tr>
<td>Oregon</td>
<td>371,256</td>
<td>426,780</td>
<td>538,930</td>
<td>550,921</td>
<td>611,645</td>
<td>643,872</td>
<td>272,216</td>
</tr>
<tr>
<td>Alaska</td>
<td>176,357</td>
<td>243,281</td>
<td>334,319</td>
<td>457,932</td>
<td>529,474</td>
<td>574,021</td>
<td>397,664</td>
</tr>
<tr>
<td>Hawaii</td>
<td>632,772</td>
<td>768,561</td>
<td>964,691</td>
<td>1,108,229</td>
<td>1,211,537</td>
<td>1,288,198</td>
<td>655,426</td>
</tr>
</tbody>
</table>

# Risk - Growing Coastal Populations

## Coastline Population by State: 1960 to 2008

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>179,323,175</td>
<td>203,211,926</td>
<td>226,545,805</td>
<td>248,709,873</td>
<td>281,421,906</td>
<td>304,059,724</td>
<td>124,736,549</td>
</tr>
<tr>
<td>Coastline counties</td>
<td>47,448,231</td>
<td>56,715,415</td>
<td>63,587,555</td>
<td>73,048,655</td>
<td>82,124,392</td>
<td>87,433,886</td>
<td>42,985,655</td>
</tr>
<tr>
<td>Atlantic</td>
<td>26,665,037</td>
<td>30,449,628</td>
<td>31,943,197</td>
<td>35,231,154</td>
<td>39,209,062</td>
<td>40,667,687</td>
<td>14,002,650</td>
</tr>
<tr>
<td>Gulf of Mexico</td>
<td>5,562,984</td>
<td>6,936,997</td>
<td>8,130,361</td>
<td>8,196,691</td>
<td>8,860,761</td>
<td>9,436,917</td>
<td>3,873,933</td>
</tr>
<tr>
<td>Pacific</td>
<td>15,220,218</td>
<td>23,440,879</td>
<td>24,574,808</td>
<td>25,743,239</td>
<td>26,215,671</td>
<td>26,709,393</td>
<td>11,489,175</td>
</tr>
<tr>
<td>New Hampshire</td>
<td>29,050</td>
<td>33,944,628</td>
<td>31,943,197</td>
<td>35,231,154</td>
<td>39,209,062</td>
<td>40,667,687</td>
<td>14,002,650</td>
</tr>
<tr>
<td>North Carolina</td>
<td>1,192,074</td>
<td>1,385,438</td>
<td>1,575,797</td>
<td>1,610,435</td>
<td>1,426,150</td>
<td>234,076</td>
<td>19.6</td>
</tr>
<tr>
<td>South Carolina</td>
<td>189,050</td>
<td>239,944</td>
<td>300,217</td>
<td>312,368</td>
<td>363,988</td>
<td>439,294</td>
<td>250,444</td>
</tr>
<tr>
<td>Georgia</td>
<td>1,254,192</td>
<td>1,564,052</td>
<td>1,800,800</td>
<td>21,748,651</td>
<td>24,135,820</td>
<td>25,161,295</td>
<td>12,907,103</td>
</tr>
<tr>
<td>Florida</td>
<td>12,305,308</td>
<td>15,082,491</td>
<td>18,009,977</td>
<td>21,504,429</td>
<td>25,161,295</td>
<td>25,161,295</td>
<td>12,907,103</td>
</tr>
<tr>
<td>Alabama</td>
<td>371,256</td>
<td>426,780</td>
<td>538,930</td>
<td>550,921</td>
<td>611,645</td>
<td>643,872</td>
<td>272,616</td>
</tr>
<tr>
<td>Louisiana</td>
<td>176,357</td>
<td>243,281</td>
<td>334,319</td>
<td>457,932</td>
<td>529,474</td>
<td>574,021</td>
<td>297,664</td>
</tr>
<tr>
<td>Texas</td>
<td>632,772</td>
<td>768,561</td>
<td>964,691</td>
<td>1,108,229</td>
<td>1,211,537</td>
<td>1,288,198</td>
<td>655,426</td>
</tr>
<tr>
<td>California</td>
<td>12,254,192</td>
<td>15,645,052</td>
<td>18,009,800</td>
<td>21,748,651</td>
<td>24,135,820</td>
<td>25,161,295</td>
<td>12,907,103</td>
</tr>
<tr>
<td>Oregon</td>
<td>371,256</td>
<td>426,780</td>
<td>538,930</td>
<td>550,921</td>
<td>611,645</td>
<td>643,872</td>
<td>272,616</td>
</tr>
<tr>
<td>Alaska</td>
<td>176,357</td>
<td>243,281</td>
<td>334,319</td>
<td>457,932</td>
<td>529,474</td>
<td>574,021</td>
<td>297,664</td>
</tr>
<tr>
<td>Hawaii</td>
<td>632,772</td>
<td>768,561</td>
<td>964,691</td>
<td>1,108,229</td>
<td>1,211,537</td>
<td>1,288,198</td>
<td>655,426</td>
</tr>
</tbody>
</table>


- **29% of US population live in a coastal county**
- **NC coastal population has increased more than 100% since 1960 (~500,000 people)**
- **40% of global population lives within 65 miles of coast**
Implications

- Areas of low-lying topography have increased coastal vulnerability
- Beach erosion will increase impacts of storms with rising sea levels
- Rising sea levels impact level of service of existing systems
- Infrastructure at risk from storm surge and flooding

Need for resilient and adaptive planning and design
Implications

- Changing **legal** implications
- Changing **insurance** framework
- **Bonding** and money risks

Duty to public to address known risks and maintain infrastructure.

Rising insurance costs (changing allocation of burden).

Leaving the growing risk of rising seas unaddressed is going to hurt municipal and government credit scores and result in higher interest rates when they borrow money.

**Moody’s Warns Cities to Address Climate Risks or Face Downgrades**

– Bloomberg

**S.E.C. Is Criticized for Lax Enforcement of Climate Risk Disclosure**

– The New York Times

**Sea level suits are the next frontier in climate change litigation**

– Daily Journal
Resiliency
the ability of a natural or built system to recover from an extreme load or event

Adaptation
adjustment in response to changes in the factors that impact the functionality of a natural or built system
Resiliency Timeline

Functionality vs. Time

- Prepare; Anticipate; Plan
- Resist; Withstand; Absorb
- Recover; Bounce Back
- Adapt; Evolve; Transform; Bounce Forward

Resilience increased:
- Less loss in functionality
- Faster recovery time

~ Adapted from USACE and Julie Dean Rosati, et al. (2015)
Resiliency and Adaptation

Resilience Improvement Cycle

Adaptive measure implemented to create new ‘normal’ reduces duration and magnitude of impact

Magnitude of Impact

Duration (time)

new level of resilience
base level of resilience
Resiliency and Adaptation

- Modeling
- Vulnerability assessments
- Design and implement resiliency measures

- Monitor
- Assess performance

- Bounce forward
- Make changes to recognize changing conditions
- Learn from past performance

- Bounce back
- Not just rebuild but improve resilience

Coastal Resilience & Adaptation
Key Components of Resiliency

TRADITIONAL ENGINEERING WORKS

- Usually designed to withstand events with a given probability of occurrence at the time of their construction
- Accept failure under more severe conditions

RESILIENCY

- Prepare for unknown (plan and evaluate projects for events outside likely scenario)
- Design for adaptability
- System response
Multidisciplinary

COASTAL RESILIENCY & ADAPTATION

- Structural Engineering
- Wetlands Ecological Assessment
- Coastal Engineering
- Geotechnical Engineering
- Civil Engineering
- Landscape Services
- Hydraulics and Hydrology Engineering
- Environmental and Permitting Services
Multilayered

**Inner Layer (Local)**
- Smaller-scale solutions
- Protect critical infrastructure
- Integrating water management and urban planning

**Middle Layer (Regional)**
- "Transition" zone
- Floodwalls, marshes, levees (multifunctional), beaches

**Outer Layer (Large Area)**
- Larger, engineered solutions
- Storm surge barriers, sea gates, Offshore structures, pump and levee systems

~ FIGURE: North Atlantic Coast Comprehensive Study (USACE, 2015)
Some Coastal Resiliency Elements

**Physical**

- **engineered structures**
  - seawalls and barriers
  - levees
  - improved drainage
  - breakwaters
  - revetments
  - groins
  - pump stations
  - temporary floodwalls
  - ...

- **nature based**
  - beach nourishment (sediment management)
  - wetland restoration
  - reefs
  - vegetation (mangroves, seagrass)

- **technology**
  - water management and monitoring systems
  - better mapping, modeling, prediction

**Social**

- **Education**
- **Information** (risk maps, tools, services,...)
- **Stewardship**
- **Government** (policy and regulation- land use, building codes, relocation, economic incentives,...)
Coastal Resiliency and Adaptation Approaches

- Raised infrastructure
- Sand stockpile
- Living shorelines
- Beach nourishment
- Buried seawall

Bay
Reef
Ocean
Coastal Resiliency and Adaptation Approaches

- Elevated Structure
- Elevated Assets
- Floodwall-Protected Assets
- Deployable Flood Barriers
- Vehicular Floodgate
- Landscaped Berm
- Floodwall

engineers | scientists | innovators
Coastal Resiliency and Adaptation Approaches

Planning and Designing System

Technology Innovation

Rain

Overtopping

Storm Surge + Tides + Sea Level Rise

Waves

Tide Gate / Valves

Adaptive use of storage - improved water quality and flood control

web-based dashboard

control panel

actuated valve outlet or pump

infiltration

stormwater infrastructure

water level sensor

NWS forecast
Coastal Resiliency and Adaptation Approaches

Retreat
move infrastructure from vulnerable areas

Accommodate
modify designs to allow for periodic flooding

Protect
design defenses to reduce flooding

Everything does not have to be built now... but you have to plan for it
Living Breakwaters

REBUILD BY DESIGN

Risk Reduction
Ecology
Culture

- Reduce wave heights and shoreline erosion
- Revive marine reef ecology and increase diversity of aquatic habitat
- Connect people to the water’s edge, enhance community stewardship

design + ecology + engineering + people
Hermosa Beach, California

- Large, coastal community affected by sea level rise and salinity in coastal areas.
- Town needed to evaluate how coastal shallow groundwater elevation and salinity responds to projected increases in sea level rise in sandy, low-lying coastal soils and evaluated the vulnerability of existing sanitary sewer and storm drain infrastructure.

- Included:
  - Climate Change Vulnerability Assessment
  - Groundwater Monitoring
  - Stormwater Monitoring
  - Groundwater Elevation & Salinity Intrusion Forecasting
Broward County, Florida

- Coastal county in southeast Florida, 2 million population
- Experiencing recurrent flooding and impacts due to sea level rise
- County needs to update flood maps to inform a comprehensive plan to
  - address sea level rise impacts
  - address impacts of sea level rise on groundwater elevations and subsequent impacts to recurrent flooding
- Develop sea level rise and climate change projections
- Hydrologic & Hydraulic modeling integrating future sea level rise, rainfall intensities, and land use
- Floodplain map update
- Stakeholder engagement and public outreach
Active Floodproofing

**Elements at a Business Scale**

- Flood risk audits
- Improve the resiliency of critical building components before, during, and after a storm
- Flood and storm surge modeling
- Flood resiliency through real time monitoring and control of pipe water levels, weather forecast and other parameters
- Controls valves automatically when conditions are indicative of a flood risk protecting building from the backflow

“NEW, INNOVATIVE, AND COST-EFFECTIVE” SOLUTIONS TO “ENABLE BUILDINGS AND INFRASTRUCTURE NETWORKS TO BETTER RESIST, ADAPT TO, AND/OR BOUNCE BACK FROM FUTURE STORMS.”
St. Augustine, Florida

Goals:
- Coastal resiliency and infrastructure sustainability in the face of future sea level rise
- Protection of City assets and structures from high tide and storm impacts
- Systematic identification of critical outfalls and tide valve retrofit options

Tide Check Valve Program Flood Mitigation Project
- Great success has been documented where the valves have been installed (elimination of nuisance tidal flooding)

Next steps – Additional Resiliency Projects
- Master Stormwater Outfall Resiliency Retrofit Plan (prioritize remaining 80+ outfalls)
- Macaris Outfall Retrofit Design and Permitting (60-inch and 30-inch pipes)
Resilience and Adaptation

Understand and Quantify Coastal and Flood Hazards

Assess and Prioritize

Resilient Planning and Design

Adapt