Coastal geology, processes, and management overview

E. Robert Thieler, Ph.D.
U.S. Geological Survey
Woods Hole, MA
Outline

- Some scientific and management dimensions of coastal change
- Beach and coast fundamentals
- Options and potential impacts of different shoreline management strategies
- Results and implications of recent sea-level rise assessments
The U.S. Coastal Crisis – Coastal population and development are increasingly vulnerable to coastal hazards

- Erosion affects all 30 coastal states
- 60-80% of coast is eroding
- Erosion caused by diverse, complex processes

- Coastal populations have doubled
- >50% live along coasts
- Infrastructure about $9 trillion
We need better science* to prepare our local responses to climate change, especially in our coastal areas.
(David Carter, Delaware Coastal Management)

*science = better understanding of processes + better situation awareness
Dynamic Equilibrium of Beaches

Sediment supply

Location and shape of the beach

Relative sea-level change

Wave energy

(after Pilkey and Thieler, 1992)
Sediment supply and coastal banks

Photo: MA CZM (courtesy MA CZM)
Sediment Sharing System

Source: Google Earth (courtesy MA CZM)
Longshore sediment transport

- Waves approach the beach at an angle.
- Longshore current.
- Wind direction.
- Path of sand particles.
- Downstream.
- Net movement of sand grains (longshore drift).

(courtesy MA CZM)
Falmouth South Shore Erosion Rates

(Falmouth CRWG, 2000)
Green Pond Shoreline Change Since 1845

- Sediment supply decreased
- Uplands armored, beaches narrowed
- Barrier has migrated into the pond

(Falmouth CRWG, 2000)
Common responses to an eroding coastline

Hard stabilization
• Seawalls, groins, breakwaters, etc.

Soft stabilization
• Beach nourishment

Relocation or retreat
• Move back from eroding shorelines

(after Pilkey and Thieler, 1992)
Hard stabilization

- Advantages
  - Most dependable way to save beachfront property

- Disadvantages
  - Degrades the recreational beach
  - Reduces beach access
  - Costly
  - Unsightly

(after Pilkey and Thieler, 1992)
Modes of beach loss by seawalls

**Placement**
- Seawall built on the beach

**Passive**
- Beach continues to retreat and narrows in front of the seawall

**Active**
- Seawall directly causes erosion

(after Pilkey and Thieler, 1992)
Shore Parallel Structures

- Erosion continues
- Cuts off sediment source
- Causes end scour
- Causes increased erosion
- Can be overtopped
- Requires monitoring
- Requires mitigation
- Costly to maintain

Photos: MA CZM (courtesy MA CZM)
Two alternative scenarios for long-term shoreline change

(Pilkey and Thieler, 1992)
Related impacts of hard stabilization

Changes to alongshore sediment transport

Reduction in sediment delivery to beach system
Shore Perpendicular Structures

Photos: MA CZM

(courtesy MA CZM)
Offshore Breakwaters

Source:
Google Earth
Sand-filled bags

Photos: MA CZM

(courtesy MA CZM)
Some 'softer' alternatives
Beach Nourishment

Photo: Woods Hole Group, Inc.

Photo: MA CZM
Relocation or Retreat

(after Pilkey and Thieler, 1992)
The end of “Climate Stationarity” requires that organizations and individuals alter their standard practices and decision routines to take climate change into account. Scientific priorities and practices need to change so that the scientific community can provide better support to decision makers in managing emerging climate risks.

• Decision makers must expect to be surprised because of the nature of climate change and the incompleteness of scientific understanding of its consequences.

• An uncertainty management framework should be used because of the inadequacies of predictive capability.
Sea-level rise impacts: A multivariate problem with uncertainties everywhere

Driving Forces
- Climate Change & Sea Level Rise

Physical & Biological Processes
- Groundwater Impact
- Wetland Loss
- Coastal Erosion
- Inundation

Potential Impacts
- Habitat Loss
- Safety

Initial Conditions

Management Decisions

Adaptation Planning Response
Some things to consider...

• **Options that maintain future flexibility**
  • Magnitude and timing of future climate change and our responses to it are uncertain

• **Holistic examination of potential impacts**
  • Geologic, biologic, economic, social...
  • Expectations of your coastal zone (resources, tourism, aesthetics, navigation, etc.)

• **Time horizon**
  • How long should something last? Until you have a better plan to address the problem? The next big storm? Two feet of sea-level rise? Forever?

• **Risk tolerance**
  • Scale with size, value, time
  • Implications of failure or over-planning/building

• **Protocols for what happens after large events**
  • Because there will be a "next time"
What causes the sea level to change?

- Land water storage changes
- Ocean currents change
- Land can rise or sink
- Warm water expands
- Ice melts into the ocean

(IPCC, 2001)
MA Historical Sea-level Rise in Context

- Global mean SLR over past century ~1.7 mm/yr
- Some contribution in MA from regional land subsidence
- Potential future rates could be much greater
Past, present, and potential future rates of sea-level rise

“Geologic past” (Fairbanks, 1989; Horton et al. 2009)

“Instrumental record” (Church and White, 2006)

“Projections” (Rahmstorf, 2007)
Sea-level Rise Projections

Recent expert assessment (n=90 experts)
0.4-0.6 m for RCP 3-PD
0.7-1.2 m for RCP 8.5

IPCC AR5

Worst case is much worse than this.

(courtesy Aslak Grinsted; AR5 projections from IPCC, 2013)
Mid-Atlantic Assessment of Potential Dynamic Coastal Responses to Sea-level Rise

Gutierrez et al., 2009

Bluff erosion

Overwash

Island Breaching

Threshold Crossing

Atlantic Ocean

EXPLANATION

<table>
<thead>
<tr>
<th>SLR Scenario</th>
<th>20th Cent. Rate*</th>
<th>20th Cent. +3 mm/yr</th>
<th>20th Cent. +7 mm/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUE</td>
<td>BUE</td>
<td>BUE</td>
<td></td>
</tr>
<tr>
<td>OEIB</td>
<td>OEIB</td>
<td>OEIB</td>
<td></td>
</tr>
<tr>
<td>OEIB</td>
<td>OEIB</td>
<td>T?</td>
<td></td>
</tr>
<tr>
<td>OEIB</td>
<td>T?</td>
<td>T</td>
<td></td>
</tr>
<tr>
<td>T?</td>
<td>T</td>
<td>T</td>
<td></td>
</tr>
</tbody>
</table>

BUE = Bluff and Upland Erosion
OEIB = Overwash, Erosion, Island Breaching
* = Indicates the condition could be marginal
T = Threshold Condition

(Gutierrez et al., 2009)
Coastal Flooding in Charleston, SC
(Built environment impacts)

- NOAA NWS Charleston issues shallow coastal flooding advisories for 7 ft tides
- 7 ft tides typically predicted to occur twice a year
- With 1.6 ft of relative sea-level rise, this advisory could be issued 355 times
Summary

• The coast as we know it today is a product of sea-level rise

• Future sea-level rise is a certain impact
  • We have already made a commitment to several centuries of rise

• Future sea-level rise is an uncertain impact
  • Rates and magnitudes poorly constrained
  • Societal response unknown

• Major changes are coming to the coast, ecosystems, and resources

• Informed preparation is important

• Being uncertain is OK