Shifting Sands and the Shorelines of Nantucket

Andrew Ashton
• Change is the constant along the coast
• The coastline is interconnected, from source to sink
• Current management problems are in most cases are not (yet!) related to human-induced climate change
• Sea-level rise and climate change effects will be superimposed on ongoing coastal change
• So wherever there are management problems now, they will get much worse.
coastal sediment budget

from Titus et al, 2009

Oldale, 2001
Erosional vs. Depositional Environments

- Cliffs and Bluffs
  - Loss is permanent
- Barriers and Dunes
  - Always changing
  - Accreting or being reworked
Geology of Nantucket

Oldale USGS, 1985
Processes Long Studied

The Outline of Cape Cod
by W.M. Davis, 1896
alongshore sediment transport

- Also known as “littoral transport”
- Sediment moved along the coast by breaking waves
alongshore sediment transport

- breaking-wave-driven alongshore sediment transport (within the surf zone) is highly dependent on deep-water wave-angle.
coastline change

Alongshore Sediment Transport

Oldale, 2001
coastline change

Alongshore Sediment Transport

Oldale, 2001
Alongshore Sediment Transport

Oldale, 2001
simulated low-angle spits
simulated low-angle spits
spits
modeled spit formation
process-based spit characterization

- **Neck**
  - $Q_s$ Increasing
  - Erosional
  - Stable

- **Fulcrum Point**
  - $Q_s = \text{maximum}$

- **Hook**
  - $Q_s$ Decreasing
  - Depositional
  - Progradational
  - Unstable

- **Overwash**
  - Retreat with minimal curvature

- **Headland**

Graphs:
- $Q_s$ (normalized) vs. $(\phi_0 - \theta)$ (°)
- Angle Effect vs. $(\phi_0 - \theta)$ (°)
different headland widths

Ashton et al., ESD 2016
different headland widths

Ashton et al., ESD 2016
different wave angles
different headland erosion rate
Cape Cod
Geology of Nantucket

Oldale USGS, 1985
alongshore sediment transport

- Also known as “littoral transport”
- sediment moved along the coast by breaking waves
smoothing of coast?
smoothing of coast?

$Q_s$ changes substantially while $\phi_0 - \theta$ remains relatively constant
evolution
examples
Nantucket Harbor
Sea-level Rise Projections

NOAA Global Mean Sea Level (GMSL) Scenarios for 2100

(Sweet et al., 2017)
shoreline flooding

Sea-level Flooding

- Flooding Predictions (Titus et al., 2009)

\[ x = \frac{1}{S_{\text{beach}}} \Delta Z \]
Sea-level Flooding

shore slope: $S_{\text{beach}}$

shoreline change: $\Delta X$

sea-level rise: $\Delta Z$

$x = \frac{1}{S_{\text{beach}}} z$

With Waves: the ‘Bruun Rule’

shoreline change: $\Delta X$

sea-level rise: $\Delta Z$

shoreface slope: $S_{\text{shoreface}}$

$x = \frac{1}{S_{\text{shoreface}}} z$
balance of components
- waves send sediment shoreward
- gravity component offshore

waves (depth)
gravity (slope)
equilibrium slope

- balance of components
  - waves send sediment shoreward
  - gravity component offshore
equilibrium slope

• balance of components
  – waves send sediment shoreward
  – gravity component offshore
equilibrium slope

- balance of components
- waves send sediment shoreward (asymmetry)
- gravity component offshore

\[ \text{shoreline change: } \Delta X \]
\[ \text{sea-level rise: } \Delta Z \]
\[ \text{shoreface slope: } S_{\text{shoreface}} \]
shoreline change

Sea-level Flooding

With Waves: the ‘Bruun Rule’

\[ x = \frac{1}{S_{\text{beach}}} z \]

\[ x = \frac{1}{S_{\text{shoreface}}} z \]
Sea-level Flooding

\[ x = \frac{1}{S_{\text{beach}}} \Delta z \]

\( S_{\text{beach}} \approx 0.1 \)
\( \Delta x = 10 \times \Delta z \)

With Waves: the ‘Bruun Rule’

\[ x = \frac{1}{S_{\text{shoreface}}} \Delta z \]
Sea-level Flooding

- beach slope: $S_{\text{beach}}$
- shoreline change: $\Delta X$
- sea-level rise: $\Delta Z$

$x = \frac{1}{S_{\text{beach}}} \ z$

$S_{\text{beach}} \sim 0.1$
$\Delta x = 10 \times \Delta z$

With Waves: the ‘Bruun Rule’

- shoreline change: $\Delta X$
- sea-level rise: $\Delta Z$
- shoreface slope: $S_{\text{shoreface}}$

$x = \frac{1}{S_{\text{shoreface}}} \ z$

$S_{\text{shoreface}} \sim 0.01$
$\Delta x = 100 \times \Delta z$
barrier coasts

\[ S_{\text{shoreface}} \sim 0.01 \]
\[ \Delta x = 100 \times \Delta z \]

\[ S_{\text{land}} \sim 0.001 \]
\[ \Delta x = 1,000 \times \Delta z \]
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