lecture 6 (second half) 10/20/08 and lecture 7, 11/3/08

Coastal Processes

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Sources

Chapter 13 - The Coastline

Global Rise in Sea Level, p. 369-370 and Coastline, p. 372, to end of chapter
also http://myweb.cwpost.liu.edu/vdivener/notes/coastal_basic.htm

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Coastal Processes

The shoreline is affected by:

- ***waves*** (produced by wind at sea)
- ***tides*** (produced by the gravitational effect of the moon and sun)
- and also by ***storms*** and changing ***sea level***

Waves

Wave height in the open ocean is determined by three factors:

- wind speed
- duration of the wind
- fetch (distance over which the wind is blowing - size of storm)

As a wave passes, water molecules move in orbital paths.

- This orbital motion is greatest at the sea surface and decreases with depth below the surface.
- At a depth of ***one-half the wavelength*** the orbital waver motion is nearly zero (actually 4% of the surface orbital diameter). This ***L/2*** depth is considered ***wave base.***

As waves approach the shore

- They slow down from drag on the bottom when water depth is less than half the wavelength (L/2).
- The waves get closer together and taller.
- Orbital motions of water molecules becomes increasingly elliptical, especially on the bottom.
- There is a growing proportion of back and forth motion and less up and down motion.
- Eventually the bottom of the wave slows drastically.
- When the wave gets too steep it topples over as a breaker.
- The dominant sense of motion is now forward and backwards resulting in the forward swash of water followed by the backwash.

Littoral Drift: As a wave crashes on the shore, the water pushes sediment up the beach and then pulls it back down the beach as the water slides back down. If the waves do not come in parallel to the beach ***longshore transport (littoral drift***) of sand occurs.

Summer/Winter Profiles During calm summer weather with waves gently lapping the shore the beach grows in size. Waves surge up the shoreface. The swash carries sediment. The swash slows, runs out of momentum, then slides back down toward the water. Some of the backwash sinks into the sand. The backwash has a little less energy to carry sediment down the beach so the beach gradually grows in size with the development of a ***summer berm***. ***The summer beach profile is broader, with a more gentle slope, and lower berm.***

During the stormy winter months, storm waves carry much energy to the beach with extra energy to suspend sediments and redistribute them in the nearshore environment. Steady strong winds from a storm can push water up on the shore raising water levels. Return flow from this ***wind setup*** helps to carry sediment away from the shore. The summer berm is eroded away and the sands deposited offshore. ***The winter beach profile is steeper, narrower, and with a higher berm.***

Coastal Sedimentation Sediments will only remain on the beach or seafloor if wave energy is too week to mobilize or remove them. Wave energy is greatest in the swash zone and shallow water offshore and gets progressively less on the seafloor in deeper and deeper water. Therefore coarse sand and gravel dominates the beach, foreshore, and near shore. Sands become finer in deeper water farther offshore. Sandy bottoms give way to silt-dominated and then clay-dominated bottom sediments (silt + clay = muds) farther offshore and out across the continental shelf.

Tides

Tides result from the gravitational attraction of the sun and the Moon on the oceans.
- Tidal force is proportional to the mass of the attracting body
  - and inversely proportional to the cube of the distance
- The sun is much much more massive than the moon
- The sun is much farther away than the moon.

The net result is that the moon exerts about twice the tide-generating force that the sun does.

Equilibrium Theory of Tides
two tidal bulges:
- one bulge (high tide) drawn up between the Earth and Moon (or sun)
- another bulge on the opposite side of the Earth due to centripetal force

tides and lunar phases: As the Moon orbits around the Earth every four weeks, the relationship of the Sun, Earth, and Moon changes. At the ***full moon*** and ***new moon*** the Sun, Earth, and Moon are aligned. At these times the gravitational and centrifugal force of the Moon and Sun combine together. The resulting ***spring tides*** are the highest high tides and lowest low tides or the greatest tidal range during the course of the lunar month. At the ***first quarter*** and ***last quarter***, the Sun, Earth, and Moon form a right angle. At these times the gravitational and centrifugal forces of the Sun and Moon act at right angles to one another. The resulting ***neap tides*** are the lowest high tides and highest low tides or the smallest tidal range.

Dynamical Theory of Tides

In reality, tide patterns as not as simple as indicated by the equilibrium theory of tides.

Tidal crests rotate once every 12 hours around *amphidromic points*
counterclockwise in the northern hemisphere
clockwise in the southern hemisphere.

Nevertheless, in most locations, there are two high and two low tides per day and spring tides occur around the full and new moon and neap tides occur around the first and third quarter moons.

Storms

Midlatitude cyclones that travel up the east coast of North America, also called ***nor'easters*** or *extra-tropical storms*, result in strong, steady winds blowing toward shore for hours or days ahead of the central Low.

Storm Surge: These constant winds push water up against the shoreline due to ***wind setup.*** Storm surge causes flooding of low-lying coastal areas.

Beach Erosion is caused by the combination of:
wind setup, producing high sea level to enable erosion of the dunes
large waves produced by storm winds strongly stir the seafloor and beach
return flow: outflow of water along the seafloor carries sediments mobilized by strong wave action

Worst conditions for coastal storm flooding and erosion:
winds blowing toward shore for many hours, or even days
high tide
spring tide (near full moon or new moon)
perigee (when moon nearest to Earth)

The 1962 Ash Wednesday storm met all of those conditions. The storm moved up the east coast very slowly due to surrounding pressure systems blocking its path. It blew wind and water toward shore for three days and five high tides, producing waves up to 40 feet high and resulting in the deaths of 40 people, injuries to many more, and destruction or severe damage to thousands of houses from the Carolinas to Long Island.

Are storms responsible for the long-term retreat of the shorelines?

Apprently not. The shoreline may recede by a large amount in a storm. But in the months and years following, the shoreline gradually grows seaward. But seldom back to the pre-storm shoreline. So another factor may be responsible for the long-term retreat of shorelines: sea level change

Changing Sea Level

Our present shoreline is the result of rising sea level.

The deeply ***embayed coastline*** of the eastern U.S. was produced by sea level rise at the end of the last ice age, as glacial ice melted and returned to the oceans, flooding coastal river valleys. Sea level rose about 100 m (~330 ft) as the glaciers melted. Sea level rose rapidly beginning about 15,000 years ago as the glaciers began to melt. The rate of sea level rise declined by 10,000 to 8,000 years ago once most of the ice had melted. Sea level rise has continued at a very slow rate.

Global Climate Change and Rising Sea Level

Sea level rose 17 cm (7 inches) during the 20th century. Today it is rising at a rate of ~3 mm per year, about twice the 20th century rate.

Carbon dioxide levels in the atmosphere have risen from 289 ppm in the mid 19th century to around 380 ppm today as a result of increasing use of fossil fuels (coal, petroleum, and natural gas). Water vapor, carbon dioxide, and methane are greenhouse gases meaning that they hold heat in the atmosphere. That is good, but too much means that the atmosphere gets warmer.

Global atmospheric temperatures have risen by a significant amount in the past 100 years. The greatest warming occurs at high latitude, the Arctic and Antarctic.

Ocean temperatures have risen by a significant amount, not just the sea surface, but the cold ocean depths

Floating ice shelves are breaking off from Antarctica allowing glaciers to flow off of Antarctica to the sea faster.

Glacial ice in Greenland is melting faster than expected.

Sea ice in the Arctic ocean is melting faster in the summer. In a couple of decades the Arctic Ocean will be ice free by the end of the summer. Open water absorbs sunlight. The Arctic ocean will warm probably causing still more melting of ice in Greenland and Arctic Canada.

Sea level rise is caused by a combination of ***thermal expansion of the oceans***, melting of continental ice sheets (Greenland and Antarctica), and melting alpine (mountain) glaciers

The scientific consensus is that rising levels of carbon dioxide and methane are the cause of rising temperatures. As these greenhouse gases continue to increase in the atmosphere global temperatures will rise at a faster rate. By sometime in the middle of this century we will have doubled the amount of $CO2$ in the atmosphere and raised methane as well. Global temperatures will be expected to rise significantly higher than they are today.

Sea level will continue to rise, very likely at a faster rate than during the 20th century, By the end of the 21st century sea level will be 1 foot, 2 feet, 3 feet ...? higher.

Rising sea level threatens low-lying countries

Much of the Netherlands (delta country) is below sea level. The Dutch have been trying to hold back the sea for centuries. It will be increasingly hard to prevent major disasters as sea level rises.

Much of Bangladesh lies on a delta with 6 million people no more than about 3 ft above sea level. Tropical cyclones will present an ever increasing hazard as sea level rises.

Barrier Island Coasts

The U.S. east coast and Gulf coast lie on the gently sloping ***coastal plain*** and ***continental shelf*** (the shelf is just the part of the continent that is below sea level). Because of the very gently slope of this surface, a small rise in sea level results in a much larger landward shift of the shoreline.

Gently sloping coasts are characterized by ***barrier islands,*** like large sandbars just off the the mainland coast. A lagoon or bay lies between the narrow barrier island and the mainland coast. Barrier islands have migrated landward over the past several thousand years, since the end of the ice age, as sea level gradually rose, though at a much slower rate than today. It is thought that barrier islands migrate by erosion of the beach and by sand being washed over to the lagoon side by large storm waves. So the barrier islands are self-maintaining systems.

Mitigation - Shoreline Protection

Much of the east and Gulf coast is moderately to severely eroding today.

Groins trap sand that is being transported along the beach via littoral drift. The beach grows wider on the updrift side of the groin but since sand is being stopped, the beach is eroded on the downstream side. Oftentimes, a whole series of groins (a groin field) is built to try to hold sand along a stretch of beach. Downdrift of groinfields the beach becomes severely sand-starved and retreats rapidly. Groins probably also cause some sand to be lost offshore.

Beach Nourishment

When beaches become too narrow due to erosion, more sand can be brought to the beach to make it wide again. Sometimes this is done by trucking in sand from sand pits on land. Usually beach nourishment is done by vacuuming sand up from the seafloor some ways offshore from the beach and pumping the sand (in a slurry with water) up onto the beach. Remember that offshore sands are normally finer and easier to erode than the sand on the beach. A beach nourishment project for a town beach will cost several million dollars. One large storm can remove most of the new sand. Even without a major storm, most of the sand is typically gone within five years.

Seawalls are erected to protect property from beach erosion and large storm waves. On a natural beach, storm waves lose strength, slow, and stop due to friction and gravity as they rise up the shoreface, berm, and perhaps even onto the dunes. They sometimes even may wash over the dunes, carrying sand with them. But when a seawall is erected, storm waves that are still rising up the beach smash into them and reflect back out to seaward carrying excess wave energy and extra sand. The result is that the sand rapidly erodes leaving little beach. The seawall and buildings are then in peril of being undermined and destroyed in future storms.

Dune stabilization by planting grasses and trees and keeping people off to allow the vegetation to thrive will anchor the dune and provide a barrier against storm waves. This seems like a good thing to do. But what affect will it have on the beach? The beach will continue to erode due to rising sea level. The beach will become very narrow. The berm will go away. The beach profile will be similar to the remnant beach following the construction of a seawall. Waves will regularly erode the dunes and wash them away.

Coastal marshes on the lagoon side of the barrier island are rich spawning and nursery grounds for ocean fish. Seawalls and bulkheads erected on the edge of the marshes don't allow marshes to migrate with rising sea level. They will eventually become drowned when the water becomes too deep thereby impacting our food supply.

Five Principles

1. Coastal erosion is a natural process rather than a natural hazard; erosion problems occur when people build structures in the coastal zone.
2. Any shoreline construction causes change.
3. Stabilization of the coastal zone through engineering structures protects the property of relatively few people at a larger general expense to the public.
4. Engineering structures designed to protect a beach may eventually destroy it.
5. Once constructed, shoreline engineering structures produce a trend in coastal development that is difficult, if not impossible, to reverse.

(Keller, 1996; after Neal et al., 1984)

So, what can be done?

It is becoming ever more apparent that methods aimed at protecting the shoreline will be temporary at best, and very expensive and ultimately futile at worst. Many call for disallowing the building of new structures or the rebuilding of damaged or destroyed ones in nearshore locations that are likely to be threatened by coastal erosion during the structure's expected lifetime.