Modelling Beach Processes – Introductory Materials

Introduction

Coastlines are dynamic features, changing shape continually and confounding human efforts to tame them. Why are coastal areas so moody? Why does each passing storm leave its imprint (erosion, deposition, or both) on a coastline that has existed for millennia? The answers to these questions lie in the nature of coastal processes, the ways in which waves affect the coast, the source of sediment, and human interference in the whole scheme. This module will help you explore these processes and see how society's interactions can interrupt or divert the flow of sand along our beaches.

Each of the ten sections described here include a link to a short animation. It is recommended that you read the material first for key concepts and vocabulary and then view the animation to assist with visualization of the material. Once you are comfortable with the concept(s) presented in the section, answer the worksheet questions before moving on to the next section.

1 - Beach Anatomy (Animation 0:32 seconds)

Beaches are a common sight along coastlines and they represent areas where deposition of sediment takes place along a shoreline. In many areas, beaches are a part of the mainland: in other areas, the beach is a part of a series of "barrier" islands off the mainland coast. The diagram presented in the animation labels the main parts of a beach system. Although not all the parts identified are present at all beaches, this scene is a common one along sandy beaches around the world. Key terminology is identified here:

Sand Dunes: Sand Dunes are hummocky deposits of wind-blown sand, commonly found along barrier island beaches. Strong coastal winds pick up dry sand from the beach and blow it farther onshore, providing a sediment supply for the dunes. Drought- and salt-tolerant plants such as grasses colonize the dunes, helping to stabilize them. Usually the sand dunes closest to the beach are the most active (that is, they have the most sand moving about and are not stabilized by vegetation). Dunes farther away from the beach may be colonized by trees as well as grasses and shrubs.

Backshore: The backshore is the portion of the beach from the high-tide level up to the sand dune. It typically stays dry except during storm events, when large waves may sweep water high onto the beach and sometimes into the dunes.

Foreshore: Also called the "swash zone," the foreshore is where waves swash back and forth, up and down the slope of sand, and where people walk to get their feet wet along the beach. It extends from the low-tide line up to the high-tide level, plus the distance of normal wave "swash" (swash is back-and-forth movement of water due to wave activity, directed up and down the beach slope). Small waves break on the foreshore and swash up the foreshore, moving sand up and down the slope. Typically, the slope of a beach foreshore is steep if the sediment is coarse-grained (pebble and cobble beaches have foreshore slopes with 10 to 15 degree angles) but more gentle if the sand is fine-grained (sandy beaches have slope angles ranging from 7 to 8 degrees).

Shoreface: The shoreface is the underwater portion of the beach, located from the base of the foreshore (low-tide line) down to the normal wave base. It is where larger waves typically break on the beach, and includes the "bar" area common along many beaches. The bar is a sandy deposit trending parallel to the beach, located a few meters or tens of meters out from the foreshore, which is higher in elevation than the shoreface on either side. Larger waves typically break directly on the bar, and the bar is commonly eroded and redeposited elsewhere during storm events.

Offshore: Offshore is the region seaward of the shoreface, in deeper water, that is affected by waves only during storm events. During "normal" conditions, smaller waves cannot cause currents to move the sand on the bottom in the offshore region. When large waves associated with storms approach, however, the effective wave base deepens, allowing sand to move around in significantly deeper water (down to the level of the storm wave base).

High-tide level: The high-tide level is the level of the water at maximum high tide. In legal terms such as those used by the US government for determining coastal jurisdictions, the high-tide line is the maximum height reached by the tides, including the typically higher levels caused by a spring high tide.

Low-tide level: The low-tide level is the level of the water at maximum low tide, typically spring low tide.

Normal wave base: The normal wave base is a water depth equal to one-half of the wavelength of an average (or "normal") wave along a given coastline. The wave base is the water depth below which so little movement of water due to wave orbital motion occurs that even fine-grained silt and clay will settle out and be deposited. Thus the normal wave base is the wave base that occurs due to waves of average height (average for a given coastline), and the depth of wave base is approximately one-half of the wavelength of that wave.

Storm wave base: The storm wave base is a water depth equal to one-half of the wavelength of a large, storm-generated wave along a given coastline. The storm wave base may be two to three times deeper than the normal wave base along any given coastline.

Surf zone: The surf zone is the region stretching from where waves first break offshore to the swash on the beach. It is an informal term, and its range changes with the weather and the size and direction of the waves.

Swash zone: The swash zone is the part of the beach foreshore where water alternately covers and exposes the beach as waves swash up and down the foreshore. With larger waves, the swash zone will usually be broader; with very small waves the swash zone may only be a few meters wide, or even less.

2 - Wave Anatomy (Animation 0:33 seconds)

Waves provide the energy that shapes most of the world's beaches. The energy of wind on the open ocean is transferred into wave motion, which is carried for thousands of kilometers until the waves rise up and break upon our beaches. That activity transfers the up-and-down motion of deep-water wave behavior into the back-and-forth motion of surf swashing onto the shore.

Crest: A crest is the high point of a wave-the point on a wave where the water is at its highest elevation.

Trough: A trough is the low point of a wave-the point on a wave where the water is at its lowest elevation.

Wave height: The difference in elevation between the crest and the trough of a wave.

Wavelength: The wavelength is the horizontal distance between two successive wave crests or between two successive wave troughs.

Amplitude: The amplitude of a wave is the difference in elevation between a wave crest (or a trough) and the average elevation of the wave. In other words, the amplitude of a wave is one-half of the wave height.

Breaker: A breaker is a wave that moves into shallow water and spills onto the beach. Waves break as they move into shallow water because friction between the wave and the sea floor slows down the bottom part of the wave even as the top of the wave continues to move forward.

Bar (not a wave term): Also shown in the animation is a sand bar, a common underwater feature found along many beaches. A bar is usually located parallel to a beach, where sand piles up higher than on the sea floor on either side of the bar. Because the water is shallower over the bar, waves often break when they reach the bar.

3 - Wave and Water Motion (Animation 0:54 seconds)

The animation in this section will show waves in deep water, waves in shallow water, and waves breaking into the surf zone. By "deep" and "shallow" water, it is meant deeper than wave base (so the waves are not affected by the sea floor) and shallower than wave base, respectively. When you view the animation, note some of the differences in the waves. Deep-water waves are longer; they shorten when they move into shallow water. Breaking wave are the tallest of all, and the wavelength is the shortest just before the waves break. Red circles in the animation will show how water particles move in response to passing waves. The motion of water beneath waves is called ***orbital motion***.

Deep water waves: The deep-water orbitals near the surface are nearly the same diameter as the wave height. The deeper you go, the smaller the orbitals become, until they disappear at wave base, which is defined as the water depth where wave motion no longer affects water particle motion. This is ½ the wavelength. Notice these orbitals remain round in deep water.

Shallow water waves: In shallow water, the orbitals change shape, from nearly circular at the surface to progressively more oval (flatter) as you look deeper in the water. This alteration of the orbital pattern occurs because of interference with the wave motion caused by the shallow sea floor. Also the wavelength of the wave is shorter than it was in deep water, and the wave is taller. The wave is shorter because the front of the wave now moves more slowly than the wave behind it (in deeper water), so the wave crests behind begin to catch up, shortening the wave. As the wave becomes compressed by shortening, the waves bunch up and get taller to compensate for this compression. Wave motion on the sea floor is now strongly back and forth, with little up-and-down component.

Breaking wave: A wave breaks because the top of the wave moves forward more rapidly than the base of the wave due to interference with the sea floor. The wave essentially trips over itself, spilling forward as a "breaker." At this point, orbital motion ceases. Instead, the water in the surf zone is turbulent and moves predominantly back and forth or along the shoreline, depending on the direction of local surge from breaking waves and swash in the foreshore.

4 - Wave Refraction (Animation 0:30 seconds)

Wave refraction is the "bending" of waves. Wherever one part of a wave slows down or speeds up relative to an adjacent part of a wave, the wave will refract, or bend, as it continues along.

In the animation, waves are moving toward the beach, but they are approaching at an angle. The leading edge of the wave slows down as it moves into shallower water. Meanwhile, the rest of the wave remains in deeper water, so it moves more rapidly. Wherever two parts of a wave move at different speeds, the wave will refract, turning toward the part of the wave that is moving more slowly. By the time it swashes on the beach, the wave is approaching nearly parallel to the beach.

Many other situations will cause wave refraction as well. Isolated shallow sand bars or underwater reefs will slow the wave, causing it to bend around the bar or reef. Also, human structures such as jetties and groins can interfere with waves and create wave refraction.

5 - Longshore Current (Animation 0:33 seconds)

The ***longshore current*** is a gradual movement of water parallel to a beach. Longshore currents result primarily from the oblique approach of waves toward the beach and the resulting wave refraction.

Foreshore swash: Oblique waves swash up and down, back and forth on the foreshore. This foreshore swash is what you feel on your toes and ankles when standing at the edge of the water. Each wave carries water (and sand) up the beach, and then back down. Because the waves approach the shore obliquely, each passing of a wave moves sand grains in a zigzag path down the beach, in the same direction that the waves were traveling as they approached the beach. Swimmers in the shoreface often find themselves moving slowly down the beach, carried by the longshore current. Sand is also moved in the longshore current, acting much like a moving river of water and sand.

Storm Waves: Large waves associated with storms contain much more energy when they break and swash, moving far more water and sediment along the beach.

6 - Rip Currents (Animation 0:33 seconds)

Rip currents are narrow currents that flow seaward from the beach out through the shoreface zone. The key element in forming the majority of rip currents is the presence of too much water in the shoreface, so that the water has to flow seaward to "escape." A common example involves a beach with a shoreface bar. When waves come in parallel (not oblique) to the shore break over the bar, the water becomes trapped between the bar and the shore. This water wants to go somewhere, and the bar and incoming waves block it from moving seaward. A rip current will form where a break (or gap) opens up in the bar. Water that has piled up in the shoreface will flow toward the gap and flow out to sea. Rip currents may be 10 meters or more wide and may flow seaward through the shoreface for 100 meters or more. The speed of the current is rarely more than 1 meter per second, but that's still faster than most people can swim. If you're ever caught in a rip current, don't fight it directly. Remember that rip currents are narrow, seaward-flowing currents. Swim to the downstream side, parallel to the beach. This action should help you get safely out of the main flow and allow you to swim back to shore with the waves.

7 - Coastal Deposition (Animation 0:36 seconds)

Over the long term (decades, centuries, millennia), the movement of sediment due to wave action causes transport and deposition of sand in interesting places. Longshore drift produces much of this sediment movement and creates many of the sandy areas associated with beaches.

The animation shows sand moving under the effects of longshore drift. Notice how erosion takes place along the ***updrift*** parts of headlands and inlets, whereas sediments accumulate on the ***downdrift*** ends (updrift refers to the direction from which longshore drift is coming, and downdrift is the direction toward which drift is heading).

A "***spit***" is the general term for sandy deposits that stick out from shore and are caused by deposition from longshore drift. The area labeled "***hook***" is a special type of spit. Longshore drift moves sediment along the beach and toward the hook. Over time, the sediment accumulates at the hook because longshore currents aren't as strong going into the adjacent inlet, toward the bay. The sand on the hook gradually wraps around the peninsula creating a "fishhook" shape, giving this feature its name.

8 - Coastal Erosion Landforms (Animation 0:49 seconds)

A ***sea stack*** is a small rocky island located just offshore from a rocky coastline. Sea stacks are clear indicators of coastal erosion; they represent a time when the rocky coastline was located that much farther seaward. This animation steps through the sequence of events that can lead to creation of a sea stack; in this case, one with a lighthouse on top for reference.

The lighthouse is initially located on a ***rocky headland***, a small peninsula jutting out from the coastline into the ocean. As waves approach the shoreline in front of the headland, the shallow water slows down the wave fronts. This change in velocity causes the waves to refract around the headland, focusing their energy along both sides of the headland. More wave energy on this rocky shore leads to higher erosion rates, especially during stormy weather.

The second scene shows that through time, erosion of the headland continues, turning the headland into a narrower peninsula. Also, erosion of the headland creates a ***rock arch***, allowing beachcombers to wander underneath the headland at low tide. The large boulders in front of the headland help dampen the wave energy acting on the front of the headland, slowing erosion there.

In the third scene, continuing erosion leads to collapse of the headland arch, leaving the rocky sea stack with the lighthouse isolated in the sea. Now water and waves can freely move behind the lighthouse.

9 - Coastal Erosion Controls (Animation 0:48 seconds)

Humans have introduced many types of engineered structures to try to manage the flow of sand along beaches and especially to reduce the effect of coastal erosion. This section illustrates four types of engineered coastal erosion controls.

Groin: A groin is a long, solid structure that is located along a beach and extends out into the water, perpendicular to the shore; it is typically built of rock or concrete. Groins trap longshore drift sediment on their updrift side by blocking the longshore drift, but they also tend to cause erosion of sand on the downdrift side because that area is starved of sediment supply from updrift.

Jetty: A jetty is a type of groin that is installed along the side of an inlet, usually in an attempt to prevent longshore drift sand from filling the inlet. The inlet may lead to a river, coastal lagoon, or harbor. Like a groin, sediment will accumulate on the updrift side of a jetty and erode on the downdrift side.

Seawall: A seawall is a structure built parallel to the shore to try to force the shoreline to stay put. Seawalls are commonly very massive rock and/or reinforced cement structures designed to withstand even large, storm-generated waves. In most cases, they represent a last defense, designed not to protect beaches from eroding, but rather to protect buildings and roadways near the shoreline from destruction. Seawalls are very expensive to build, and they must be anchored in the sediment as storm waves tend to gradually erode the sediment away from the base of the seawall, causing it to collapse over time.

Breakwater: A breakwater is also built parallel to shore, but it is located offshore at some distance away from the beach or shoreline. Breakwaters are designed to slow down and reduce the energy of waves acting on the coastal area. Placing a number of breakwaters in a line offshore reduces the amount of wave energy hitting the beach by a significant amount. In some areas, breakwaters have slowed the local longshore drift to the point where sand actually accumulates behind the breakwaters, making the beach grow larger.

10 - Save My Beach Model (Animation 1:47 seconds)

Mr. Smith and Mrs. Jones own adjacent beachfront properties along Oceanside Beach. There is a dominant longshore current and drift moving from the northwest to the southeast along the shore. Mrs. Jones recently watched a documentary about beach erosion, and she realized that perhaps she should join with her neighbor to something about it. Unfortunately, Mr. Smith holds a grudge against Mrs. Jones for building her new driveway so close to his swimming pool. Mr. Smith decides to “help” Mrs. Jones by offering to install some coastal management structures…his “treat.” He plans to hire the local coastal engineering firm to place some structures in just the right places.

The coastal engineer has designed simulations to show Mr. Smith the effect of different types of coastal management structures. The animation for this section shows these different simulations. As you view the impact of the placement of each structure, see if you can determine which structure Mr. Smith is likely to choose (Grinch that he is).

This activity has been modified from a tutorial originally developed by faculty at the University of Kentucky, Earth & Environmental Sciences.

Supporting documents are modified from a prior activity developed by Professors Patty Deen and Lisa Yon of Palomar College, San Marcos, CA.