Beaches are a unique habitat formed by thousands of tiny sand particles. Sand is formed by the breakdown of rocks after being exposed to wind and water. **Sandy beaches** are a wide expanse of land with very few trees or other plant life; leaving animals that live in this habitat open to unpredictable conditions.

**MODULE 1: OCEAN AND COASTAL HABITATS**

**SECTION 6: SANDY SHORES**

**SUNSHINE STATE STANDARDS**


**OBJECTIVES**

- Learn and understand the Sandy Shores Ecosystems
- Identify the different types of beaches
- Learn about sand formation and deposition in the beaches
- Learn about adaptations of animals to sandy shores

**VOCABULARY**

**Beach**- The zone above the water line at a shore of a body of water, marked by an accumulation of sand, stone, or gravel that has been deposited by the tide or waves.

**Berm**- is a level space, shelf, or raised barrier separating two areas.

**Coralline algae**- are red algae in the Family Corallinaceae of the order Corallinales. They are characterized by a thallus that is hard because of calcareous deposits contained within the cell walls. The colors of these algae are most typically pink, or
some other shade of red, but some species can be purple, yellow, blue, white or gray-green.

**Cups** - Short ridges that are separated by crescent-shaped troughs. They are found on the foreshore at relatively evenly spaced intervals. Cuspate pertains to a shoreline which follows smooth arcs in between cups.

**Dune** - is a hill of sand built by aeolian processes. Dunes occur in different forms and sizes, formed by interaction with the wind. Most kinds of dunes are longer on the windward side where the sand is pushed up the dune and have a shorter "slip face" in the lee of the wind. The valley or trough between dunes is called a *slack*. A "dune field" is an area covered by extensive sand dunes. Large dune fields are known as ergs.

**Infauna** - Benthic animals that live in the substrate of a body of water, especially in a soft sea bottom. Infauna usually construct tubes or burrows and are commonly found in deeper and subtidal waters. Clams, tubeworms, and burrowing crabs are infaunal animals.

**Macrofauna** - animals large enough to be seen by the naked eye

**Meiofauna** - living between grains of sand have made some fancy adaptations to their harsh environment. Some have hooks on their feet, used to grab the sand.

**Rip** - A surface current that is often of short duration and that flows seaward from the shore.

**Shore or shoreline** - is the fringe of land at the edge of a large body of water, such as an ocean, sea, or lake.

**Sand** - is a naturally occurring granular material composed of finely divided rock and mineral particles. The composition of sand is highly variable, depending on the local rock sources and conditions, but the most common constituent of sand in inland continental settings and non-tropical coastal settings is silica (silicon dioxide, or SiO2), usually in the form of quartz.

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**BACKGROUND**

**Introduction**

Sandy shores or beaches are loose deposits of sand, gravel or shells that cover the shoreline in many places. They make up two-thirds of the world’s ice-free coastlines. Beaches serve as buffer zones or shock absorbers that protect the coastline, sea cliffs or dunes
from direct wave attack. It is an extremely dynamic environment where sand, water and air are always in motion. Beaches also provide important coastal recreational areas for a many people. Fine-grained sand beaches tend to be quite flat.

A beach is a geological landform along the shoreline of an ocean, sea or lake. It usually consists of loose particles which are often composed of rock, such as sand, gravel, shingle, pebbles, waves or cobblestones. The particles of which the beach is composed can sometimes instead have biological origins, such as shell fragments or coralline algae fragments.

Wild beaches are beaches which do not have lifeguards or trappings of modernity nearby, such as resorts and hotels. They are sometimes called undeclared, undeveloped, undefined, or undiscovered beaches. Wild beaches can be valued for their untouched beauty and preserved nature.

Beaches often occur along coastal areas where wave or current action deposits and reworks sediments.

Although the seashore is most commonly associated with the word "beach", beaches are found by the sea or ocean or lakes.

The term 'beach' may refer to:

- small systems in which the rock material moves onshore, offshore, or alongshore by the forces of waves and currents; or
- geological units of considerable size.

The former are described in detail below; the larger geological units are discussed.
elsewhere under bars.

There are several conspicuous parts to a beach, all of which relate to the processes that form and shape it. The part mostly above water (depending upon tide), and more or less actively influenced by the waves at some point in the tide, is termed the beach berm. The berm is the deposit of material comprising the active shoreline. The berm has a crest (top) and a face — the latter being the slope leading down towards the water from the crest. At the very bottom of the face, there may be a trough, and further seaward one or more longshore bars: slightly raised, underwater embankments formed where the waves first start to break.

The sand deposit may extend well inland from the berm crest, where there may be evidence of one or more older crests (the storm beach) resulting from very large storm waves and beyond the influence of the normal waves. At some point the influence of the waves (even storm waves) on the material comprising the beach stops, and if the particles are small enough (sand size or smaller) , winds shape the feature. Where wind is the force distributing the grains inland, the deposit behind the beach becomes a dune.

These geomorphic features compose what is called the beach profile. The beach profile changes seasonally due to the change in wave energy experienced during summer and winter months. The beach profile is higher during the summer due to the gentle wave action during this season. The lower energy waves deposit sediment on the beach berm and dune, adding to the beach profile. Conversely, the beach profile is lower in the winter due to the increased wave energy associated with storms. Higher energy waves erode sediment from the beach berm and dune, and deposit it off shore, forming longshore bars. The removal of sediment from the beach berm and dune decreases the beach profile.

The line between beach and dune is difficult to define in the field. Over any significant period of time, sand is always being exchanged between them. The drift line (the high point of material deposited by waves) is one potential demarcation. This would be the point at which significant wind movement of sand could occur, since the normal waves do not wet the sand beyond this area. However, the drift line is likely to move inland under assault by storm waves.
Beach Formations

Sandy beaches are soft shores that are formed by deposition of particles that have been carried by water currents from other areas. The transported material is in part derived from the erosion of shores, but the major part is derived from the land and transported by rivers to the sea. The two main types of beach material are quartz (=silica) sands of terrestrial origin and carbonate sands of marine origin. The carbonate sand is weathered from mollusk shells and skeletons of other animals. Other material includes heavy minerals, basalt (=volcanic origin) and feldspar.

Beaches are the result of wave action by which waves or currents move sand or other loose sediments of which the beach is made as these particles are held in suspension. Alternatively, sand may be moved by saltation (a bouncing movement of large particles). Beach materials come from erosion of rocks offshore, as well as from headland erosion and slumping producing deposits of scree. Some of the whitest sand in the world, along Florida's Emerald Coast, comes from the erosion of quartz in the Appalachian Mountains. A coral reef offshore is a significant source of sand particles.

The shape of a beach depends on whether or not the waves are constructive or destructive, and whether the material is sand or shingle. Constructive waves move material up the beach while destructive waves move the material down the beach. On sandy beaches, the backwash of the waves removes material forming a gently sloping beach. On shingle beaches the swash is dissipated because the large particle size allows percolation, so the backwash is not very powerful, and the beach remains steep. Cusps and horns form where incoming waves divide, depositing sand as horns and scouring out sand to form cusps. This forms the uneven face on some sand shorelines.

Origin of the sand

Sand is one of the components that make up soil (For a lengthy explanation, see the chapter on soil). The diagram shows how soil is made and sand. Every kind of rock weathers slowly by breaking apart into different substances. Whereas mechanical forces such as wind, rain, hail and ice may break the rock into smaller parts with identical chemical properties as the parent material, spontaneous and chemical weathering change its nature. It produces minerals and nutrients, oxides of iron and alumina, and silica, which combine into clay. The two other components are silt and sand (quartz). The combination of clay + silt + sand is called a loam.
When soil erodes, all of its components wash down into the sea. Here the water movement sieves the loam into its components, each sedimenting in different areas of the continental shelf and slope. Sand being the largest, is transported by waves towards the coast where it may end up on a beach. Silt and clay may remain in the coastal zone for a while but eventually settle out in the calm waters of the deep ocean.

The grain size of sand varies from very fine to very coarse. The particle diameter is shown in the table below. As said before, the two main types of beach material are quartz (=silica) sands of terrestrial origin and carbonate sands of marine origin. Quartz sands have a slightly lower density (2.66 g cm$^{-3}$) than carbonate sands (2.7 to 2.95 g cm$^{-3}$). The quartz particles also seem to be more rounded. Calcium carbonate particles sink more slowly in water due to their more irregular shapes, even if their density is higher.

**Generic Name Particle Diameter (mm)**

<table>
<thead>
<tr>
<th>Particle Diameter</th>
<th>Diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very coarse</td>
<td>1.0 to 2.0</td>
</tr>
<tr>
<td>Coarse</td>
<td>0.50 to 2.0</td>
</tr>
<tr>
<td>Medium</td>
<td>0.25 to 0.50</td>
</tr>
<tr>
<td>Fine</td>
<td>0.125 to 0.50</td>
</tr>
<tr>
<td>Very Fine</td>
<td>0.0625 to 0.125</td>
</tr>
</tbody>
</table>
Porosity is the volume of void space in the sand. It is the volume of water needed to saturate a given weight of dry sand. Most sands have a porosity of about 30 to 40% of the total volume. The finer a sand the greater its porosity. Permeability is the rate of flow or drainage of water through the sand. Fine sands have lower permeabilities due to their smaller pore sizes. Penetrability is related to particle size and porosity. It can be important to the macrofauna. All species must be able to burrow into the substratum. To determine the penetrability, the proportion of clay and silt and the water content are very important.

Beaches

The two basic beach types are dissipative and reflective. Together with the intermediate types, there are six major microtidal beach types. The reflective type occurs when conditions are calm and/or the sediment is coarse. There is no surf zone and waves flow upon the beach. It reflects a major part of the incoming wave. When bigger waves cut back a beach and spread out its sediments to form a surf zone, the reflective beaches create a series of intermediate types. When wave action is strong and/or sediment particle size is fine, the dissipative beach type is created. This type has a flat and maximally eroded beach. The sediments are stored in a broad surf zone that may have multiple sandbanks parallel to the beach. The intermediate types are characterized by high temporal variability, sand storage both on the beach and in the surf zone and sandbanks and troughs.

Beach types can also be based on the degree of exposure. This ranges from very sheltered over sheltered and exposed to very exposed.
At the end of the last ice age, the ocean's level was about 120m lower than today, due to the amount of water locked up in the polar and mountain ice caps. The beaches then were close to the edge of the continental shelf, and the flat land between there and where they are today, was covered in forest. Then the climate warmed, the sea level rose, and the beaches moved landwards, and with them, the sand that formed them. This sand is rather young, and its quantity has not changed very much since the end of the ice age. It took about 4000 years for the ocean to rise, and that process was completed some 6000 years ago.

The diagram shows the extent of the beach sand into the sea. The top drawing shows a typical beach profile, first descending rapidly near the coast, then following the slope of the continental shelf to depths over 40m. The sand depth, shown in the bottom drawing, is about 2m near the shore, decreasing to about 20cm at 40m depth. This point may be 10km out in sea, depending on the width and slope of the continental shelf. Occasionally storms are large enough to stir the bottom this deep, and to sweep its sand towards the shore. It is here that the beach effectively ends.

**Beach Type**

Beach type refers to the prevailing nature of a beach, including the waves, tides and currents, the extent of the nearshore zone, the width and shape of the surf zone, including its bars and troughs, and the dry or subaerial beach.

**Wave-dominated beaches**

Wave-dominated beaches occur predominately along the higher wave energy open coast where the spring tide range is predominately less than 1.5 m. and average waves range between 0.5 and 3 m. The six wave-dominated beaches range from the high energy dissipative, through the four rip-dominated intermediate beaches to the lower energy reflective beach type.
1. Dissipative

Dissipative beaches only occur on parts of the high energy southern coast where waves regularly exceed 2.5m and where the beaches are composed of fine sand. These combine to maintain a low gradient surf zone up to 500m wide with usually two to occasionally three shore-parallel bars, separated by subdued troughs. Waves begin breaking several hundred meters offshore as spilling breakers on the outer bar, then reform in the outer trough to break again and again on the inner bar or bars. In this way they dissipate their energy across the wide surf zone. The beach has a wide, low gradient swash zone, with the high tide swash reaching to the back of the beach, often leaving no dry sand to sit on at high tide. The shoreline tends to be relatively straight and uniform alongshore with no rip currents.

![Dissipative Wave-dominanted beach conceptual model](image)

**Figure**- Dissipative Wave-dominanted beach conceptual model showing waves spilling over two shore parallel bars located up to a few hundred meters offshore.

2. Longshore bar and trough

Longshore bar and trough beaches are characterized by waves averaging 1.5-2 m, which break over a near continuous longshore bar located between 100-150m seaward
of the beach, with a 50-100m wide, 2-3m deep longshore trough separating it from the beach. The beach face is straight alongshore and depending on sand size may have a low tide terrace (fine sand) and/or a reflective beach with beach cusps (medium sand). The bar is usually crossed by rips every 250-500m. The deep trough and the presence of rips make this a particularly hazardous swimming beach.

Figure- Longshore bar and trough Wave-dominated beach conceptual model showing the offshore bar and trough, with rip feeder currents converging to flow seaward as a rip current (arrows).

3. Rhythmic bar and beach

They usually consist of relatively fine-medium (0.3mm) sand and exposure to waves averaging more than 1.5m. They are characterized by an outer bar which is separated from the beach by a deep trough, however unlike the longshore bar and trough type, the bar varies in width and elevation alongshore, and it is rhythmic. Waves break more heavily on the shoreward-protruding rhythmic bar sections with the broken wave and white water flowing shoreward as a wave bore. The bore then flows off the bar into the deeper trough, where it moves shoreward and longshore as a rip feeder current. Part of the wave reforms in the trough and breaks again on the shore. The water from both the wave bore and the swash piles up in the rip feeder channel and moves sideways toward
the adjacent rip embayment. The converging feeder currents turn and flow seaward as a rip current through the trough and across the deeper seaward-protruding sections of the rhythmic bar.

**Figure**- Rhythmic bar and beach Wave-dominated beach conceptual model with a rhythmic bar and beach consisting of a seaward protruding section (with cusps) and an embayed section with a curving erosion scarp. Converging rip feeder currents flow seaward as a strong rip current (arrows).

4. **Transverse bar and rip (TBR)**

They occur primarily on beaches composed of fine to medium sand (0.3mm) and exposed to waves averaging 1.5m. This beach type received its name from the fact that the bars are transverse or perpendicular to and attached to the beach, separated by deeper rip channels. The bars and rips are usually regularly spaced and range from 150m on the lower energy sea-dominated beaches to 250m along the higher energy southeast coast and 350m along the exposed southern coast. Waves break heavily on the shallower bars and less in the deeper rip channels resulting in lower energy swash in lee of the bars and higher energy swash/shorebreak in lee of the rips. The shoreline is rhythmic building a few metres seaward behind the attached bars as deposition occurs forming the megacusp horns and being scoured out and often scarped in lee of
the rips forming the embayments. The surf zone has a cellular circulation pattern. Waves tend to break more on the bars and move shoreward as wave bores. This water flows both directly into the adjacent rip channel and, closer to the beach, into the rip feeder channels located at the base of the beach. The water in the rip feeders converge and return seaward as a strong rip current.

Figure - Transverse bar and rip (TBR) Wave-dominated beach conceptual model. Note the bar is attached to the beach where it protrudes seaward, while the adjoining embayments are scarped. Waves flow off the shallow bar onto the feeder channels, the water converging and flowing seaward in the deeper rip channel as a strong rip current (arrows).

5. Low tide terrace

Low tide terrace beaches tend to occur when waves average about 1m and sand is fine to medium. They are characterized by a moderately steep beach face, which is joined at the low tide level to an attached bar or terrace, hence the name - low tide terrace. The bar usually extends between 20-50m seaward and continues alongshore, attached to the beach. It may be flat and featureless, have a slight central crest, called a ridge, and may be cut every several tens of meters by small shallow rip channels, called mini rips. At high tide when waves are less than 1m, they may pass right over the bar and not
break until the beach face, which behaves much like a reflective beach. At spring low tide, however, the entire bar is usually exposed as a ridge or terrace running parallel to the beach and waves break by plunging heavily on the outer edge of the bar. At mid tide, waves usually break right across the shallow bar, when they are most likely to generate rip currents. The water is returned seaward, both by reflection off the beach face, especially at high tide, and via the mini rips, even if no rip channels are present. The rips, however, are usually shallow, ephemeral or transient meaning they will flow strongly for a few minutes then dissipate.

Figure - Low tide terrace Wave-dominated beach conceptual model showing the beach face with cusps and continuous low tide terrace (at low tide) cut by a small mini-rip.

6. Reflective

Reflective sandy beaches lie at the lower energy end of the wave-dominated beach spectrum. They are characterized by relatively steep, narrow beaches usually composed of coarser sand (0.4mm). On the open coast, sandy beaches require waves to be less than 0.5m to be reflective. For this reason they are also found inside the entrance to bays, at the lower energy end of some ocean beaches and in lee of the reefs and islets that front many beaches. Reflective beach morphology consists of the
steeper, narrow beach and swash zone, with beach cusps commonly present in the upper high tide swash zone. They have no bar or surf zone as waves move unbroken to the shore, where they collapse or surge up the beach face.

Figure- Reflective Wave-dominated beach conceptual model showing waves breaking right at the shore where they may form cusps (left) or a straight berm (right) on the high tide beach.

**Tide-modified beaches**

Tide-modified beaches occur predominately where higher tide ranges and lower waves result in the spring tide range being three to ten times greater than the average breaker wave height. They consist of three types.

**7. Reflective plus low tide terrace**

Reflective plus low tide terrace beaches are the most common tide-modified beach occurring predominantly where they are exposed to short period waves averaging 0.45 m in height, with tide range averaging up to 10 times the wave height (i.e. 4.5 m). These are characterized by a relatively steep cusped reflective high tide beach, usually composed of medium sand (0.45 mm). The beach face slopes to low tide where it abruptly grades into a low gradient, usually finer sand low tide terrace, which can extend tens of meters seaward. At high tide waves pass unbroken over the terrace and only
break on reaching the high tide beach, similar to the reflective tide-dominated beach. As the tide falls, waves begin to increasingly break across the terrace and at low tide break on the outer edge producing a wide, shallow surf zone across the terrace. If rips are present, they will cut a channel across the terrace and are only active at low tide.

Figure - Reflective + low tide terrace (+rips) Tide-modified beach conceptual model shown at low tide with the steep cusped high tide beach face, 100 m wide low tide terrace cut by one small rip.

8. Reflective plus low tide rips

Reflective plus low tide rips beaches are the highest energy of the tide-affected beaches exposed to waves averaging 0.7 m, together with medium sand and tides averaging 2.5 m. At high tide the waves pass over the bar without breaking until the beach face, where they usually maintain a relatively steep beach with cusps. As the tide falls, waves begin breaking on the bar and at low tide there is sufficient time and wave energy to generate the rips and scour rip channels, which have an averaging spacing of 140 m. These are similar to the transverse bar and rip systems, but only operate at low tide, begin covered by up to a few meters of water at high tide.
Figure - Reflective plus low tide rips Tide-modified beach conceptual model shown at low tide with a steep cusped high tide beach, a 100-200 m wide intertidal zone with a low sand ridge, and outer low tide zone cut by regularly spaced rip channels and currents, which only flow around low tide.

9. **Ultradissipative**

Ultradissipative beaches occur in higher energy (waves averaging 0.6 m high) tide-modified locations, where the beaches are also composed of fine sand. They are characterized by a very wide (200-400 m) intertidal zone, with a low to moderate gradient high tide beach and a very low gradient to almost horizontal low tide beach. Because of the low beach gradient waves break across a relatively wide, shallow surf zone as a series of spilling breakers which continually dissipate the wave energy, hence the name ‘ultradissipative’. The fine sand and shifting breaker zone act to plane down the beach, while the continuously shifting breaker zone precluding the formation of bars and rips, which require a more stationary surf zone.
10. Reflective plus ridged sand flats

Reflective plus ridged sand flats is the highest energy of the tide-dominated beaches, occurring where waves average 0.5 m and tides average 4.5 m. They are characterized by a relatively steep, occasionally cusped high tide beach, which abruptly grades into a very low gradient sandy intertidal zone, covered by regularly spaced low amplitude (5-10 cm), shore parallel sand ridges.

Figure - Ultradissipative Tide-modified beach conceptual model showing the cusped high tide beach and 300 m plus wide low gradient intertidal beach.
Figure. Reflective plus ridged sand flats Tide-dominated beaches conceptual model showing the multiple low shore parallel sand ridges.

11. Beach plus sand flats

Beach plus sand flats is the most common beach type. They are similar to the ridged sand flats, except waves are lower (mean=0.26 m) and tides higher (mean=5 m). These conditions produce a relatively small, steep high tide beach, which grades abruptly into intertidal sand flats that average 300 m width (range 10-3000 m). The sand flats are low and featureless apart from small wave ripples, indicating wave energy is still sufficiency high to imprint itself upon the flats, but not high enough to form sand ridges.
Figure. Beach plus sand flats Tide-dominated beaches conceptual model showing the narrow high tide beach and wide, flat, essentially featureless intertidal sand flats.

12. Beach plus tidal sand flats

Beach plus tidal sand flats differ from the sand flats in that they receive lower waves (mean=0.16 m) though similar tides (mean=5 m). They usually have a small, steep reflective coarse-grained high tide beach, fronted by intertidal sand flats averaging 350 m width (range 50-2500 m). The tidal energy is sufficiently high for the tidal currents to imprint themselves on the tidal flats, and in some locations for mangroves to colonize the upper intertidal zone. Many of these flats grade from inner sand flats to outer mud flats, with the sand averaging 300 m wide and the mud extending out on average to 500 m.

13. Beach plus tidal mud flats

Beach plus tidal mud flats occur in similar wave regimes to the tidal sand flats, with waves also averaging 0.16 m, but with tides averaging to 8 m or more. In addition they are usually located near a river mouth which to supplies the mud to the shoreline. They usually have a low narrow high tide beach composed of coarse shelly sand, which grades often very abruptly into wide, very low gradient intertidal mud flats, with mangroves often colonizing the upper intertidal. The flats average 500 m in width,
ranging from 50-2000 m. Most of these beaches occur in the Kimberley and Northern Territory.

**Figure.** Beach plus tidal sand/mud flats Tide-dominated beaches conceptual model The sandy high tide beach may be fronted by sand, sand then mud or pure mud flats which may contain tidal drainage features including tidal channels.

**Beaches plus rock/reef flats**

The wave-dominated, tide-modified and tide-dominated beaches consists of two types.

**14. Beaches fronted by intertidal rock flats**

This beach type is dependent more on local geology than wave-tide processes and they can occur in low through high wave and tide environments. The intertidal rock flats average 270 m in width and range from 50-3000 m wide. They usually consist of a steep high tide beach with the rocks extending seaward from the base of the beach. The beaches tend to the relatively short ranging between 400-800 m in length, and are usually bounded by rock headlands or reefs. At low tide, depending on the elevation of the flats, the waves may only break on the outer edge of the rocks, with a bare intertidal rock surface and no wave reaching the beach.
15. Beaches fronted by fringing coral reef

The beaches consist of a usually steep, high tide reflective beach often composed of coarse coral fragments, fronted by the reef. The reef flats average 300 m in width but can range from 50-2000 m. On those reefs that grow to sea level, waves only reach the beach at high tide as they break across the reef flats, while at low tide, the reef is exposed and waves break on the reef edge.

Figure - Reflective plus rock/reef flats conceptual model shown at low tide exposing the hard rock flats or fringing coral reef. The outer edge of the rocks or reef often drops abruptly into deeper water.

The Beach and Dunes
The beach shown in the diagram is typically found together with sand dunes. Not all beaches are like this. In the picture, the levels of high and low tide are shown and the wet beach is the area between them. The near shore zone extends to a depth of about 5m. In this zone much sand is moved because it is stirred easily by most waves. But the shore extends further down, to depths of 20m or more. At some time during a year or decade, the sand here is stirred by large storms and moved towards the beach.
Going from the wet beach inland, one encounters the dry beach, outside reach of the waves, but high waves during spring tide may deposit sand here. This part of the beach is partly formed by wave overwash and by the wind heaping the sand up. It can even be considered a fore-fore dune. Further back from here extends the back shore with its fore, mid and rear dunes.
This diagram shows how the sand moves in the water, on the beach and behind the beach. Large waves occasionally move sand towards the beach and when they do, they move large quantities. Closer to the beach the sand movement is an every day affair and in the breaker zone huge quantities are moved almost every hour. As waves move sand towards the beach, gravity and back-wash move it back again at the same rate. Most of the movements cancel each other out and by and large, the sand remains in place.
The big difference comes once the sand remains on the beach, dries out during the low tide and is removed by the sea wind. This sand can no longer be reached by normal waves. As the wind brushes over the dried beach, it pushes sand up-hill in a jumping motion (saltation). The sand grains of which dunes are made, are too large to blow like dust clouds in the wind but they can saltate rapidly like a moving sheet over the ground. Once particles fall into the lee (wind shade) of the foredune, they stay there, making it appear as if the dune rolls backward to the next dune and so on. In this manner sand is pumped out of the sea. It is the mechanism by which a beach can repair (rebuild) storm damage. The wind transportation is much slower than that of water and it may take weeks to repair the damage a storm can do in one hour.

![beach during and after a storm](image)

**Storm damage**

The picture shows how a beach reshapes itself during a storm and how, afterwards, it rebuilds itself again. In the top picture the dotted line shows the beach profile before the storm and the solid profile during the storm. The two horizontal lines in the water correspond to high and low tide, the normal extent of the wet beach. Storms not only arrive with higher waves, but also with a storm surge that lifts the water level. During high tide the waves attack the beach above its normal level. The foredune is carved out and its sand creates a new beach at the level of attack. Sometimes lower down a bank is formed, which helps to break the waves. The storm **brings** new sand but **borrows** sand from the dunes.
After the storm (bottom picture), the forces of waves and wind gradually restore the damage wrought. Waves \textit{spread} the increased amount of sand and sea winds gradually \textit{store} it back onto the dunes where it came from.

\textbf{Beach cycles}

A beach's ability to rebuild itself, makes it a formidable bastion against the sea. Whereas headlands and cliffs erode, beaches can hold their own against the anger of the sea. The components of self repair are: 1) Beach sand being able to dry because of a receding tide and sunshine and wind; 2) Sea wind to blow the sand inland; 3) A sand storage in the dunes.

Thus a beach can store sand and grow during years of good sea winds, few rains or storms and much sunshine. As the \textit{sand pump} pumps sand from the wet beach, it causes the beach to lie steeper. During years with opposite conditions, the beach can erode and lie flatter.
Note that beach erosion occurs mainly during large storms. These storms also bring new sand from deeper down towards the beach. Note also that healthy beaches, having sand pumps with over capacity, may still be capable of repairing themselves during bad years. But once this self repair mechanism becomes impaired, beaches become more sensitive to weather conditions and climate cycles. The diagram shows actual beach erosion of Westhampton Beach (USA), over a period of 40 years. The situation is typical for many beaches, all over the world. A twenty year cycle appears to overlay the general trend of 50 ft (15m) in 40 years.

Note that the rapid oscillations are depicted as growth during one year, followed by shrinking during the next year. What the author intended to show was growth during summer and shrinkage during winter, an oscillation twice as fast.

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**Sediment transport**

This rather complicated looking sand balance or sand budget diagram attempts to depict how sand moves in a dune/beach system. It is a model to sharpen our understanding. Scientists use such models to study the transport of sediment near beaches. From left to right, traversing the four boxes (compartments), runs the profile of a beach. The size of the boxes could be a part of the beach or the entire beach, and it is called a 'beach cell'. Sand can move out or into the beach cell by coastal drift parallel to the coast (sea currents). Sand moves towards the beach by wave action and away from the beach by gravity down its gradual slope.

- The yellow part depicts the dry sand: the dry beach and the dunes. In the lower left corner the origin of the sand is shown. Sand arises from coastal erosion and is transported by rivers towards the sea.
- The blue part comprises the wet sand: the wet beach, the nearshore with possible sand bank and the offshore deep sand compartments.
- As rivers deposit sand nearshore and offshore, it enters the corresponding compartments. The land area that drains directly into the beach cell (catchment area) erodes at a rate depending on land use and rock type.
Following the boxes from right to left, the sand in the deep sand compartment is stirred only by large waves that may pull sand towards the beach or allow it to drift deeper down by the force of gravity.

Sand moving out of the deep sand compartment towards the beach, enters the sand bar or nearshore compartment which is subject to much more wave action and corresponding sand movement. From there, the sand is moved to the intertidal zone, the actual beach. Sea winds move it further onto the dunes but large waves can do so too by washing over the dry beach and dunes. Sand can also be lost this way, ending up further inland or back into rivers or estuaries. The breaker zone is the area with the highest transport of sand. Waves keep large volumes of sand in suspension, allowing it to be moved by ocean currents, tidal currents or wind induced currents. Some beaches are claimed to move half a million cubic metres of sand one way only, each year, the equivalent of 70,000 large truck loads or 200 trucks every day of the year!

As can be seen from the above, sediment transport along the coast is a complicated process, which is difficult or even impossible, to measure.

Transport and Sedimentation

The diagram shown here is of utmost importance in understanding how material is transported by water (and wind). Theoretical work was done by the British mathematician Sir George Gabriel Stokes (1819-1903), who formulated that drag experienced by a perfectly round sphere falling through a medium (straight line above)
is proportional to diameter and speed. For the sake of simplicity, he assumed that the flow of the medium was laminar, thus without eddies that would increase friction. In practice, this is not so, hence the left and right-hand curves, which have been established experimentally. The diagram spans enormous scales: vertically soil particles from 1 micron to 10mm and horizontally water velocities from 0.1mm/s to 10m/s (36km/h). The right-hand curve shows what water speeds are necessary to erode a cohesive bed, whereas the left-hand curve shows at which speeds the moving particles start settling out again.

The graph shows that pebbles (grey size zone) are dislodged at about 100cm/s (1m/s), but settle down at about 20 cm/s. Sand (yellow zone) moves more easily, but silt and clay (brown zones) are hard to dislodged, once clumped together, whereas they need almost stagnant water to settle out again.

It shows how a beach is formed by a wave's forward wash, as long as the particles can resist its back wash. It also shows that mud flats cannot form where wind blows, and it illustrates that mud cakes, deposited by cyclonic rain storms, may take a decade of lesser storms to be worn away.

Reader, please note that a similar diagram is required to explain erosion and deposition by wind, but this important work has not been done. Since particles that are moved by air follow the same logic, and air being 800 times lighter than water, the wind transportation and sedimentation diagram can be approximated by shifting the
horizontal scale by an unknown quantity to the right (for instance, 100cm/s may read 100km/h). Winds strong enough to shift pebbles are uncommon, whereas silt and mud stay air-borne. As a result, a narrow range of particles forms dunes (sand of 0.2-1.0 mm).

**Why is sand deposited on a beach?**

![Diagram of beach formation](image)

Why does sand stay put as the water draws back from a beach? Scientists say that the water that pushes sand up the beach, partly flows back through the sand bed. Thus the amount of water flowing back over the sand bed is less than which arrived there, and the sand stays. This is a myth because the amount of water draining back through the beach sand is negligible compared to what flows back over the sand, and there is a much better explanation.

Sand is transported over the sea bed towards the beach when waves 'stumble' such that their crests become narrower than their troughs. This produces a swift forward flow followed by a slower backward flow.

On the beach the top of the wave breaks and mingles with the foot of the wave, both dashing forward with a force driven by the energy from the height and speed of the collapsing wave. The resulting rush of water is fast and strong and moves sand effortlessly up the beach. The water then comes to a rest as the sand particles settle out. The water then begins flowing back down the beach, first slowly and then faster until it dislodges cohesive sand grains. But the forcing power is much less than that of the on-rushing waves. The particles that settled at the top of the forward rush, stay because of the *hysteresis* (lagging behind) between erosion speed and settling speed in the diagram above. **Thus sand settles on the beach only when the tide recedes.**
How does sand move to deeper depths?

The common idea is that sand simply flows downhill, but this idea cannot work because the bottom gradient is so small (the sand bottom is nearly horizontal). We know that 'stumbling' waves move the sand towards the beach, so how can it flow away from the beach?

It happens by those waves that do not 'stumble' but do stir the bottom, such that the forward motion of the water over the sea bottom is about the same as the backward motion. Sand is then moved both towards and from the beach, but as it accidentally reaches deeper water, the water movement becomes less, allowing it to settle out. Sand that accidentally moved to shallower water, keeps moving until it is accidentally moved to deeper water. Eventually the bottom becomes so deep that even the deepest waves can no longer transport the sand towards the beach. From this boundary, the sand keeps moving towards the deep, and this is where the beach ends. See the chapter on mining the sea sand for more information.

Very light particles such as mud (silt + clay) move in this manner all the way to the edge of the continental shelf and clay moves even further down the continental slope. It should be noticed that currents, such as tidal currents, play an important role at these depths in combination with deep (long) waves.

The mystery of the pebble beaches

Many 'beaches' do not consist of sand but of pebbles or boulders, sometimes with sandy beaches in between. Why is this so, whereas there occurs so much sand in the sea, starting right at the foot of the pebble beach? The photo shows such a beach, having formed a tall and wide dyke. The answer must be
found in the sedimentation/transportation diagram above. First of all, the coarse material must be available, such as originating from a fast flowing river nearby. Since pebbles do not move as easily as sand, pebble beaches occur only close to the origin of their material (a river). Only fast water movements in excess of 1 m/s are capable of moving pebbles, so pebble beaches form only along very exposed shores. The reason that they are not topped over by sand, is that pebbles are capable of staying put much better than sand, resisting the wave's back-wash much better. As a result, they form steep beaches with strong back-wash, too strong for sand to settle out. So the sand remains at the foot of the pebble beach. However, in less exposed places, the process reverses, allowing sand to lay over a deeper bed of pebbles. As a result one may find sand and pebble beaches seemingly 'alternating'. Note that pebbles laying on top of the sand, prevent the formation of dunes. Note that all pebbles on the photo have the same flat shape which allows them to be transported easily in water, while also staying put outside the water.

Where a variety of coarse material exists, ranging from pebbles to large boulders, one finds the boulders cast high up the beach or along the sides of pocket beaches, out of reach of average storms. Underneath or more towards the middle of the beach, one finds successively smaller stones. With it the slope of the beach also becomes more gradual.

**Rips and cusps**

![Diagram of rips and cusps](image)

- **Rips**: Areas of strong water flow that occur between the beach and the shoreline. They are characterized by deep, narrow troughs and can be dangerous for swimmers. Rips can be identified by the presence of white water and undertow.

- **Cusps**: Point-like features that form at the intersection of rips and the shoreline. They serve as natural barriers, preventing sand from being flushed out to sea. Cusps are often associated with the formation of dunes and other coastal landforms.
Some beaches are notorious for their rips. Rips are unpredictable currents, flowing away from the beach. They pull swimmers into deeper water and are very focused and strong. Rips arise when breaker upon breaker pushes new water onto the beach, not allowing much time for it to flow back. Normally a wave that runs up a beach will flow back underneath the next one, causing an undertow current, familiar to swimmers. Where waves arrive in rapid succession, a rip may occur, allowing the piled-up water to flow back to the sea.

Because rips are narrowly focused currents, swimmers should swim out of them in a direction parallel to the beach. Where rips occur, the water level is lowest and so are the waves. Where water flows towards the beach, both the water level and the waves are highest. A swimmer should swim to such a place. Some beaches have irregularities such as under water reefs where rips always form. Don't swim near reefs and groynes.

![Diagram of rips and cusps](image)

This diagram provides an aerial view of rips and cusps. The left side shows waves heading straight for the shore. If the shore is exactly the same everywhere, a rip may form anywhere. It causes a current jet back to sea and two corresponding deep eddies.

When the wind blows at an angle to the beach, a regular pattern of cusps (Latin word for spear points) appears in the beach, particularly at high tide. The beach is lowest at a cusp and highest in between. Each cell produces a circulating current pattern. Along the beach, the cusps are synchronised by an edge wave running along the beach in the breaker zone. This wave dips at each cusp and rises in between.

**Beaches as habitat**

A beach is an unstable environment which exposes plants and animals to changeable and potentially harsh conditions. Some small animals burrow into the sand and feed on material deposited by the waves. Crabs, insects and shorebirds feed on these beach dwellers. The endangered Piping Plover and some tern species rely on beaches for nesting. Sea turtles also lay their eggs on ocean beaches. Seagrasses and other beach plants grow on undisturbed areas of the beach and dunes.

Ocean beaches are habitats with organisms adapted to salt spray, tidal overwash, and shifting sands. Some of these organisms are found only on beaches. Examples of these
beach organisms in the southeast US include plants like sea oats, sea rocket, beach elder, beach morning glory aka Ipomoea pes-caprae, and beach peanut, and animals such as mole crabs aka Hippoidea, coquina clams aka Donax, ghost crabs, and white beach tiger beetles

**Functioning and adaptations**

The intertidal zone is covered part of the day by water and is part of the day exposed to air. High tides bring nutrients and food with it. When the tide retreats, waste products, eggs and larvae are taken. This causes changes for the organisms that live here. They have adapted to this changing environment, as seen on rocky shores.

The **burrowing** must be **rapid** and **powerful** on high-energy sandy beaches. This is because the animals must not be swept away by incoming waves and swash. They also need to be **high mobile** and must be able to deal with the swash climate. In contrast with rocky shores, desiccation is not an overriding concern, because the animals can retreat into the substratum or below the water table. Intertidal filter-feeders cannot feed while the tide has retreated. Many species of the meiofauna use **vertical tidal migrations** through the sand column. Other species move up and down the beach with the tides. This is inadequate for the maintenance of appropriate rhythmic behavior so responses to changing environmental factors are essential. There is a difference between directional (such as light, slope of the beach, water currents) and nondirectional (such as disturbance of the sand, changes in temperature, hydrostatic pressure) stimuli. Directional stimuli act as orientational signs, while nondirectional stimuli act as releasing factors. Because of the absence of attached macrophytes, the predominant feeding types are filter-feeding and scavenging. Adaptations to **respiration** of animals in low-energy sandy beaches are different from those on surf-swept beaches. Some adaptations are an increased ventilation rate or increased efficiency, reduced metabolic rate or other ways of conserving energy. Many sheltered-shore animals are facultative anaerobes. This is an adaptation during ebb tide. Other animals in oxygenated surf-swept beaches are essentially aerobic. The majority of the intertidal animals have **tolerance levels** of natural variables that exceed those necessary for survival in their particular habitats. Some species descent into the burrow to escape high temperatures. Another solution is **evaporative cooling** by replacing water through entering the burrow, plunging into the sea or absorption from the substratum. Another problem for intertidal animals is the time of **reproduction**. There is variation in the number of eggs, the anatomy of the reproductive organs, the morphology of the egg cases, times of breeding, mating behavior and developmental stages. Adaptations for this is to reproduce at frequent times (**iteroparous**) or to
reproduce just once in a year (semelparous). This depends from species to species. Some species follow the lunar cycle to reproduce at the right time. To avoid predation, several behaviors are developed. The first one is to burrow very deep. Another one is tidal migration, so the animals remain protected from predation. Other responses are escaping movements or an impressive threat display by crabs by holding their chelae open and aloft. According to circumstances, the behavior of the animals can be modified. This is called phenotypic plasticity.

Several groups of vertebrates make use of sandy beaches for foraging, nesting and breeding. Turtles nest on the backshore of sandy beaches. Birds use the beach for foraging, nesting and roosting. Seals use several areas of the beach for nesting, molting, breeding and raising pups. Other terrestrial animals such as otters, baboons, raccoons, lions,… They descend onto the beach to forage

**Biota**

The distribution and abundance of the sediment infauna is mostly controlled by complex interactions between the physicochemical and biological properties of the sediment.

The **physicochemical** properties are:

- Grain size
- Water content
- Flushing rate of water through the sediment
- Oxidation-reduction state
- Dissolved oxygen
- Temperature
- Light
- Organic content

The **biological** properties are:

- Food availability and feeding activity
- Reproductive effects on dispersal and settlement
- Behavior that induces movement and aggregation
- Intraspecific competition
- Interspecific competition and competitive exclusion
- Predation effects

Most invertebrate phyla are represented on sandy beaches, either as interstitial forms or as members of the macrofauna. The macrofaunal forms are by far the better known. Some of them are typical of intertidal sands and their surf zone, while others are more characteristic of sheltered sandbanks, sandy muds or estuaries and are less common on open beaches of pure sand.
Macrofauna

Macrofauna of the sandy beaches are often abundant and, in some cases, attain exceptionally high densities. Their main feature is the high degree of mobility displayed by all species. These animals may vary from a few mm to 20 cm in length. The macrofauna community consists of those organisms too large to move between the sand grains. The macrofauna of sandy beaches includes most major invertebrate taxa although it has been recognized that molluscs, crustaceans and polychaetes are the most important. There is a tendency for crustaceans to be more abundant on tropical sandy beaches or more exposed beaches and molluscs to be more abundant on less exposed and on temperate beaches although there are many exceptions of this and polychaetes are sometimes more abundant than either of these taxa. Generally crustaceans dominate the sands towards the upper tidal level and molluscs the lower down level. Physical factors, primary wave action and particle size of the sand largely determine distribution and diversity of the invertebrate macrofauna of sandy beaches. Food input and surf-zone productivity may determinate the abundance population. Water movement is important parameter controlling macrofaunal distribution on beaches.

Meiofauna

In contrast to the wave-swept surface sand inhabited by most of the macrofauna, the interstitial system is truly three-dimensional, often having great vertical extent in the sand. The porous system averages about 40% of the total sediment volume. Its inhabitants include small metazoans forming the meiofauna, protozoans, bacteria and diatoms. The meiofauna is defined as those metazoan animals passing undamaged though 0.5 to 1.0 mm sieves and trapped on 30 mm screens. On most beaches the interstitial fauna is rich and diverse, even exceeding the macrofauna in biomass in some cases. The dominant taxa of sandy beach meiofauna are nematodes and harpacticoid copepod with other important groups including turbellarians, oligochaetes, gastrotrichs, ostracods and tardigrades.

Insects

Terrestrial insects and vertebrates are frequently ignored in accounts of sandy beaches. These animals are usually a conspicuous component of the ecosystems, often rivalling the aquatic macrofauna in terms of biomass and having a significant impact on the system with regard to predation and scavenging.

Artificial beaches

The soothing qualities of a beach and the pleasant environment offered to the beachgoer are replicated in artificial beaches, such as "beach style" pools with zero-depth entry and wave pools that recreate the natural waves pounding upon a beach. In a zero-depth entry pool, the bottom surface slopes gradually from above water down to depth. Another approach involves so-called urban beaches, a form of Public Park
becoming common in large cities. Urban beaches attempt to mimic natural beaches with fountains that imitate surf and mask city noises, and in some cases can be used as a play park.

Beach nourishment involves pumping sand onto beaches to improve their health. Beach nourishment is common for major beach cities around the world; however the beaches that have been nourished can still appear quite natural and often many visitors are unaware of the works undertaken to support the health of the beach. Such beaches are often not recognized (by consumers) as artificial.

A concept of IENCE has been devised to describe investment into the capacity of natural environments. IENCE is Investment to Enhance the Natural Capacity of the Environment and includes things like beach nourishment of natural beaches to enhance recreational enjoyment and snow machines that extend ski seasons for areas with an existing snow economy developed upon a natural snowy mountain. As the name implies IENCE is not quite mainstream natural science as its goal is to artificially invest into an environment's capacity to support anthropogenic economic activity. An artificial reef designed to enhance wave quality for surfing is another example of IENCE. The Surfrider Foundation has debated the merits of artificial reefs with members torn between their desire to support natural coastal environments and opportunities to enhance the quality of surfing waves. Similar debates surround Beach nourishment and Snow cannon in sensitive environments.
ACTIVITY: EXAMINING THE SAND AND ROCKS FROM THE SEASHORE

DURATION: 1 hour

MATERIALS

- Sugar Cubes
- Jar with lid
- Samples of mud, sand, shingle, stones, rocks and shells fragments

PROCEDURE

Step 1. Discuss with the students what they walk on when they are at the beach. (Encourage students to think about the different types of seashores - mud, sand to rocky shores).

Step 2. Create a seashore centre in the classroom showing samples of mud from the seashore, sand, shingle, stones / rocks and shells fragments.

- Examining the sand and rocks from the seashore will help students think about where sand comes from.
- Get the students to touch, describe and document what the different textures feel like. Using the magnifying glass get the students to describe and document what they see. Explore the similarities and differences of the sand, rocks and shells fragments.

Step 3. Discuss with the students what they think sand is made of and where it comes from.

- Guide the students to learn that grains of sand (depending on which beach it has come from) are tiny pieces of rocks and/or shells that have been broken into very tiny pieces. Discuss how these particles have been tumbled and banged against each other over time by tides, currents and waves.
- Depending upon where and how far the rock and shells have travelled before it ends up on the seashore can influence the how soft or hard the sand is. Sand and rocks found on the beach may be either angular or very rounded and smooth. The more distance the sand and rocks travel the more likely it is to be knocked around, breaking off sharp edges, leaving a smoother, more rounded surface to the grain.

Step 4. To demonstrate how rocks can be broken into tiny grains of sand, divide the class into groups. Give each group a jar with a few sugar cubes in it. Explain to the groups that the sugar cubes represent stones and rocks travelling out to sea from the rivers.

- Each person in their group should take turns shaking the sugar cubes in the jar.
• Explain that this represents the rocks and seashells be tumbled about by the waves.

Step 5. Observe and record the results of what happens to the cubes of sugar when they tumble and bang against each other.
**ACTIVITY: EROSION... CAN YOU FIGHT IT?**

How much energy is involved with waves and erosion? Can humans stop erosion of the shoreline? Should we? Is it cost effective?

**OBJECTIVES**

Students will be able to:
- determine how much energy is in a wave
- list structures used for shoreline defense
- determine the types of materials appropriate for a shoreline and the cost effectiveness of using different types of materials

**MATERIALS**

Computers with Internet access
Calculators
Student Worksheet (.doc)
Optional: stream tables, water, sand, piece of rock, masonry, wood, steel, and concrete

**BACKGROUND**

Several engineering solutions are used for coastal protection and beach restoration. In the past, construction of hard structures such as groins and sea walls have been used with varying degrees of success. Some solutions have been successful, some require expensive ongoing maintenance and others have caused even more problems. Another method of coastal protection is to artificially nourish the beaches by transporting sand from another location to restore a beach. Once again, this method has varying levels of success.

Groins, usually made of timber, rock or concrete, are built perpendicular to a beach and into the water to trap sand. On beaches where waves arrive at right angles to the shore, a series of groins can trap sand, creating a series of small beaches. On beaches where waves arrive at an angle to the shore and the beach is affected by longshore drifting, a different situation arises. As the water and sand move by, the first groin will trap sand meanwhile starving the beach of sand (and other groin) further along the shore. Groins can be designed to allow some sand to spill around the structure and minimize downstream erosion.

Groins are not successful in all circumstances contributing to further erosion. A careful analysis of wave approach and currents should precede any decision to install a groin, and the structures should be carefully designed for the specific location.
Seawalls may be constructed of timber, rock, steel or concrete and are placed at the back of a beach. Although seawalls can protect the land directly behind, they can also accelerate erosion at the end of the wall and/or cause erosion of the beach in front of the seawall. When waves hit the wall and retreat, the wave action scour sand from the beach back into the water. Ultimately, the beach becomes lower and flatter, creating a condition where waves become larger, which increases the scouring action and the beach is eventually lost.

Artificial beach nourishment (replenishment) is the depositing of sand from elsewhere to replenish eroded beaches. Sand may be trucked in or dredged and pumped from offshore. But it is not as easy as it sounds. The nourishing sand must be as coarse as the sand that is currently on the beach. If the nourishing sand is of a finer grain, the sand will be easily swept away by normal wave action. On beaches where sand has been lost through longshore drifting it is likely that nourishing sand will also be lost. Sometimes in this scenario, groins are constructed to trap drifting sand.

It is important to remember that coastal erosion is a natural process and does not always have a negative outcome. It is the natural erosion process which gets sand on beaches in the first place, but if interference occurs with natural erosion and deposition patterns, undesired outcomes requiring further action can occur.

The decision to take action is the responsibility of coastal managers. Coastal Managers often face difficult decisions involving roads and buildings that are in danger of damage or destruction. In some cases, the preferred long term solution may be to relocate or abandon structures instead of fighting a losing battle with the sea. However, this is usually impractical due to the investment value of coastal properties and financial benefit of coastal tourism.

If the decision is made to construct coastal protection structures, the Army Corps of Engineers usually becomes involved. During the process, the Corps determines the amount of wave energy is unleashed on the beach, then searches for the most economical, environmentally sound and socially acceptable solutions. In some cases, this will involve hard structures or in many other cases, the preferable approach is beach nourishment.

Corps shore protection projects are usually cost-shared with the State, the local jurisdiction where the project is located, or both.

In this lesson, students will work in cooperative groups as engineering teams charged with creating a coastal protection solution.

**PROCEDURE**

Problem
Your engineering team has been charged to submit a bid for a design for a 600 meter
seawall to protect a major coastal highway. Your team must design the wall right at the edge of the water. The structure must be able to withstand the impact of the ocean waves. You cannot spend any more money on the project than is necessary, so it is crucial that the team know what materials can be used in construction and how much each material will cost. It is also important to know that there will be no funding available for beach nourishment (replenishment) in the future. Your team will have to give a 10 minute presentation on the seawall design and submit the bid to the Project Manager (teacher).

1. To determine the amount of wave energy, use an equation to calculate the amount of energy based on the height of a wave. First, determine the amount of energy for every square meter of wave, the energy (joules) is equal to 1260.6 times the square of the wave height.

\[ \text{Wave Energy} = 1260.6 \times (\text{Wave Height})^2 \]

2. To determine the Total Energy in a wave, calculate the total surface area of the wave and multiply that by the wave energy.

\[ \text{Total Energy} = \text{Wave Energy} \times \text{(surface area of wave)} \]

For example, calculate the energy for an average open water wave that is 2 meters high, 7 meters wide and 500 meters long:

\[
\begin{align*}
\text{Wave Energy} &= 1260.6 \times (2)^2 \\
\text{Wave Energy} &= 1260.6 \times 4 \\
\text{Wave Energy} &= 5042.4 \text{ Joules/m}^2 \\
\text{Total Energy} &= 5042.4 \text{ Joules/m}^2 \times (7 \text{ meters} \times 500 \text{ meters}) \\
\text{Total Energy} &= 17,648,400 \text{ Joules} \text{ or } 1.76484 \times 10^7 \text{ Joules}
\end{align*}
\]

3. For this activity, the waves will be 8 meters wide, and the section of the seawall that the waves will hit is 300 meters long. Determine the highest water height for this month. Go online and visit the Sandy Hook website on NOAA

4. Calculate the Total Energy of the wave.

5. Using the table of materials below, your team must design a wall to withstand the
wave energy calculated above.

<table>
<thead>
<tr>
<th>Material</th>
<th>Strength</th>
<th>Cost/cubic meter</th>
<th>Amount needed</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Rock</td>
<td>30 million joules</td>
<td>$50/cubic meter</td>
<td>900 cubic meters</td>
<td></td>
</tr>
<tr>
<td>Masonry</td>
<td>40 million joules</td>
<td>$150/cubic meter</td>
<td>300 cubic meters</td>
<td></td>
</tr>
<tr>
<td>Wood</td>
<td>4 million joules</td>
<td>$25/cubic meter</td>
<td>2000 cubic meters</td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td>90 million joules</td>
<td>$225/cubic meter</td>
<td>300 cubic meters</td>
<td></td>
</tr>
<tr>
<td>Concrete</td>
<td>50 million joules</td>
<td>$180/cubic meter</td>
<td>800 cubic meters</td>
<td></td>
</tr>
</tbody>
</table>

Note: The Strength represents how much energy the material can absorb PER WAVE before it structurally fails. The Amount Needed column represents how much material needed to supply the stated strength. For example, a wall of 2,000 cubic meters of wood can absorb a maximum of 4 million joules from each wave that hits it.

6. One of the highest waves in recorded history for this site was 5 meters high. This wave occurred during an exceptionally large storm. Would this information change your design? If so, explain.

7. Using all of this information, create a bid for a design for the seawall project described in the Problem Statement.

Your team must create a 10 minute presentation on the seawall design and submit the bid to the Project Manager (teacher).

When preparing your project, your group might also want to consider if the project will be cost effective, possible alternatives, tourism dollars, etc.

Any mix of materials is allowable, but remember that your bid and presentation will be judged according to:

- calculations
- structural integrity
- projected longevity
- aesthetics
- environmental concerns
- cost
Development-protecting seawalls debated

The Associated Press

**EROSION:** Opponents say beach armoring destroys beaches for the public, is costly, and often does not work.

**OCEAN SHORES** - A barricade of rocks dumped on a public beach to save a row of condos from the hungry Pacific is at the heart of a growing battle over the fate of Washington's wind-swept ocean beaches.

The central question: Should the state allow rock walls and other "beach armoring" to protect development from erosion on the state's largely untouched south coast?

Property owners, developers and some local government officials so far are saying yes - at least to temporary walls like the one here. It's an approach neighboring Oregon has already rejected, choosing to let nature take its course.

Without intervention, seawall supporters say, millions of dollars in property will be lost to beach erosion, which, for reasons not entirely understood, has been quickening in recent years.

**OTHER STATES**

The 850-foot seawall thrown up here to protect condominiums from the Pacific Ocean would be illegal in at least four coastal states and was recently rejected as a solution by fifth - Oregon.

North Carolina, South Carolina, Maine and Rhode Island "are making a concerted effort to save beaches for the next generation" said Orrin Pilkey, a Duke University geology professor and an expert on ways to preserve beaches in the face of human development.

Seawalls and other "hard solutions" to beach erosion are outlawed in those states because they destroy beaches, Pilkey said. Several other coastal states virtually ban "armoring" as the practice is called.

One of those states is Oregon, whose governor, John Kitzhaber, refused to bend state rules to save 32 luxury homes threatened by a sloughing-dune at Oceanside. The homeowners are still trying to find a way to save their properties.

**Fighting Erosion**

The beach at ocean Shores receded by 35 feet in the winter of 1996, after the 850-foot-long rock seawall was installed. Geologists say it would have receded another 35 feet, and taken out the condos, had the wall not been there. Other areas along the south coast are seeing similar erosion.
The wall "has been absolutely fabulous. It has done more than we had hoped for," said Terra Tosland of Point Brown Resort, which manages the wooden timeshare condos for out-of-towners.

State regulators, environmentalists and a national expert of beach erosion say they're fighting to protect Washington's ocean beaches too. They just disagree over what that means.

Seawall opponents say beach armoring destroys beaches for the public, is costly, and often does not work. At best, they say, what little beach is left eventually gets washed away, leaving only the seawall. Gone is an open beach for strollers, surfers, clammers and beachcombers.

'Newjerseyisation'

At worst, the sea goes around the wall and turns it into an island, foes say.

"Construction of this wall flies in the face of a huge national experience with seawalls beginning in New Jersey 150 years ago," says Duke University geology professor Orrin Pilkey, a national expert on beach erosion.

"Newjerseyization of the southwest beaches has begun," he said in a 1997 study titled Management of Washington's Ocean Beaches: A Banana Republic Approach?

Pilkey, director of Duke's Study of Developed Shorelines, dismisses state regulators' characterization of the wall here as a "temporary measure."

"That's not a temporary wall. It's going to get bigger and longer. That's speaking statistically," he said.

Pilkey and other geologists say pent-up wave energy simply transfers to the unprotected beach at each end of such walls, increasing erosion there and requiring construction of more wall.

In fact, the city has already asked the state for permission to extend the barrier with 600 feet of "geotube," 112-foot wide plastic tubing filled with sand.

The dispute has shaken state regulators awake.

Despite seemingly tough environmental laws, Washington has no coherent policy for dealing with the beach-erosion problem. The 15-foot-high "wave revetment" at Ocean Shores, financed by property owners, has become the flash point for the issue in Washington.
The rock-pile wall, also called a "wave bumper" is the first on a Washington ocean beach and could set a precedent for erosion-control revetments at a score of other erosion hot spots.

The wall, just north of the city's North Jetty at the mouth of Grays Harbor, was erected in October 1996 as the ocean licked at a row of condominiums. It was built under an emergency decree that allowed the city to bypass necessary hearings and permits under the state Shoreline Management Act.

Scientists believe the erosion is the result of a loss of replenishing sand that once flowed from the Columbia River and was swept north by ocean currents. That sand now is trapped by the 14 dams constructed along the river since 1930, scientists believe, causing a shrinkage of beaches up and down the south coast. The erosion began after decades of beach expansion.

What to do

State and local government officials and regulators at both levels now argue over how to deal with coastal erosion.

"What we're finding is that there isn't much policy to address these issues. A lot of this stuff is like going back to the drawing board, and unfortunately we don't have a lot of time," said Sue Patnude, Ocean Shores' city planner.

At the state level, the departments of Ecology and of Fish and Wildlife only reluctantly removed environmental hurdles to building the wall, which they specified must be removed after two winters - by late May. The state hasn't decided whether to extend the temporary permit or order homeowners to tear out the wall.

Fish and Wildlife granted a permit after initially resisting on grounds the wall could threaten habitat of a fish species, the surf smelt.

Ecology did not intervene when the city bypassed restrictions in the state Shoreline Management Act on grounds it faced an emergency - the loss of condos. But records of internal mail among Ecology regulators show debate raged hot and heavy.

"If armoring is permitted at this location, we may have great difficulty arguing against it anywhere else on ocean beaches," Hugh Shipman, Ecology's geologist, told superiors a few months before the wall was built.

The man who represented Ecology in its dealings with Ocean Shores, Chuck Gale, championed construction of the wall, to the chagrin of many colleagues. Gale helped the city and its consultant, Harry Hosey, figure out how to bypass his agency's permitting and public-review processes.
Gale’s boss, Sue Mauermann, removed him from his role as go-between last spring, in part because the ill will between Gale and his coworkers. In January, Gale quit his 10-year job to work for Hosey's company, Pacific International Engineering of Edmonds.

On another front, Pilkey collided with Hosey over the consultant's advice and methods at Ocean Shores.

Hosey's solution to coastal erosion "are in disregard to the future well-being of Washington's beaches," Pilkey says.

Calling the rock barricade "very temporary," Hosey says it was a necessary stop-gap while the parties forge long-term solutions.

"My company's mandate for our clients is to save them from pending disaster," he said.

Strong disagreement over how to deal with shoreline erosion continues within the city of Ocean Shores as well.

Patnude, the city planner, has clashed with Hosey and some of his city-government backers over what is best for the beach and shoreline homeowners.

She favored moving the condos back from the brink, saying construction so close to the shore should never have been allowed.

"I totally do not agree with hard stabilization structures," Patnude said. "I've seen what happens on the beach, and beaches are too precious to mess with."

City Manager Jack McKenzie, who took office after the wall was built, defends the seawall and the request to extend it with geotubes. He doesn't believe the condos should have been moved.
RESOURCES

http://en.wikipedia.org/wiki/Beach

http://thewebsiteofeverything.com/habitats/Sandy_Shoreline_and_or_Beaches,_Sand_Bars,_Spits,_Etc.html

http://www.marbef.org/wiki/Sandy_Shores

http://limpetsmonitoring.org/docs/Natural%20History%20Beach.pdf

http://www.crd.bc.ca/watersheds/ecosystems/sandgravel.htm

http://www.hillsdalecounty.info/planningeduc0025.asp#INLINK004

http://www.mbgnet.net/salt/sandy/sandy.htm

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http://www.naturalhazards.net.nz/tools/nzcoast/coastal/about/nz_beach_type_classification/beach_types

http://www.poemsinc.org/oceano/beach.htm

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http://www.coastalchange.ucsd.edu/st3_basics/waves/html

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