Chapter 6
Powerful Forces Shape Our Coast

California is a coastal state, with the vast and powerful Pacific Ocean as a next-door neighbor. Our state has been formed by natural processes that change short term by the seasons, and long term over millions of years. Seismic forces, in addition to the forces of waves, wind, and water, shape our coast. These forces uplift coastal bluffs, erode cliffs and riverbanks, build dunes, and form beaches.

Coastal erosion and accretion have been shaping our coast for many thousands of years. The present day shape of the coast reflects thousands of years of sea level change, continental uplift and subsidence, landslides, earthquakes, and ocean waves. Interactions among these forces episodically accrete (add to) and erode the coastline, resulting in the spectacular beaches and cliffs that border much of coastal California. As sea level rises over time, water gets closer to the cliffs and they are battered by waves.

Our coast also changes over the seasons and the short term, from violent storms, periodic events such as El Niño, and random events such as tsunamis. Consequently, it is important to realize some geologic and oceanographic processes are constant, others are cyclical, some are intermittent, and some are random. Some operate rapidly and are easily observed, while others operate very slowly and cannot be measured except through a long period of continued observation.

New Words and Phrases

erosion; accretion; tsunami; coastal armoring; sea level; global warming; sea walls; groins; jetties; beach profiles; uplift; subsidence; landslides; longshore sand movement

California Coastal Commission Area of Critical Concern: Coastal Processes

Relevant California Science Content Standards, Grade 6: Earth Sciences 2. a, c

Coastal erosion is natural, but things people do alter it. People build seawalls to protect buildings built close to the ocean. Human barriers to erosion, such as seawalls and retaining walls, can protect what is behind (landward of) them, but do nothing to protect the beach. As waves interact with these structures, erosion may increase up and down the beach. Building dams on rivers reduces the amount of sand that reaches the coast, making for smaller beaches that may inadequately protect cliffs. We can increase erosion with the increased runoff caused by developing the coast. Climbing up and down the bluff face, disturbing sand dune vegetation, digging for fossils, or carving in cliffs also increases erosion.

Beach accretion (sand build-up on beaches) is also natural. Sand beaches form upcoast of headlands and points, in the protected portion of bays, along the seaward portion of sand dunes, and on the open coast where there are rivers to maintain a supply of new sand to the coast. Engineering structures such as groins and jetties can cause sand to build up on

Grade 6 Activities

These activities bring our dynamic coast to life. Students experience firsthand the natural and human made changes to the coast, and conduct experiments and calculations that help them visualize the impacts of erosion and sand movement.

Activity Goals

6.1. Beaches: Here Today, Gone Tomorrow?

Students will:

1. Know how to conduct a beach transect.
2. Have a basic knowledge of beach substrate, geologic formations, erosion, and methods of beach monitoring.

6.2. Shifting Sands

Students will:

1. Know how waves move sand and cause erosion.
2. Understand how barriers like groins and jetties alter coastal processes.

6.3. Rollin' Along the Sand Highway

Students will:

1. Use harbor dredging records to calculate the amount of sand that moves along California's coast.
2. Understand human impacts on sand movement and beach size.

the upcoast side. Breakwaters can provide a protected harbor area landward of the structure, but also can trap sand and build up beach areas. Structures such as groins and jetties will usually produce accretion (more sand added to the beach) in one area but may produce erosion in another. Beach nourishment, which takes sand from offshore deposits or from inland reservoirs and dams, can add new sand to beaches and provide for beach accretion without causing erosion elsewhere.

To sustain California's open coast, we must learn to live with the forces that shape the coast. To do this successfully and safely, we must understand how coastal processes work, set development back from the bluffs, and reduce human impacts to beaches and bluffs.

Coastal accretion and erosion cannot be studied alone, as there are many interrelated processes that operate within and outside the coastal zone. A study of the coast can be an entryway into a host of different areas in Earth sciences, including global climatic change, fluctuations in beach size, sea level fluctuations, faulting, earthquakes, tides, and more.

Natural forces on the coast affect erosion:

- Number one cause is the rise in sea level, a natural phenomena that is accelerated by human influence (see below).
- Wave action and resulting sediment transport.
- Runoff from land.
- Storm events and irregular events (El Niño, La Niña, tsunamis).
- Combination of big waves with high tides.

Human forces on the coast contribute to erosion:

- Damming rivers reduces amount of sand that reaches the coast; smaller beaches offer less protection to coastal bluffs.
- Coastal development that increases impermeable surface and changes runoff patterns may cause bluffs to be less resistant to erosion.
- The rise in sea level caused by global warming from the accumulation of greenhouse gases in the atmosphere.
- Armoring the coast by building barriers to protect naturally eroding cliffs may cause increased erosion of beaches on either side of the barrier.
- Climbing up and down cliffs, trampling sand dune plants, digging out fossils from cliffs, disturbing cliffs in general.

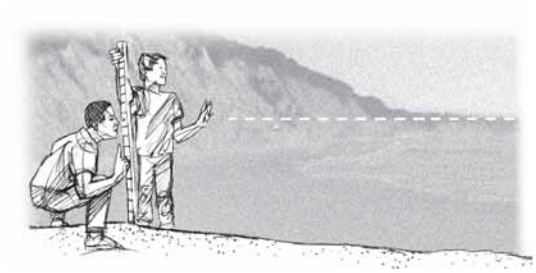
Natural and human forces contribute to accretion:

- Storms and high flood events may add sand to beaches.
- Harbor dredging can add sand to nearby beaches when dredged sand is dumped on these beaches.
- Beach nourishment projects, in which sand is transported to beaches from elsewhere.

Grade 6 Activity

Activity 6.1
Beaches: Here Today, Gone Tomorrow?

The ocean is constantly in motion. Every day, the combinations of currents, tides, and waves move and shape our coastline. Find out how these forces work their magic through measuring a beach profile. This activity requires a trip to the beach, but Step 1 may be done on its own in the classroom.



Science skills
- Measuring
- Calculating
- Observing
- Hypothesizing
- Recording

Concepts
- Beaches change with the seasons and over time.
- Changes are due to waves, erosion, and discharge of sediments from rivers.
- Beach profiles can be used to document how a beach changes.

California Science Content Standards
Earth Sciences

2. Topography is reshaped by weathering of rock and soil and by the transportation and deposition of sediment. As the basis for understanding this concept:

2.a. Students know water running downhill is the dominant process in shaping the landscape, including California's landscape.

2.c. Students know beaches are dynamic systems in which the sand is supplied by rivers and moved along the coast by the action of waves.

Objectives
Students will:
1. Measure the shape or profile of a beach.
2. Understand that beach profiling is a valuable method of monitoring the erosion and accretion patterns of beaches.
3. Have a basic awareness of beach shape, geologic formations, erosion, and methods of beach monitoring.
4. Understand why beaches change with the seasons, and where sand goes in winter.

Background
Did you ever go back to a beach in the winter that you had visited in the summer? Chances are, it was a very different beach! The wide, white sand beach you were expecting may have turned into a narrow, steep, rocky platform. Or, it may even be underwater. Not to worry, beaches change naturally between the summer and winter months. In general, beaches get wider in the summer months, and narrower in the winter months. Sand is delivered to the beaches in the winter through storm runoff and increased flow of water (and sediments) from rivers. At the same time, the big waves pull sand off the beaches and deposit it just offshore so the beach gets narrower. Much of the sand is stored just offshore in underwater sandbars, and some of the sand moves downcoast as it gets carried by longshore currents that are generated by breaking waves. In the summer months, the smaller waves pick up sand from the underwater sandbars and move it back up onto the beach.

Changes from year to year, especially if one of those years is an El Niño year, can be quite dramatic. Big winter waves occurring simultaneously with very high tides have been responsible for massive amounts of property damage costing millions of dollars in coastal areas.

The cyclical interaction of winter storms bringing sediment to our coast, and summer waves washing the sand up onto the beaches, provide a perfect natural venue for winter adventure and summer fun.

A single line transect is an effective way to study beach shape, beach activity, and geologic formations. This activity allows students to measure the natural changes that occur on our beaches, and graphically represent the natural forces that shape our coast.

Time to complete

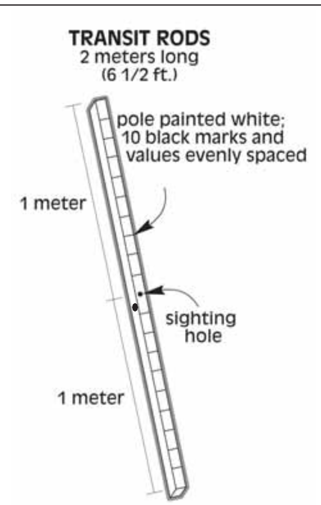
Classroom discussion: 0.5 hour.
Field trip: time on beach, approximately 1.5 hours. Analyzing and graphing data: 0.5 hour.

Mode of instruction

Classroom discussion followed by small group activity on field trip.

Activity

1. On overhead projector, show “Beaches: Here Today, Gone Tomorrow?” transparency. Lead a whole class discussion on what students know about how beaches are formed. From where does the sand on beaches come? Do beaches look the same year round? Why do some beaches have fine, white sand, while others have coarse sand? Where do beaches go in winter?



How to Make Transit Rods and Line

Make one pair of transit rods per group; the two rods must be made identical to each other. Each rod is approximately 5 cm (two inches) square and 2 meters (six and a half feet) long. You may use a single 2” x 4” cut in half lengthwise—you can have this cut at a lumber store. A hole (1/2” diameter) should be drilled through the center of each pole for use as a sighting device; it’s not necessary, but simplifies the measuring process. You can have them drill the hole at the lumber store, also. Poles should be painted white and marked in decimeters from the center using black paint or permanent marker, with minus values marked above the hole and plus values marked below the hole. Put marks on same side of rod as the hole.

To make the line, it’s preferable to use polyethylene, as it is light, doesn’t stretch much, and may be purchased in white or yellow. Twine also works. Mark the line in increments of one meter each, using a permanent marker or by wrapping it with black electrical tape.

Materials

For whole class:

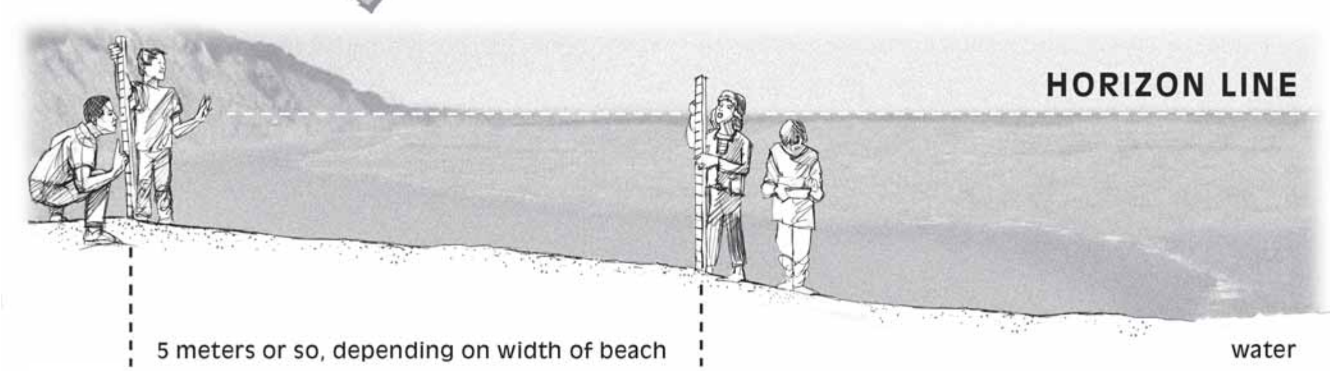
1. Local tide table
2. Spreadsheet with graphing capability (optional)
3. Camera (optional)
4. Overhead projector

For each group (4-6 students):

1. Two transit rods
2. Line: heavy twine or light rope that will not stretch, about 10-15 meters
3. Additional line and a line level, inexpensive and available at hardware stores (optional)
4. Sight marker (old ping pong paddle, a book, or a student)
5. Clip board with “Beach Profiling” worksheet
6. Graph paper

2. Ideally, first conduct the beach profiling activity on a slope on your school grounds. If this isn’t possible, you will need to explain what the activity is and how to measure beach profiles before you leave the classroom for your fieldtrip. Review the “Beach Profiling Worksheet” and discuss how to collect data.

3. **Beach Profiling Activity.** Once you are at the site to be profiled (initial dry run on school grounds, or real activity at beach), divide the class into small groups (4-6 students). Hand out a set of materials to each group. Have each group establish a “permanent benchmark,” a permanent reference point or starting point (if you have access to a Global Positioning System [GPS], this is ideal). Your permanent benchmark can be a house, tree, permanently attached bench, massive rock, etc. Something that doesn’t move. Groups should be positioned no closer than 50 feet up and down the beach from each other.



Preparation

Locate a beach within an easy field trip distance. This activity can be done at the same time as a tide pool field trip, or a beach cleanup day.

To reduce preparation time, make only two sets of transit rods and line, and have student groups rotate from tide pooling or beach cleanup to beach profiling (you will need another adult assistant to monitor groups at the alternate activity).

If possible, choose a beach that you know changes drastically between winter and summer. For the most dramatic experience, do this activity twice in a school year; once near summer or fall (June, September or October) and once in mid-winter (January or February). Do yearly at the same beach, and keep records for students to compare their profiles with profiles from previous years. Photographs make a nice graphic complement.

Outline

Before class

1. Weeks before: arrange field trip details, assemble materials, and make transit rods.
2. Photocopy data recording sheets.
3. The day before your field trip, try this activity as a teacher-led demonstration at your school. You will need three assistants. *Note: you must have a large, gradual sloping area in which to work, and a clear horizon.*

During class

1. Arrive at field trip location.
2. Divide class into groups of four to six students (four to five groups total). Have students in groups divide themselves into transit rod holders and recorders (minimum two of each).
3. Pass out materials, one set to each group (clip board, transit rods and line, data sheet). Or, if doing tide pooling or beach cleanup at same time, assign tasks accordingly.
4. Review method of collecting beach profile data and how to record it.
5. Assist groups with finding a starting point.
6. Circulate among groups to assist with questions during profiling exercise.
7. Regroup at end to compare experiences.

4. Direct students in measuring the beach transect.
   a. Students record benchmark location, tide level, evidence of plant or animal material, and sand or soil type on worksheet.
   b. Set the first transit rod at the starting point. Take the second transit and move it to a location closer to the water, following a line perpendicular to the water line. You may use an even increment of distance (such as five meters) but it is best to move to the next point of change in elevation patterns (such as the edge of a berm or center of a depression), but rarely more than 10 meters. Use the line to measure the distance, keeping the transit vertical and the line perpendicular to the transits. The person at the first transit sights through the hole to the second transit and reads the value on the second transit where the horizon appears on the transit. This is a level line. If the person cannot make out the numbers due to distance, the person on the second transit can be guided to move their finger up or down until they point to the mark on the transit. Record the number on the data sheet.
   c. Following the first measurement, move the first rod transit to the new location closer to the water. Keep the second transit rod in place as it will now serve the same role as the first transit. Place the marker at the site of the first transit as a guide to allow the profile to follow a straight line. Repeat this process, leapfrogging over each transit rod for subsequent measurements.
   d. <u>If a horizon is not available</u> (i.e, it is a cloudy day), use the line level: use a separate line with the level. One end of this line must be at the site of the first transit with the line pulled taut between the two transit rods. The line level is hung on the line at the center between the two transit rods, and the line is moved up and down on the second transit rod until the level reads as level. Use another person to do this. When the line is level, its position at the second transit marks the elevation change. Do not use large increments of distance if you use the line level; five meters is optimum.
   e. Continue measuring and recording elevations until you measure to sea level (the glistening part of the sand when the waves retreat). This is the end of the beach profile recording exercise.

5. Optional: Take pictures of the beach from several angles for later reference or for posting on the Internet (see Ext. #2).

6. Back in class, students can either enter their data into a spreadsheet program with graphing capability, or plot their data points on graph paper. The values they measure will generally be negative values from the starting point. These may be adjusted to reflect your own needs in terms of the graphs you wish to produce or how you wish to view them. For example, if the starting point is referred to as “0” and sea level appears at –53 decimeters and a distance of 120 meters, you may want to change them to represent sea level as “0” and your actual starting point as an elevation of 53 decimeters at a distance of 120 meters from sea level. Data kept on a spreadsheet can more easily be compared with previous years’ results.

Results and reflection

1. Do students understand the profiling procedure, and are they aware of what they measured? Conduct a whole class discussion on their profiling experience.
2. Do students understand how the beach profile will change over the year, and the physical forces that influence the beach profile? Have students draw an illustration of a beach during the summer and winter.
3. Students will create a graph that shows the beach profile using the data they collected.
4. Scientists have found that more coastal erosion occurs in episodic events, such as an El Niño or a big storm, than the erosion that occurs slowly over time. In a big storm year, waves are often stronger than usual storm waves, and if they coincide with high tides, the effects can be devastating. In a classroom discussion, have students picture two different beaches: a normally narrow summer beach, say one downcoast from a rocky point, and a normally wide beach. What would be the effect of large storm waves on structures that are built close to the sand in each of these locations?
5. What do your students think of the process of sand mining (trucking beach sand away from the beach to be used elsewhere)? What about beach nourishment (bringing in sand from other places to replace sand lost due to wave erosion, or on beaches that are not normally wide)? Or how about dredging (pumping the sand from offshore back to the beach). How do these activities affect the beaches? How about the beaches on either side of the beach that is being mined, nourished, or dredged—how are they affected? Conduct a classroom discussion on the pros and cons of artificially moving sand from one place to another.

Conclusions

California's beaches are constantly being shaped and sculpted by natural forces whose origins can be thousands of miles from our coast. Understanding the seasonal and episodic processes that form our beaches leads to greater understanding of the potential hazards involved with living on the coast.

Extensions and applications

1. Carefully measured profiles may be recreated on cardboard or firm stock, cut out, and used to create a physical model of the beach. Find local information about the substrate rock material to incorporate into your model. Use samples of the different types of sand (from coarse gravel to fine sand or shells) found at your beach. If possible, locate historic aerial photographs of your beach area and look at the changes over time. Has it become smaller or larger? How has the population changed in the area of your beach over the same time? Any new dams, breakwaters, jetties, or groins?
2. The California Coastal Commission's Public Education Program may be posting profile data and photographs at *www.coastforyou.org*.
Call (800) Coast-4u for information.

Adapted from

Rumpp, George W. and Phyllis E. *Seastar: Beach Profile Project. http://mciunix.mciu.k12.pa.us/~seastar/*
Activity adapted from The Maury Project, American Meteorological Society.

Beaches: Here Today, Gone Tomorrow?

Which of these images are summer beaches? Which are winter beaches?
What are some of the differences between the two beaches?






Beach Profiling Worksheet

Beach location:

Date:

Time:

Tide status:

Other observations (beach or sand type such as fine sand, cobbles, gravel; near river or harbor; steep drop-off or wide gently sloping beach, etc.):

	Change of elevation	Cumulative change in elevation	Distance from last measurement	Cumulative Distance
Beginning elevation	0	0	0	0
First measure				
Second measure				
Third measure				
Fourth measure				
Fifth measure				
Sixth measure				
Seventh measure				

Draw a rough diagram of your beach profile here:

Grade 6 Activity

Science skills

- Hypothesizing
- Experimenting
- Observing
- Deducting

Concepts

- Currents, waves, and wind move sand along the coast of California.
- Human-built structures alter the natural movement of sand along beaches.

California Science Content Standards

2. Topography is reshaped by weathering of rock and soil and by the transportation and deposition of sediment. As the basis for understanding this concept:
2.a. Students know water running downhill is the dominant process in shaping the landscape, including California's landscape.
2.c. Students know beaches are dynamic systems in which the sand is supplied by rivers and moved along the coast by the action of waves.

Objectives

Students will:

1. Describe the forces that naturally shape California's beaches.
2. List the benefits and risks of human-made structures that alter coastal bluffs and beaches.

Time to complete

One hour 15 minutes

Activity 6.2 Shifting Sands

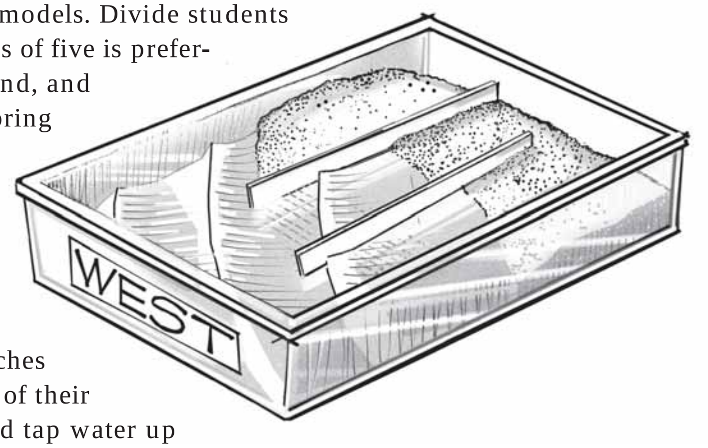
The ocean is constantly in motion, and nearshore currents carry sand and sediment along with them. Structures we build to protect the coast from erosion can change the shapes of beaches, for better or for worse!

Activity

1. Have students read background material from "Background and Model Instructions" worksheet (allow 10 minutes or so).

2. Lead whole class discussion on beach erosion, cliff erosion, and the protection of beachfront property. Describe the processes that create beaches. (*Wind, waves, currents bring sand to beaches; currents and waves move sand along the coast*). What types of structures do people build to protect their coastal property? (*Groins, rip-rap, seawalls.*) What happens when you disrupt the natural flow of sand along our coast? (*Some beaches are built up, while others get smaller. Smaller beaches increase the risk of erosion of coastal cliffs and bluffs.*)

3. Following instructions on worksheet, guide students in building the models. Divide students into small groups (groups of five is preferable). Distribute pans, sand, and rulers. Students should bring a pencil and unlined paper to their group. Students use tape to label the shorter sides of the pan "East" and "West." Students pour up to 4 inches of sand into the east end of their pans, and then gently add tap water up to 2 inches deep on the west end of the pan.



4. Students fold their paper into fourths. Using one section labeled *Diagram #1*, students draw their experimental models.

5. Student #1 uses a ruler to create a gentle wave action in the pan, in a general west-to-east movement.

6. Each student draws how the model appears after wave action (label it *Diagram #2*). What are the effects of erosion? How has the coastline changed as a result of the wave action?

7. Student #2 positions the sand in its original model configuration. Student #3 sets two to three rulers on-edge into the sand lengthwise about 4 inches apart, representing groins. Student #4 uses a ruler to create the same gentle west-to-east wave movement. What happens in between the groins? What happens to the shoreline? Students draw *Diagram #3*. Now, Student #5 makes waves coming from the northwest.

Mode of instruction

Whole class discussion followed by small group hands-on activity.

Materials

1. 12-inch rulers (4 for each group)
2. Rectangular pans or plastic bins (9" or 12" deep, more than 12" long, one for each group)
3. All-purpose sand (79 lb. Bag)
4. Tap water
5. Overhead projector
6. Photocopies of "Shifting Sands Background and Model Instructions" worksheet, one per student
7. Overhead transparency, "Groins and Jetties"

Preparation

Collect materials for beach models. Photocopy overhead transparency "Groins and Jetties," and "Shifting Sands Background and Model Instructions" worksheet.

Outline

Before class

1. Gather materials for the number of groups (five students per group).
2. Photocopy onto overhead transparency "Groins and Jetties." Photocopy "Shifting Sands Background and Model Instructions," one for each student (two pages).
3. Prepare a beach model on your own to determine how much sand needs to go into the pans you have, and experiment with making waves. Prepackage the appropriate amount of sand into sealable plastic bags—about two cups, depending on size of pan.

During class

1. Lead whole class discussion on beach erosion and the effects of groins, jetties, and cliff protection structures.
2. Divide class into small groups (five students per group).
3. Distribute materials to each group. Describe how to label the model and how to create waves.
4. Have students illustrate their results.
5. Display and discuss overhead transparency.

Do beaches in between the groins change? Students draw *Diagram #4* to indicate how the beaches look after completing this wave action.

Results and reflection

1. Display the overhead transparency of the beach images with groins and jetties. Ask students what they think are the forces at work here. (*Currents, waves, actions of waves hitting a vertical surface, water carrying sand in suspension*).
2. Compare and contrast jetties with groins. *(Groins protect beaches from getting washed away by waves and currents. Jetties help to protect inlets and harbors from filling up with sand moving along shore. Both jetties and groins can be constructed of rock. Both affect beaches to either side.)*
3. Discuss social and political aspects of building beach protective structures on public and private land. What happens if a beachfront homeowner wants her or his beach to be larger, because she or he is concerned the home is threatened by waves, and builds a groin to nourish the beach? The homeowner's property is located north of a public beach, and the longshore current goes north to south. What will happen to the homeowner's beach? What will happen to the public beach? Should he or she be allowed to build the groin? Who will be responsible for the loss of the multi-million dollar home if the groin is not built and the waves destroy the home and property? How could this situation have been prevented? *Note: in most cases, a California homeowner would not be permitted to construct such a groin.*

Conclusions

Currents, waves, and wind determine movement of sand along our coast. Structures we make to protect beaches may have unintended effects. Living on the coast requires cooperation and compromise.

Extensions and applications

Hold a classroom discussion or have students write research papers on the following topics.

• What are the effects on the coast due to the armoring of coastal cliffs that normally would be eroding?

• Rules, regulations, and laws govern the construction of groins, jetties, and concrete cliff barriers. How can we balance public safety and recreation needs with needs of private property owners?

• What are the benefits and risks of building on coastal cliffs and bluffs or beaches? How can we allow the natural forces of accretion and erosion to occur with minimum disturbance to human-made structures?

Adapted from

Erosion Creates a Change in the Landscape, from Consortium for Oceanographic Activities for Students and Teachers (COAST). Walker, Sharon H. and Kimberly Damon-Randall (Senior Editors) and Howard D. Walters (Associate Editor). 1998. Oceanography and Coastal Processes Resource Guide. Institute of Marine Sciences, J.L. Scott Marine Education Center and Aquarium, administered by The University of Southern Mississippi, Biloxi, Mississippi.

Additional resources
www.wsspc.org/tsunami/CA/CA_survive.html
www.epa.gov/owow/estuaries/coastlines/dec99/lossmaui.html

Shifting Sands: Groins and Jetties

Jetties are built to protect the entrance channel to a harbor so boats can enter and leave safely, as well as to stabilize the entrance. In California, beaches upcoast of jetties are usually larger than beaches downcoast of them. Why?

Most piers are built on pilings, large poles sunk into sediment or rock underwater. Most piers allow sand to flow underneath them; the pier in the middle of this photograph does not affect the flow of sand. However, the solid groin at the end of the sandy beach does.

The scalloped shape of the beaches shown in this image from southern California reflects the result of many groins built to protect sandy beaches.

What happens to sea cliffs when protective sand beaches aren't present?

Shifting Sands
Background and Model Instructions

Glossary

Seawall: a structure built on a beach, often made of concrete, parallel to shoreline, designed to protect buildings from the action of waves.
Revetment or rip-rap: A structure consisting of large rocks or other materials stacked in front of an eroding cliff, dunes, or structures to protect from wave attack.
Groin: A structure built perpendicular to the shoreline designed to trap sand moving along the shore due to the longshore current. A groin or group of groins usually extend to the end of the surf zone and are used primarily to replenish or stabilize beaches.
Jetty: Structures built in pairs that extend further into the ocean than a groin, to stabilize a navigation channel and keep the water calm for harbor entrances. The construction of both groins and jetties severely affects the flow of sand moved by the longshore current, depriving downstream beaches of sand.
Beach nourishment (replenishment): the process of moving sand from the offshore continental shelf or inland areas and depositing it onto the beach. Sand is dredged from the offshore shelf, often a mile or so from shore, and is loaded onto a barge which carries it close to the shore. The sand is sprayed onto a beach with the intent of widening the beach and increasing its height. The process of beach nourishment can be expensive, and it works best when the sand will stay in place for a long time. In some areas, winter storms have removed the sand added by the nourishment process within a single year.

Background

The ocean is in constant motion, fueled by currents, winds, tides, and waves. Every time you visit California's coast, you witness the effects of the powerful forces of ocean waves and currents (whether or not you can see them at the time). Currents usually can't be seen from the surface, but you can see waves as they break on the beaches, cliffs, or just offshore over submerged reefs. The word "wave" is used to describe an actual swell of water, as well as energy that moves through water.

Tsunamis. Waves can be caused by wind, undersea volcanic eruptions, or earthquakes, though most waves are caused by wind. Those caused by volcanic activity or earthquakes are called "tsunamis." A tsunami is a series of sea waves most commonly caused by an earthquake beneath the sea floor. In the open ocean, tsunami waves travel at speeds of up to 600 miles per hour. As the waves enter shallow water, they increase in height. The waves can kill and injure people and cause great property damage where they come ashore. The first wave is often not the largest; successive waves may be spaced many minutes apart and continue arriving for a number of hours.
Since 1812, the California coast has had 14 tsunamis with wave heights higher than three feet; six of these were destructive. The worst tsunami resulted from the 1964 Alaskan earthquake—it caused twelve deaths and at least $17 million in damages in northern California. Evidence suggests that large earthquakes capable of producing large tsunamis recur every two or three hundred years (California OES Earthquake Program, Earthquake Education Center, Humboldt State University). For information on what to do in case of tsunami, check this web site: *www.wsspc.org/tsunami/CA/CA_survive.html*

Surface Waves and Currents. Though both are powered by wind, waves and currents are different from each other. Waves transfer energy across the ocean surface from one part of the ocean to another. Surface currents are powered by the frictional drag of the wind on the ocean's surface, can be swift, sustained, and river-like, and are responsible for mixing water and transporting sediments and nutrients long distances. Surface currents are quite regular, and are formed in conjunction with major global wind patterns, whereas surface wave direction and velocity are affected by changing winds during storms and vary widely. As waves transfer the energy to the sea surface, the ocean water moves up and down, like a float bobbing on the water. The stronger and longer the duration of the wind, and the greater the distance over which it blows, the larger the waves. When a wave enters shallow water, it starts to feel the ocean floor and the lower part of the wave slows down while the upper part continues until it topples over. This is when it "breaks" on the beach. Breaking waves (or "breakers") also stir up sand and move it onto the beach.

Erosion, Transport, and Deposition. Currents and waves also move sediments along the shoreline. Removal of the sediments is called *erosion*. Movement of the sediment is called *transport*. When the sediments settle out on a beach, it is called *deposition*. During storms, waves and currents have more energy and more sand is removed. *Coastal erosion* is a natural process that occurs as cliff, bluff, or beach erosion. Coastal erosion is a fact of living on the coast, though many people (usually home and business owners who have valuable ocean front property) see it as a problem that must be contended with. Deposition causes some harbors to be filled with sand, and they then must be dredged regularly.

Building Beaches. Coastal engineers can "build" the size of their beach by constructing groins. An unfortunate side effect of jetties and groins happens on the beaches downcurrent of the structures. As the water moves with the longshore current, it carries sand with it. The water and sand hit the side of the groin, and the sand builds up on the beach that is upcoast of the jetty or groin. But, this means that the beach on the other side of the jetty or groin gets less sand, as the sand is stopped by the groin. What property owners do on their property can affect beachside property nearby and even public beaches.

Building a Beach Model

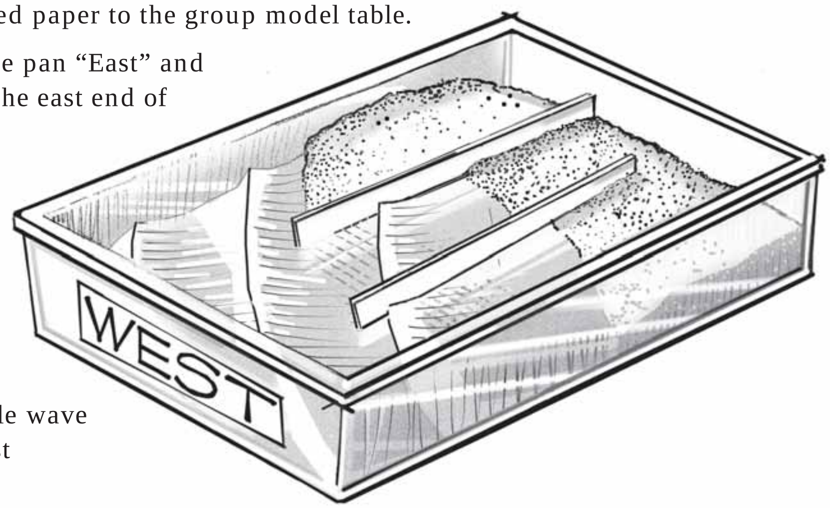
1. Each student brings a pencil and unlined paper to the group model table.

2. Using tape, label the shorter sides of the pan "East" and "West." Pour up to 4 inches of sand into the east end of the pans.

3. Gently add tap water up to 2 inches deep on the west end of the pan.

4. Fold your paper into fourths. Draw experimental model on one section and label it *Diagram #1* (use one-fourth of the paper).

5. Student #1 uses a ruler to create a gentle wave action in the pan, in a general west-to-east movement.



6. All students draw how the model appears after wave action (*Diagram #2*). What are the effects of erosion? How has the coastline changed?

7. Student #2 positions the sand to its original model configuration. Student #3 sets two to three rulers on-edge into the sand lengthwise about 4 inches apart, representing groins. Student #4 uses a ruler to create the same gentle west-to-east wave movement. What happens in between the groins? What happens to the shoreline? Draw *Diagram #3*. Now, Student #5 makes waves coming from the northwest. Do the beaches in between the groins change? All students draw *Diagram #4* to indicate how the beaches look after completing this wave action.

Grade 6 Activity

Activity 6.3
Rollin' Down the Sand Highway

Did you know there is a highway carrying truckloads of sand down our coast? You can't see it—it's underwater!

Science skills

- Data collecting
- Analyzing
- Hypothesizing

Concepts

- Truckloads of sand are moving along California's coast every hour of every day, driven by currents and waves.
- Human constructions along the coast affect the longshore movement of sand, and can cause beaches to grow or shrink.
- The coast of California is composed of a series of littoral cells that affect the distribution of sand along the coast.

California Science Content Standards

Earth Science

2. Topography is reshaped by weathering of rock and soil and by the transportation and deposition of sediment. As the basis for understanding this concept:

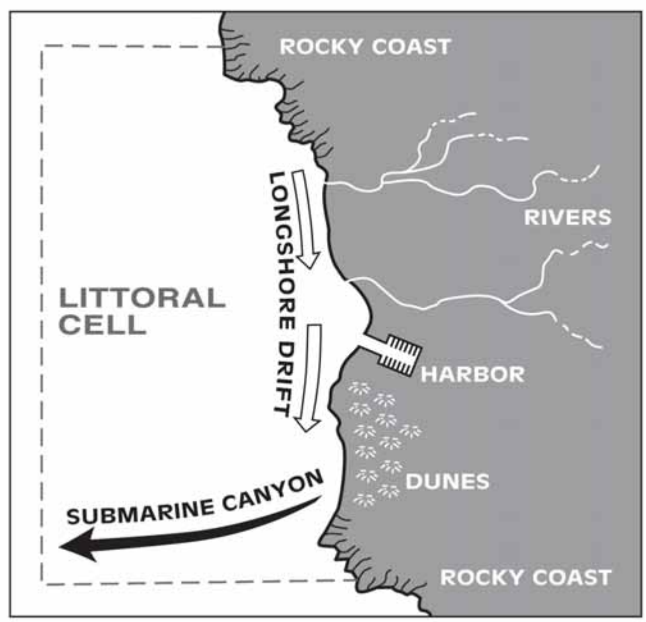
2.a. Students know water running downhill is the dominant process in shaping the landscape, including California's landscape.

2.c. Students know beaches are dynamic systems in which the sand is supplied by rivers and moved along the coast by the action of waves.

Background

Most everybody loves the beach and the sand between their toes. Beaches are an invaluable social, economic, and cultural resource in California. Southern California's beaches are the most popular recreation destination in the state, bringing tourists from all over the world. The sand for these beaches comes primarily from rivers, and is moved down the coast from north to south by longshore currents in most areas. What happens to this sand directly impacts the size of the beaches both seasonally and over a period of years. Understanding how and where sand moves helps us recognize the changes and impacts of the coastal harbors and structures we build along the coast.

California's coast can be separated into discrete coastal compartments termed *littoral cells* (the littoral zone is the region of shallow water along the shore of a body of water). A littoral cell is a self-contained system that may be bounded by rocky headlands or by a submarine canyon that intercepts the sand as it moves along the coast. Sand, supplied by rivers (80 to 90 percent) and bluff erosion (10 to 20 percent), moves in the system by waves and currents. Waves move sand onshore and offshore, and the longshore current moves sand along the coast.



Most of the sand is delivered to the coast by rivers during winter storms. Once it arrives at the coast, large waves wash ashore and drag the sand seaward where it is deposited in nearshore underwater sandbars (like a deposit in a sand bank!). In the summer, milder waves slowly move the sand that has been stored in the sandbanks back up to the dry beach (a transfer in the bank from the offshore account to the onshore account). Many beaches become narrow in the winter then recover their original width in the summer because of this sand banking system.

The predominant direction of longshore sand movement in California is from north to south. An incredible amount of sand is transported

California Mathematics Content Standards

Number Sense

1.2. Interpret and use ratios in different contexts (e.g., batting averages, miles per hour) to show the relative sizes of two quantities, using appropriate notations (*a*/*b, a* to *b*, *a*:*b*).

Algebra and Functions

2.0. Students analyze and use tables, graphs, and rules to solve problems involving rates and proportions:

2.2. Demonstrate an understanding that *rate* is a measure of one quantity per unit value of another quantity.

2.3. Solve problems involving rates, average speed, distance, and time.

Objectives

Students will:

1. Measure the amount of sand that moves down California's coast.
2. Understand human impacts on sand movement and beach size.

Time to complete

One class period

Mode of instruction

Video, followed by whole class discussion. Students fill out worksheet with calculations, with a whole class discussion wrap up.

Materials

1. Video—*Beach: A River of Sand* (you may borrow it from the California Coastal Commission, *www.coastforyou.org, 800-Coast-4u*)
2. Overhead transparency of "Harbor Breakwaters and Jetties" and "Littoral Cell"
3. Overhead transparency of map of California, or map on wall
4. "Sand Highway" worksheet and "Harbor Dredging Data" table, one per student
5. Overhead projector

Preparation

Order video from Coastal Commission 2-3 weeks in advance of class. Read background material, photocopy overhead transparencies and worksheets.

underwater and along the beach face by longshore currents. Much of this sand ends up in submarine canyons (in which case the sand is gone from the coast forever because it is too deep to be brought up by small waves). Large quantities of sand are also carried by winter waves into harbors. This creates a big problem for the harbors that must be kept at a depth so boats can go in and out. Many harbors maintain an adequate depth by periodically dredging sand, a costly necessity. A few natural harbors in California do not need to be dredged: Bodega, Moss Landing, and Newport, for example. Moss Landing and Newport are between or at the upcoast end of littoral cells, and Bodega has a strong enough tidal flow to maintain an entrance channel. Crescent City, Monterey, Redondo-King, and Dana Point are successful constructed harbors that need little dredging because they are at the beginning of a littoral cell, or south of a submarine canyon.

A delicate balance exists between sand supplies, transport, and losses. Alterations to the system affect this balance. Coastal streams and bluffs, the two main natural sources of sand for our beaches, have been impacted by development in coastal watersheds. Dams and debris basins, in-stream sand and gravel extraction, and streambank and bed channelization have also reduced the sand supplies, particularly in highly urbanized southern California. Coastal armor designed to protect bluff-top coastal structures prevents the sand that would naturally erode from the bluff from reaching the beach.

Activity

1. Ask students, "Did you know that sand travels down the coast of California every day? Have you seen this sand travel? Why not?" Get a prediction from students of how much sand moves along our coast each day.

2. Watch the video *Beach: A River of Sand* with your class. Discuss the video with students; review how the coast is divided into discrete littoral cells with inputs and sinks. Project the transparency of littoral cells on the overhead projector. Tell them that within many of these littoral cells there are harbors that are regularly dredged to keep them deep enough for boats to enter. Without dredging, these harbors would eventually fill up with sand. Lucky for us, since it's because these harbors are dredged that we have a way to estimate exactly how much sand travels down the coast! We can measure the amount of sand that gets dredged out of the harbors—as long as the harbor is north of a submarine canyon or sink, that is. (If it is south of a sink, it may not need dredging—why not?)

3. Hand out a copy of "Harbor Dredging Data" to students. Have students spend some time looking at the numbers on the table. Notice the difference between the amounts of sand dredged from the different harbors. Students then choose a harbor that is located on a part of the coast in which they are interested. Perhaps they have visited beaches in that area, camped alongside or visited a major river that is the main sand-carrying river for the area. Students may do more than one harbor, and more than one student may do the same harbor.

Outline

Before class

1. Order video from Coastal Commission (see "Materials" above).
2. Photocopy overhead transparencies and worksheet.

During class

1. Watch video.
2. Whole class discussion on longshore sand movement.
3. Students complete worksheet.
4. Whole class discussion.

4. On the worksheet, students note the average yearly amount of sand (average sand: cubic yards/year) dredged from the harbor and write it down. Next, they calculate how many dump trucks it would take to move this amount of sand over a year (10 cubic yards per truck: trucks/year), visualizing a freeway of dump trucks full of sand moving down the coast. Students then calculate how much it costs to dredge that sand out of the harbors each year ($5 per cubic yard/year).

Results and reflection

After completing the worksheet, lead a whole class discussion on sand movement and littoral cells. You may use the following questions as a discussion guide.

1. When building a harbor, the Army Corps of Engineers usually builds jetties or a breakwater to protect the mouth of the harbor from big waves entering the harbor and destroying boats. When was the last time you heard about big waves wrecking boats in a harbor? Do these jetties and breakwaters do the job they were intended for? What are some other consequences of building jetties? What happens to beaches north of jetties? What happens to beaches south of jetties? Where would you rather have a house on the beach—north or south of a jetty?
2. Many of California's harbors were constructed before this "river of sand" was understood. If you were to build a new harbor today, where would be an ideal location to minimize dredging?
3. Look at the harbor dredging data. Can you tell which harbors are most likely downcoast from a sand sink such as a submarine canyon? Which harbors are likely downcoast from a major river? Check a map to see if you are right.

Conclusions

Truckloads of sand travel down California's sand highway. The sand travels underwater, moved by currents and waves. Beaches are changed and sometimes replenished by the sand highway.

Extensions and applications

The beaches in southern California, especially San Diego and some in Los Angeles, are suffering from lack of sand due to increased coastal and inland development and river damming. What would you recommend to preserve these beaches? (*One alternative is beach nourishment, a costly but sometimes effective remedy that trucks sand to beaches from areas with lots of sand. Once sand is in place, it may stay for several years.*)

References

California Public Beach Replenishment Study, Department of Boating and Waterways and The California Coastal Conservancy, 2002. *www.dbw.ca.gov/beachreport.htm*

Harbor Dredging data courtesy of Gary Griggs, professor of Earth Sciences, University of California, Santa Cruz (UCSC) and Kiki Runyan, UCSC Earth Sciences graduate student.

Harbor Breakwaters and Jetties

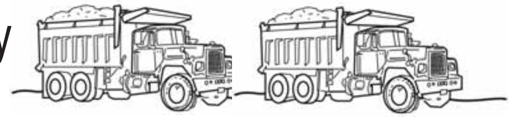
Human activities have impacted our coast. One way our coast has changed is through the alteration of the flow of sand when sand is trapped at large structures such as harbor breakwaters and jetties.

Harbor in Santa Cruz shows sand accumulation upcoast.

Santa Barbara Harbor has a long breakwater. The other structure in the photograph is a wharf, with pilings that do not obstruct sand flow.

Headlands and points serve as natural groins along the coast. They trap sand that accumulates on beaches.

Rollin' Down the Sand Highway



1. Choose a harbor from the data table. Notice some harbors need no dredging at all, other harbors need dredging every day, while others need it only every few years or just once or twice, ever. What makes such a difference? *(Hint: Locate your harbor on a map of California and see if it is near a river. Is the river large or small? Where is the harbor in relation to the river? If you have a map that shows submarine canyons, you will have one clue as to why the sand doesn't build up very quickly.)*

2. For your harbor, look at the average of the amount of sand that has been dredged over all the years the harbor has been in operation. What is the total amount of sand that has been dredged? What is the average amount per year (cubic yards of sand/year)?

A Sandy Problem

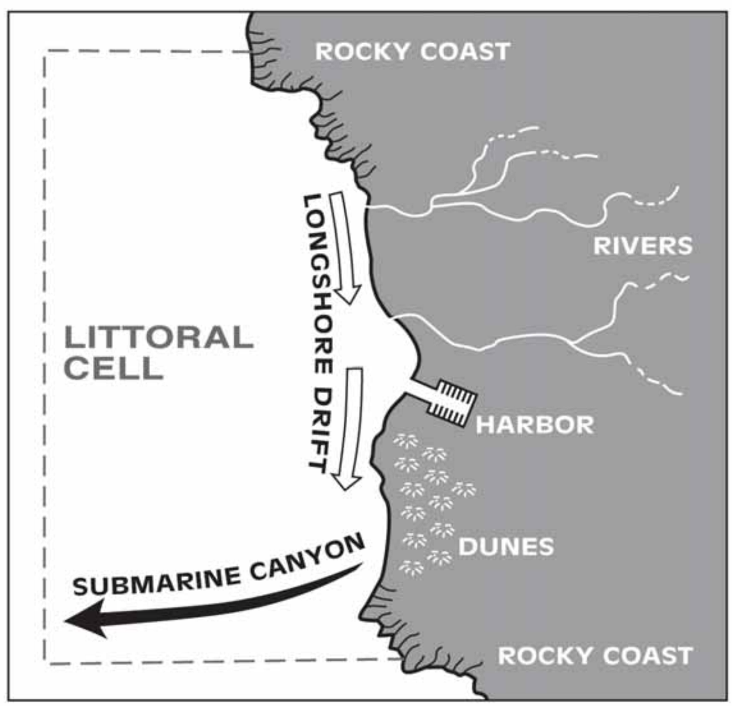
We love beaches, but not in our harbors. How does the sand get there? The predominant direction of longshore sand movement in California is from north to south. An incredible amount of sand is transported underwater by longshore currents. Much of this sand ends up in submarine canyons (in which case the sand is gone from the coast forever because it is too deep to be brought up by small waves).

Large quantities of sand are also carried by winter waves into harbors. This creates a big problem for the harbors that must be kept at a depth so boats can go in and out. Many harbors maintain an adequate depth by periodically dredging sand, a costly necessity. A few natural harbors in California do not need to be dredged: Bodega, Moss Landing, and Newport, for example. Moss Landing and Newport are between or at the upcoast end of littoral cells, and Bodega has a strong enough tidal flow to maintain an entrance channel. Crescent City, Monterey, Redondo-King, and Dana Point are successful constructed harbors that need little dredging because they are at the beginning of a littoral cell, or south of a submarine canyon.

3. Choose a year that is close to the average amount for all the years and use it to make this calculation: One large dump truck can hold 10 cubic yards. How many dump trucks would it take to hold all of the sand dredged from your harbor for one average year (trucks/year)?

4. You are sitting on the beach looking at a calm day on the ocean, but you know there is a lot going on underwater, out of sight. Imagine that all of that sand being carried by the longshore current is actually barreling down the coast in front of you in dump trucks. Over a year's time, how many dump trucks per minute would you see pass by, day and night (trucks/minute)?

5. It costs about $5.00 per cubic yard to dredge sand from harbors to keep them open for boats to sail in and out, and for big ships to conduct their business. How much does it cost each year to keep your harbor open ($/year)?



California Harbor Dredging Data

(in cubic yards)

Year	Crescent City	Humboldt Bar/ Entrance	Bodega Bay	San Francisco	Half Moon Bay	Santa Cruz Harbor	Monterey Harbor	Morro Bay	Ventura Harbor	Los Angeles	Newport Harbor	Ocean-side Harbor	San Diego Harbor
1936	48,449												
1937	27,756												
1938	16,353												
1939	58,396												
1940	0												
1941	0												41'-47':
1942	0												29,868,000
1943	0												
1944	0												
1945	0												
1946	0												
1947	0												
1948	0												
1949	0												
1950	0												
1951	0												
1952	0												
1953	0												
1954	0	1,049,574											
1955	0	550,450		1,429,500									
1956	120,466	161,300		309,000									
1957	0	241,000		595,000									
1958	0	243,000		626,000									
1959	0	198,700		3,840,000	Built: no								
1960	0	400,000		763,000	dredging								
1961	0	322,500	302,821	875,000	since								
1962	0	742,500	0	1,145,000									
1963	0	954,500	0	842,000								3,615,175	
1964	187,372	568,788	0	581,000					191,000				
1965	0	362,000	0			70,000			180,000				
1966	0	575,600	0			34,000			143,000			684,000	
1967	0	527,500	0			57,000			239,000			177,910	67'-'76:
1968	0	473,100	106,561			60,000		406,891	257,000			433,890	3,485,000
1969	0	534,000	0			79,000		0	1,883,000			353,000	
1970	0	370,000	0			94,700		0	325,000			0	
1971	0	220,500	0			108,300		0	1,113,000			300,000	
1972	0	405,500	0			90,000		0	17,000			0	
1973	0	319,000	0			109,000		0	1,193,820			346,760	
1974	0	390,500	0			60,000		352,257	420,000			0	
1975	0	381,500	0	1,430,920		91,000		0	160,000			507,712	
1976	61,013	234,800	0	887,254		98,000		0	152,000			459,888	
1977	0	369,000	0	310,000		199,000		0	911,000			0	
1978	0	304,500	0	761,000		55,000		0	496,000			306,470	5,880,000
1979	0	193,098	0	843,500		162,000		0	1,021,500			0	0
1980	0	224,562	69,609	778,635		190,300		596,454	320,000	356,000		0	0
1981	0	465,500	0	0		187,700		0	812,900	0	81,000	461,000	0
1982	125,319	389,030	0	915,816		138,200		0	1,186,000	0	0	0	0
1983	40,221	1,009,876	0	635,500		154,500		0	1,427,000	0	0	406,305	0
1984	0	494,002	0	77,969		79,500		597,000	1,332,900	0	0	473,000	0
1985	0	958,071	0	890,550		145,200		0	0	0	0	0	0
1986	0	991,339	0	903,200		207,000		0	910,000	0	0	393,012	0
1987	0	402,179	0	686,159		206,400		460,000	363,100	0	0	0	260,313
1988	62,192	715,022	0	667,650		230,400		0	800,000	0	0	251,680	130,000
1989	0	429,623	0	198,150		214,500		0	230,314	0	0	0	97,470
1990	0	321,337	0	524,150		173,600		475,321	271,913	0	0	248,970	0
1991	0	410,000	69,082	272,287		163,300		0	377,183	0	0	0	0
1992	0	230,067		441,870		220,600		125,000	524,702	0	0	187,725	0
1993	37,487	651,246		417,672		124,300		0	486,478	0	0	0	0
1994	0	484,721		886,588		234,400		637,000	470,000	0	0	482,642	0
1995	0	635,304		294,070		170,700		1,040,491	271,357	47,022	0	176,107	0
1996	0	474,888		1,008,996		101,900		0	833,000	0	0	162,107	118,563
1997	0	458,693		480,775		118,200		63,009	449,128		0	128,516	
1998	0	632,740		398,758		399,300		115,388	741,975	122,930	268,403	254,000	
1999	35,000	309,274		268,076		317,900		134,234	639,173			172,334	
2000		648,329				262,300		236,883	818,477			282,000	
2001						195,050		180,467	654,000				
Ave.	**12,813**	**464,764**	**17,680**	**722,222**	**0**	**151,412**	**0**	**159,423**	**593,893**	**29,220**	**19,411**	**218,544**	**341,387**

Notes