EXERCISE 11

Coastal Hazards

INTRODUCTION

Coastal zones are among the most highly populated regions on Earth. In the United States, it has been estimated that about 80 percent of the population lives within 50 miles of a coast. Worldwide, the number is probably 50–60 percent. Coasts, therefore, have great potential for either good or bad interactions between natural processes and human activities. The number of people living near coasts will rise in the future, both as world population rises and as more people move to cities, many of which are near coasts.

Processes in coastal zones are distinct from other geologic processes such as earthquakes, volcanoes, floods, or landslides, in that coastal processes are always active. Between earthquakes there is no shaking. Between coastal storms, however, both water, in the form of waves and currents, and sediments, in the form of sand (if we are looking at a typical beach), are continuously in motion. Indeed, coastal zones, like rivers, can be thought of as integrated systems of both water movement and sediment movement. Coasts, of course, can also be impacted by other geologic processes such as landslides, river and coastal floods, earthquakes, and volcanic eruptions.

Thirty of the 50 states in the United States are considered coastal states; that is, they have either marine or Great Lakes shorelines. Nearly all of these states have some coastal areas that are experiencing moderate to severe erosion problems (Williams et al., 1990), as shown in Figure 11.1.

Coasts are highly energetic zones, where dynamic processes related to water and wind interact with land-related processes. Natural and human activities impact both water and land processes. Table 11.1 summarizes the causes of coastal land loss. Note that sediment transport, and, in some cases, volcanic eruptions, can also lead to coastal land gain.

Long-term observation of the interactions of people and coasts has led to the development of several principles, which are listed in Table 11.2.

The nature of coastal issues also depends on whether a coast is predominantly broad sand beaches or narrow beaches below steep cliffs. A broad sand beach will be more vulnerable to high waves, storm surges (water pushed toward shore by the force of winds), and tsunamis, as it will let the waves travel further inland. A steep cliff will break up waves before they can travel inland. In some areas, one type of coast will dominate for many miles; in other areas coasts are diverse assemblages of rocky cliffs, regolith bluffs, and small pocket beaches of sand or gravel.

Worldwide sea-level rise, attributed partly to global warming, has magnified the problems of the ocean coasts in recent years. Natural long-term fluctuations in lake levels have caused problems for coastal installations and transportation systems on large lakes.

In this exercise, we look at shoreline erosion (Part A) and lake level trends (Part B) in the Great Lakes, tsunami hazards along the west coast (Part C), and storm and/or hurricane-related geologic hazards along the east and south coasts (Part D). There is a wide range of vulnerability of oceanic coasts to sea-level rise. Throughout these exercises, look for causes listed in Table 11.1 and applications of the principles in Table 11.2. Note that the cases in this exercise are general examples. Should you ever decide to live along a coast, site-specific investigation of water, beach, and land processes will help you assess the specific risks you will face.

PART A. COASTAL EROSION, LAKE ERIE

In many areas along the shores of the Great Lakes, shore and bluff erosion present serious hazards to structures. In this part of the exercise we examine recession rates on the south shore of Lake Erie. (Refer to Figure 11.1 for the location of Lake Erie.)

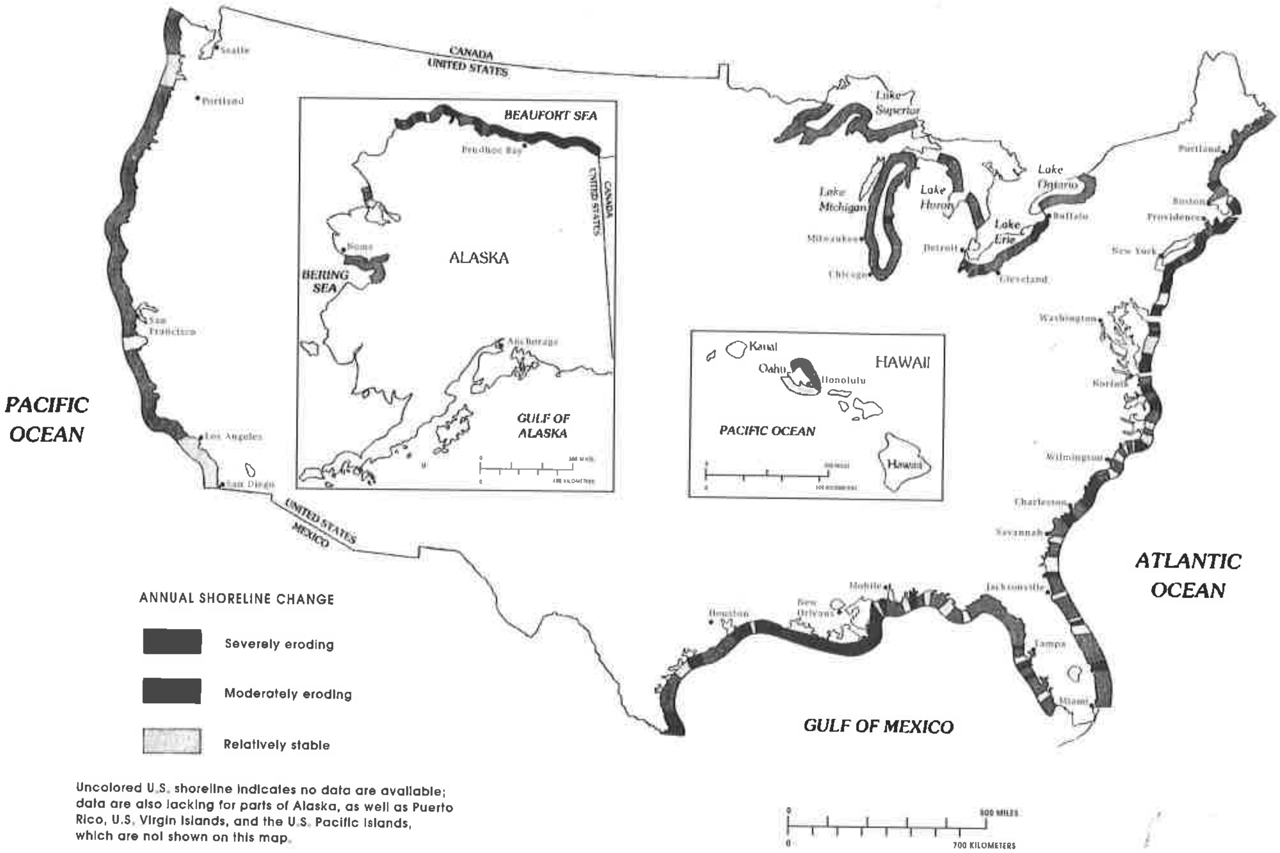


FIGURE 11.1 Annual shoreline change due to erosion in 30 states (Williams et al., 1990, and others).

TABLE 11.1 Primary Causes of Coastal Land Loss

Natural Processes	
Agent	**Examples**
Erosion	waves and currents storms landslides
Sediment Reduction	climate change stream course changes source depletion
Submergence	land subsidence sea-level rise
Wetland Deterioration	herbivory freezes fires saltwater intrusion
Human Activities	
Agent	**Examples**
Transportation **Coastal Construction**	boat wakes, altered water circulation sediment deprivation (bluff retention) coastal structures (jetties, groins, seawalls)
River Modification	control and diversion (dams, levees)
Fluid Extraction	water, oil, gas, sulfur
Climate Alteration	global warming and ocean expansion increased frequency and intensity of storms

TABLE 11.1 Primary Causes of Coastal Land Loss (continued)

Excavation	dredging (canal, pipelines, drainage) mineral extraction (sand, shell, minerals)
Wetland Destruction	pollutant discharge traffic pumping-induced saltwater intrusion failed reclamation burning

Modified from http://pubs.usgs.gov/of/2003/of03-337/intro.html (downloaded September 17, 2007)

TABLE 11.2 Principles of Interaction of People with Coasts (Keller, 2000)

- Coastal erosion is a natural process that becomes a hazard when people build along the coast.
- Any shoreline construction causes change.
- Stabilization of the coastal zone by engineering protects the property of a few people at the cost to many (through state and federal taxes and emergency assistance).
- Engineering structures that are designed to protect a beach can instead, given enough time, contribute to the destruction of the beach instead.
- Once engineering structures are built, it can be very difficult to reverse their impacts.

Over 3 million people live in the Ohio counties bordering Lake Erie. Land loss due to shoreline erosion is a critical problem for those living immediately adjacent to the lake, with millions of dollars of property damage occurring annually.

The 220 miles of Ohio shore is made up largely of regolith comprised of glacial till, clay, and sand, plus resistant limestone and dolostone bedrock exposures in the Catawba and Marblehead peninsula area at the western end of the lake and shale exposures in the Lorain and Cleveland area in the west central part of the lake. Wetlands, low bluffs, and gently sloping shores characterize the western one-third of the coast. Sandy beaches generally overlie clay deposits along the shore in this area.

The low relief and location of the western shoreline make it susceptible to flooding because of wind setup during storms out of the northeast. This wind setup, usually associated with low atmospheric pressure events (in which the water level rises), leads to a phenomenon known as a *seiche,* where water that has piled up at one end of the lake then sloshes back and forth in the elongated basin of Lake Erie. The out-of-phase water levels between Toledo and Buffalo (Figure 11.2) are an example of this phenomenon.

Most of the eastern third of Ohio's Lake Erie shoreline consists of nonresistant lake clay, sand, and glacial till, which form bluffs 10–60 feet high. In this section shoreline erosion has historically been a problem, just as it is today. Whittlesey (1838) reported that most of the Ohio shoreline from the Pennsylvania line to Marblehead had lost an average of 130 feet of land to the lake between 1796 and 1838. Although natural processes such as wave erosion and mass wasting were almost solely responsible for the erosion recorded in the earlier years, structures such as groins, breakwaters, and dikes have had an influence in more recent times (Carter, 1973).

The amount of land lost and rate of shoreline recession over nearly a century (1876–1973) in an area in Lake County, Ohio, east of Cleveland, is shown in a diagram of shoreline locations taken from topographic maps of the area (Figure 11.3). Aerial photographs

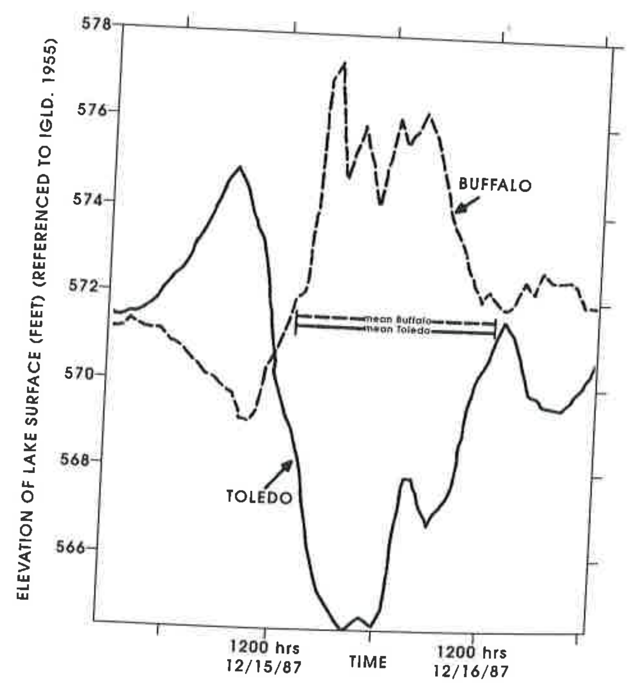


FIGURE 11.2 Water-level curves for Buffalo and Toledo during the storm of December 15–16, 1987 (Fuller, 1988).

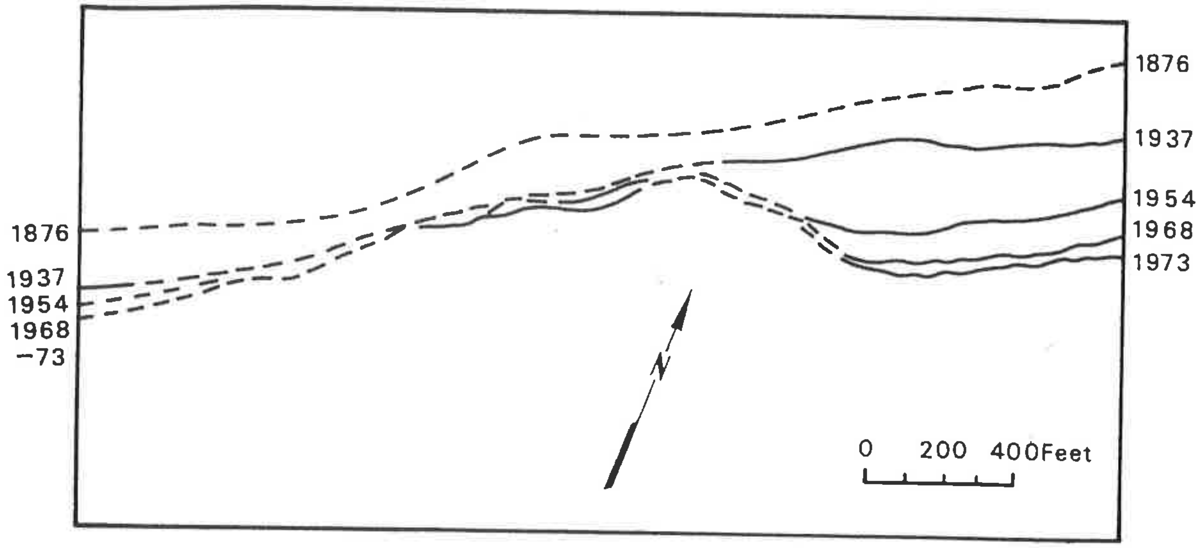


FIGURE 11.3 Shoreline retreat, 1876–1973, Lake County, Ohio (Carter, 1976).

taken at two different times, in 1954 and in 1973 after 19 years of erosion (Figure 11.4), show the changes for the same area of the coast.

Between 1954 and 1973 a portion of the shore eroded away. Shore erosion occurs through the combined effects of waves and currents. Waves, especially during storms, attack the bluffs along the shore, causing them to fail. (See Exercise 8.) Waves and wave-formed currents transport the sand along the shore. These longshore currents flow in a predominant direction. Any obstruction traps the sediment carried by the currents on its up-current side (the side from which the current is coming). On the down-current side of the obstruction the currents pick up a new load of sand. Because sand, in the form of a wide beach, is an effective buffer against storm waves, groins cause deposition of sand that slows bluff erosion on the up-current side. On the down-current side additional erosion occurs.

QUESTIONS 11, PART A

Refer to Figure 11.1 to answer Questions 1 and 2. For Questions 7 and 8 you will need a sheet of tracing paper the size of the photos (about 4″ by 8″). (Questions 7–18 are modified from Kennedy and Mayer, 1979.)

1. Which coast of the United States (north, south, east, or west) has the least problem with severe erosion?

2. According to Figure 11.1, which Great Lake has the highest percentage of U.S. shore in the severe erosion category?

3. Many factors affect rates of coastal erosion (see Part B). List three.

4. Refer to Figure 11.2. What was the maximum change in feet from high to low water level at Toledo during the December 1987 storm?

5. If the water-level differences between Buffalo and Toledo were due mainly to atmospheric pressure differences, over which end of the lake would the low-pressure area have been at midnight on December 15, 1987?

6. Refer to Figure 11.3 and determine average annual rates of coastal retreat between 1876 and 1937. Measure distances perpendicular to the coast and use the scale given. Record measured distances, too.

a. Half-inch from the east margin of the diagram? Rate = _______ ft/yr

b. Half-inch from west margin of the diagram? Rate = _______ ft/yr

c. Coast with the least change? Rate = _______ ft/yr

7. Compare the 1954 and 1973 photos (Figure 11.4). Describe the physical and cultural changes that have occurred along the coast. (The photos are almost the same scale; Figure 11.8 shows lake level change.)

8. The straight objects jutting into the water are *groins*, structures designed to protect the bluffs by trapping sand and gravel. What changes have occurred from 1954 to 1973 in the number of groins?

9. List the physical processes involved in the changes that have occurred on this coast. Our next task is to compare the 1954 and 1973 shorelines and bluff bases by sketching on tracing paper these and other coastal features. (Another approach is to make a transparency copy of the 1954 photo, overlay it on the 1973 photo, and mark in pen the changes as described for the tracing paper technique.)

10. Cover the 1954 photo with a half sheet of tracing paper and secure it with paper clips or removable masking or clear tape.

a. Outline major streets within an inch of the east–west road along the top of the bluff, to provide reference marks.

b. With a sharp pencil on the tracing paper, trace the base of the bluff with a solid line and the shoreline with short dashes. Label the figure "1954."

c. Draw and label the groins.

d. Now construct six parallel reference lines approximately perpendicular to the coast on the tracing paper so that we can measure the actual change in the position of the bluff

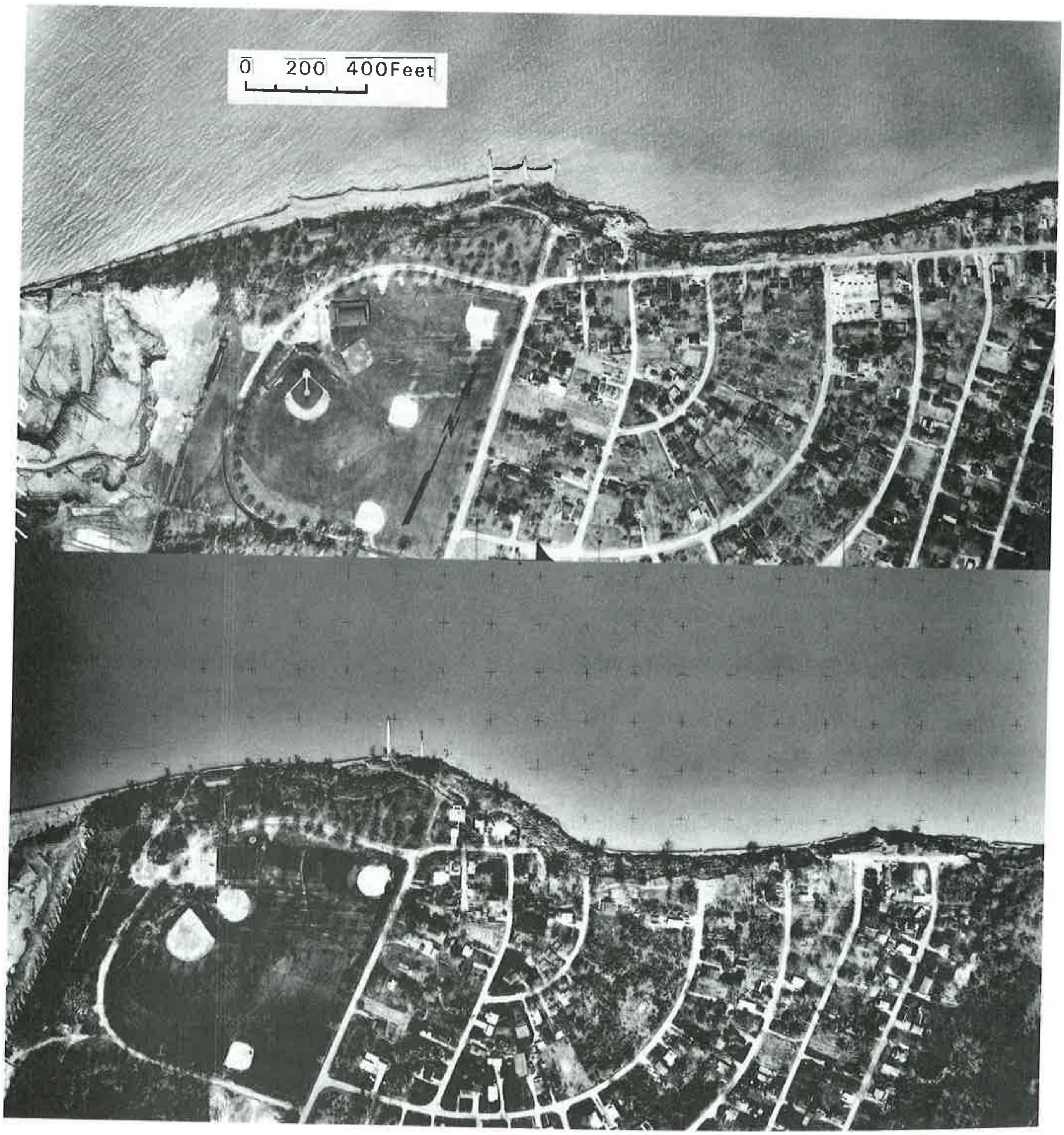


FIGURE 11.4 Aerial photographs for 1954 (top) and 1973 (bottom) of Painesville Township Park, Lake County, Ohio (Ohio Department of Transportation).

base. Draw the first line parallel to and along the largest groin. Mark this line C. Draw two more parallel lines (A and B) one-inch apart to the west. Draw and label three lines (D, E, F), again parallel to line C and one-inch apart, to the east.

e. Remove the 1954 tracing paper and place it over the 1973 photo. Align the streets where you can, so the tracing and the photo can be accurately compared.

f. Using a colored pencil, trace the base of the bluff with a solid line and the shoreline with short dashes. Label the colored-pencil lines "1973."

11. What is the maximum width of beach lost between 1954 and 1973?

12. Shade the area between the 1954 and 1973 solid lines representing the base of the bluff. What does the shaded area represent?

13. Compare and explain the changes in the coast west and east of the groins.

14. From your observations of the beach in the top photo and the net change in the coast, what direction does the dominant longshore current flow?

15. What really protects the bluffs along the coast from the energy of the waves when groins are installed?

In this part of the exercise we will use the changes in the position of the base of the bluff, as measured along the six reference lines, to determine the rate of recession of the coast and to predict the future position of part of the coast.

16. At each of the reference lines (A–F) on the tracing paper or overlay, measure the distance between the solid lines (base of the bluff) you drew for 1954 and the lines you drew for 1973. Use the scale given in the photos to measure the distances. Record the distances in the appropriate boxes below.

West lines			East lines		
Profile line	**Distance between 1954 and 1973 bluffs, in ft**	**Rate of bluff change, in ft/yr**	**Profile line**	**Distance between 1954 and 1973 bluffs, in ft**	**Rate of bluff change, in ft/yr**
A			D		
B			E		
C			F		
Average			Average		

17. Divide each measured distance between 1954 and 1973 bluffs by 19 years (the time between 1954 and 1973) to obtain the average annual rate of change in the position of the bluff for each profile line. Record these data in the indicated spots in the table in Question 16.

18. Determine the average distance and rate for the western and eastern part of the coast. What geologic processes can explain the differences in the average rates?

19. Assuming the annual rates determined at the two reference lines with the most rapid recession, calculate how much recession would be expected at these lines by 1993.

a. At line _____, the recession in feet expected between 1973 and 1993 is _____

b. At line _____, the recession in feet expected between 1973 and 1993 is _____

20. Plot on your tracing paper map, using long dashes, the expected 1993 coastline between the two lines with the most rapid recession. You have now used your understanding of past geologic processes to predict future changes. Since 1993 is now past and a photograph is available (Figure 11.5), you can determine how close your prediction is to the actual change that occurred.

21. Place your tracing paper map over the 1993 photograph (which is approximately the same scale), and use another color to draw a solid line to mark the location of the base of the bluff in 1993.

FIGURE 11.5 Aerial photograph taken in 1993 at Painesville Township Park, Lake County, Ohio (Ohio Department of Natural Resources).

22. Describe the differences between the actual recession and the recession that you predicted. What are possible reasons for the differences, if any?

23. What were the average annual recession rates at the two lines that had the most rapid retreat between 1973 and 1993?

a. At line _____, the recession rate in feet/year between 1973 and 1993 was _____

b. At line _____, the recession rate in feet/year between 1973 and 1993 was _____

24. Compare the position and number of houses in the 1954, 1973, and 1993 photographs. What changes occurred?

25. How do the average annual rates for recession of the bluffs for the periods 1954–1973 and 1973–1993 compare with the rate of recession from 1876–1937? What factors might explain the differences?

26. If installation of the groins was a factor in the different rates, when do you think they were installed? _____ Explain. Refer to Figure 11.3.

27. Many coastal experts have suggested that structures that interfere with longshore drift should not be build along shorelines because they produce net erosion. Do you agree or disagree with the experts? Explain.

28. As a consulting coastal geoscientist, you are asked by the residents of the area for help in solving their problem. What advice do you give them?

PART B. ANNUAL AND LONG-TERM WATER-LEVEL FLUCTUATIONS ON THE GREAT LAKES

Many factors control erosion rates on coasts. In addition to engineered structures, earth material, and wave energy, among others, water level is also important. High-water and low-water levels on the Great Lakes cause problems for coastal communities and transportation systems. The problems associated with high water generally cause the greatest losses for individual homeowners.

Flooding of docks, farmland, roads, and residential areas is the result of high water due to long-term (climatic), annual (seasonal), or short-term (meteorological) conditions. Increased erosion or the potential for it leads to lost property or expensive engineered shore-protection systems. Even recreation is impacted

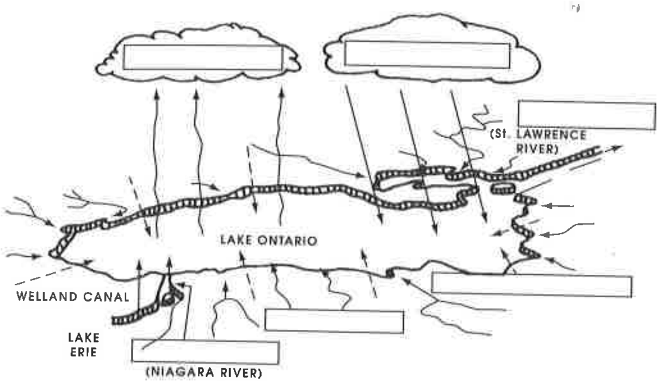


FIGURE 11.6 Factors affecting lake levels. Boxes represent processes described in the text. Dashed lines represent groundwater discharge (Freeman and Haras, n.d.).

by fluctuations in water level. High water reduces clearances under bridges, covers beaches, and reduces harbor protection; low water results in damage to boats, makes harbors inaccessible, reduces shipping capacity, and impacts some domestic water systems. Both high- and low-water conditions can impact wetlands and fishing.

Long-term fluctuations in lake levels are controlled by the climate over the Great Lakes basin. In the period of continuous records for Lake Erie, the variation in lake levels has been slightly more than 5 feet (Fuller, 1987). Annual fluctuations are due to yearly variations in precipitation, evaporation (and temperature), surface runoff, groundwater discharge, inflow, and outflow (Figure 11.6). If losses and gains to the lake do not balance, then water-volume and lake-level changes occur. In the case of Lake Erie, the much higher than normal levels of the 1970s and 1980s (Figure 11.7) are primarily due to above-normal precipitation in the Great Lakes basin.

QUESTIONS 11, PART B

1. Read the introduction to Part B and enter the processes controlling lake levels in the appropriate boxes in Figure 11.6.

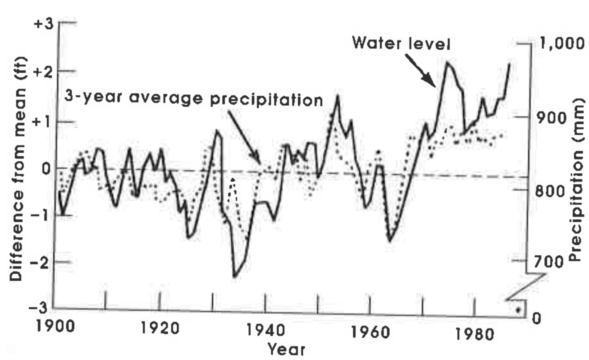


FIGURE 11.7 Annual Lake Erie water levels, 1900–1987, and average precipitation for the Great Lakes Basin (Fuller, 1987, after NOAA).

2. (Web research question) Lakes Huron and Michigan are at low levels. One factor appears to be the enhanced scour at the head of the St. Clair River at Port Huron and Sarnia. Search online for the latest developments and summarize them.

3. In Figure 11.7, the lowest level shown occurred at the time of the "dust bowl" on the western plains. When was this low level of Lake Erie? From the figure, is there any evidence that the evaporation rate from Lake Erie must have been high?

4. On an annual basis, in what months is Lake Erie (and the other Great Lakes) likely to be highest? When is it likely to be lowest?

5. Study Figure 11.8. In what periods (by beginning and ending years) since 1860 has Lake Erie been unusually high? Assume a mean elevation of about 570.4 feet.

6. In what years has Lake Erie been unusually low?

7. What are the highest and lowest annual mean elevations for Lake Erie?

8. What are the hazards associated with high lake levels?

9. Are there any hazards or impacts on society of low lake levels? Explain.

10. From the information gathered in Parts A and B of this exercise, we have seen that the water levels in the Great Lakes are likely to continue fluctuating. Although global warming could change averages and ranges of water levels, in any case erosion is expected to be a problem in some areas. To reduce losses to individual coastal residents and to taxpayers (who pay for roads, water supplies, insurance subsidies, tax deductions for lost buildings, and rescue costs in the coastal zone), expanded land-use planning and zoning of coastal areas by state, provincial, or municipal governments may be warranted. On a separate sheet of paper:

a. Discuss the advantages and disadvantages of a 50-year building-setback zone. With such a setback zone, no permanent residential structures may be installed on the coast within the expected 50-year erosion zone.

b. Also discuss any alternative that would minimize interference with the physical and biological processes along the coast, resource loss, and costs to individuals and to society.

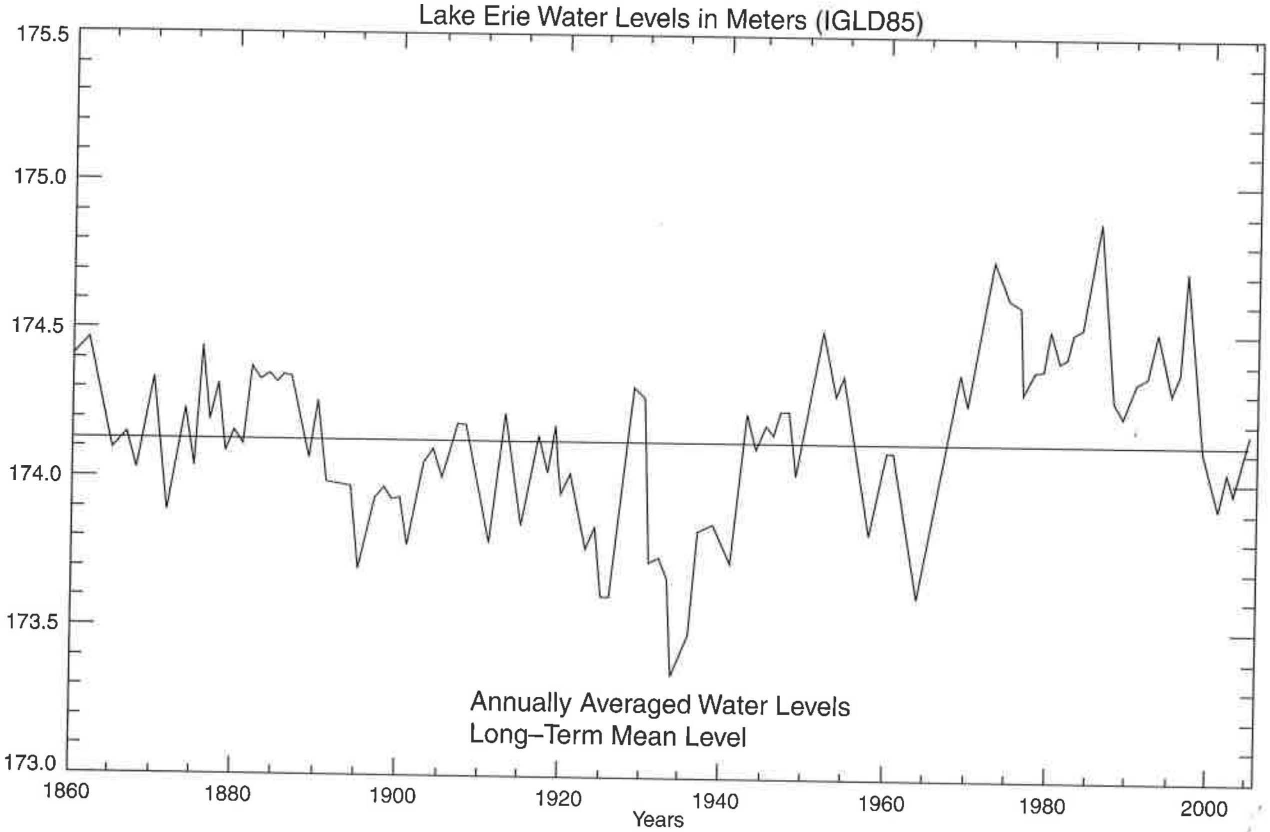


FIGURE 11.8 Lake Erie annual mean water levels, in meters, 1860–2005. (Modified from NOAA)

PART C. TSUNAMI HAZARDS ON THE WEST COAST

Tsunamis

The tsunami of December 2004, in the Indian Ocean, reminded the world about the destructive impacts these waves can have. This tsunami, triggered by a magnitude 9.1 earthquake, killed an estimated 200,000 people. The waves reached heights of 30 meters (approximately 100 feet), and destroyed many buildings and communities.

The size of the rupture zone that was associated with the Indian Ocean earthquake has been approximated by study of the distribution of aftershocks. This rupture zone, when overlaid on a map of the Pacific Northwest (Figure 11.9), shows that a similar earthquake could be anticipated adjacent to the United States. This local earthquake could also trigger a local tsunami. In January 1700, the last time a major earthquake shook the northwest, a tsunami traveled across the Pacific Ocean and was recorded in Japan.

The Pacific coast of the United States is also subject to tsunamis that have been generated by earthquakes elsewhere in the Pacific Ocean. A tsunami that was triggered by the 1964 Alaskan earthquake caused damage along the west coast of the United States. In addition to the amount of energy released by the earthquake and the proximity to the coast, the height of a tsunami at a specific place is influenced by the tidal stage when the waves hit, tidal currents, topography of the land (how much low-lying land is along the shore), changes in topography due to earthquake-related uplift or subsidence, and the bathymetry (depth and shape) of the seafloor immediately offshore.

Coastal Processes

When tsunamis impact barrier islands, spits, and broad, low-sloping coasts, or where they travel far in kind along rivers the destruction of engineered structures and modifications of landforms can be rapid and very significant. Tsunamis can be survived, if individuals are educated about warning signs and actions to take (Atwata and others, 1999). Communities must also be prepared (Samant and others, 2008), for example by having clearly marked evacuation routes.

The plate tectonic setting of the coast of Washington, Oregon, and northern California is generally similar to the plate tectonic setting of the Sumatra earthquake of 2004. In the area of Sumatra, the India Plate is subducting beneath the Burma microplate. In the Pacific Northwest, the Juan de Fuca plate is subducting beneath the North America plate. The Sumatra earthquake had a magnitude of 9.1, and it is anticipated that the Pacific Northwest could have a similar size event, which could also unleash a major tsunami.

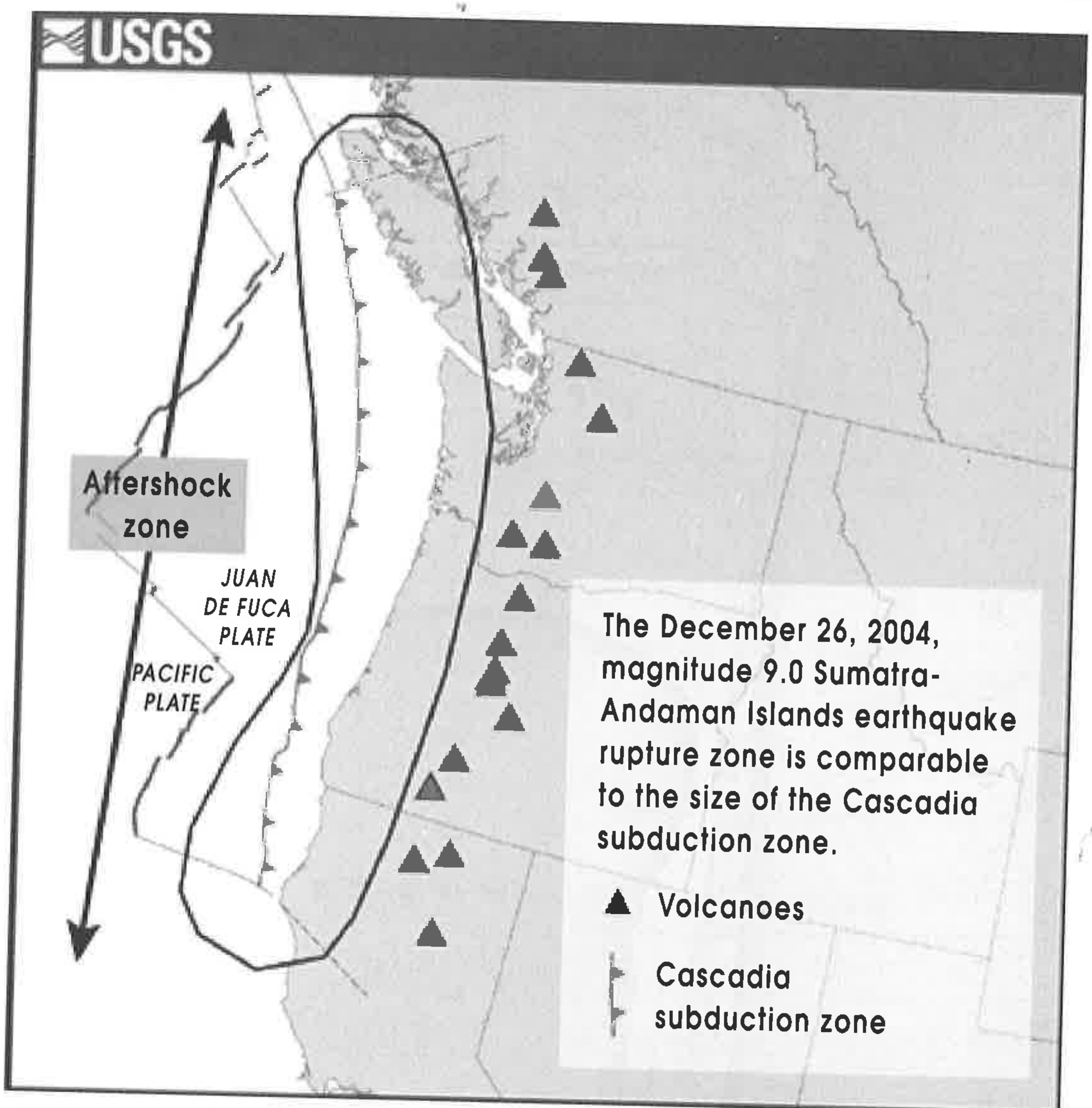


FIGURE 11.9 Sausage-shaped region depicts the rupture zone size of the Sumatra earthquake of December 2004, overlaid on a map of the Pacific northwest. Aftershocks occurred throughout the entire rupture zone. (http://soundwaves.usgs.gov/2005/03/cascadiaLG.gif)

Ocean Shores, Washington, is a popular vacation destination for people from the Tacoma–Seattle metropolitan area. Its population of slightly more than 4,000 residents can increase ten-fold on busy summer weekends. Ocean Shores is proud of its designation as "tsunami aware." It has signs that remind visitors of tsunami hazards, and pamphlets and signs that illustrate tsunami escape routes. The tidal range in this area can be more than 3 m (12 feet).

QUESTIONS 11, PART C

Refer to Figures 11.10 and 11.11, which are two maps of the Washington coast. Figure 11.10 is a 1915 map that shows the Ocean Shores area, and Figure 11.11 shows the same area in 1994. The original maps were different scales, and they have been reduced for use in this exercise.

1. What changes have taken place between 1915 and 1994 in the shape of the coast near Ocean Shores? It is especially important to look in the area of the two jetties at the entrance to Gray's Harbor.

2. Based on these maps, has deposition or erosion been dominant between 1915 and 1994 near Ocean Shores? Near Westport? Explain your evidence.

3. What changes in land use have taken place between 1915 and 1994 in the area shown on these maps?

4. What is the highest elevation of land in Ocean Shores? Westport?

5. What do the changes in land use imply about the risks from storm waves or tsunamis in this area?

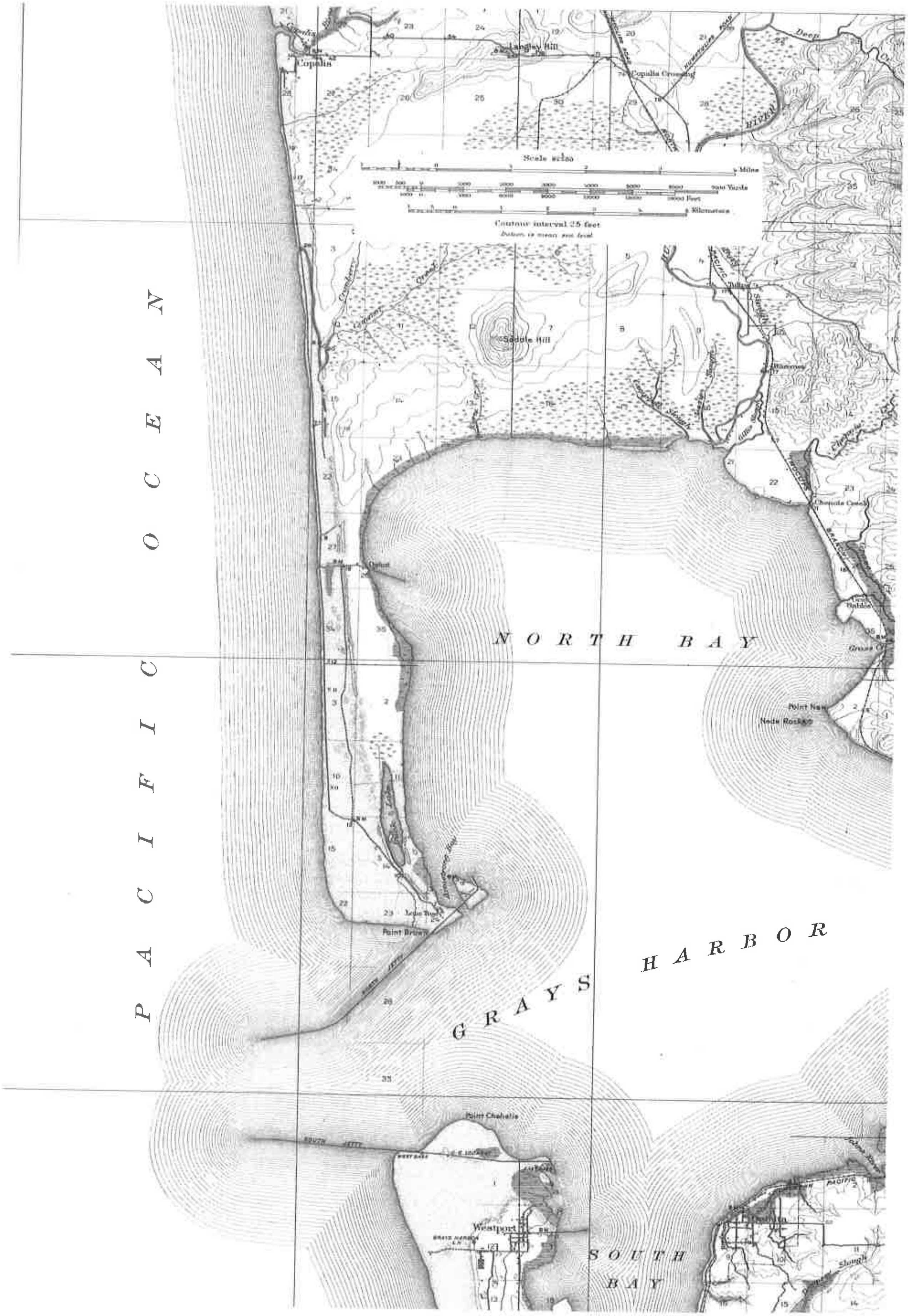


FIGURE 11.10 Ocosta, Washington (now better known as the Ocean Shores area), topographic map from 1915.

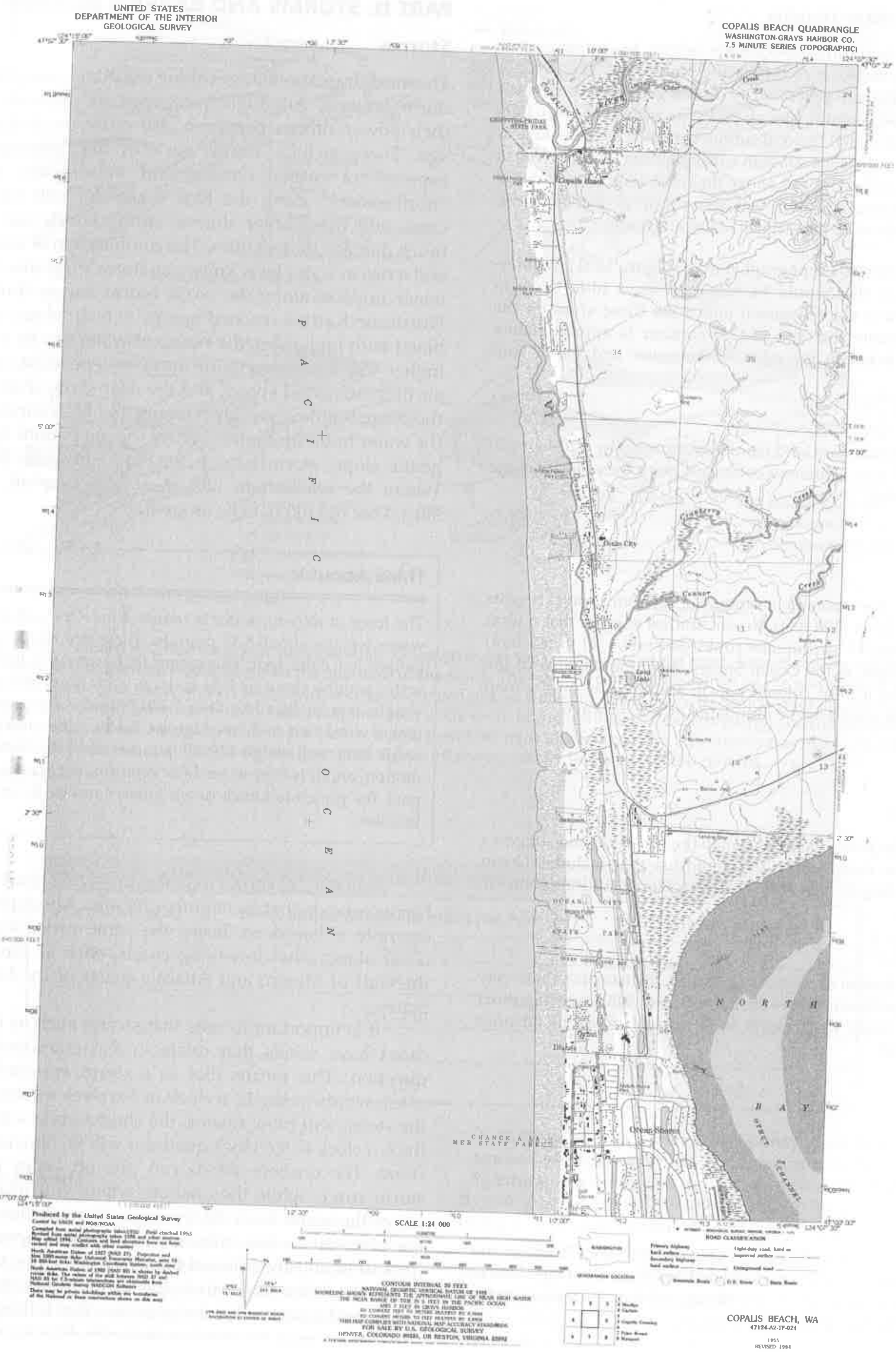


FIGURE 11.11 Ocean Shores, Washington, topographic map from 1994.

Tsunami Wave Heights

There are two different common origins for tsunamis that can strike the coast of the Pacific Northwest. The first are tsunamis that are generated by distant geologic events, such as the Alaska earthquake of 1964. The second are tsunamis that are generated by local subduction zone earthquakes.

After the 1964 Alaskan earthquake, tsunami waves in this area reached 9.7 feet above the water level of the tides at Ocean Shores, and 14.7 feet above tide at Wreck Creek, which is about 20 miles north of Ocean Shores.

6. Study the 1994 topographic map (Figure 11.11) to determine areas that would be impacted by a 10-feet rise in water. Use a colored pencil and mark these areas on the map. Assume that the 10-foot contour is approximately halfway between the edge of the water and the 20-foot contour.

7. How much more land would be impacted by a 20-foot rise in water? Use a different color, and mark these areas on the map as well.

8. After the Sumatra earthquake, tsunami wave heights reached 30 m (100 feet). Recent studies suggest that a local magnitude 9+ earthquake could generate a 20 m (65 foot) wave height at the Ocean Shores, Washington, area of the coast. Use a third colored pencil, and indicate on the map areas that would *not* be inundated by a 20 m wave.

Escape?

9. Use the 1994 topographic map (Figure 11.11) and suggest a route for escape from the peninsula that includes Ocean Shores. Sketch your route below or clearly indicate it on the map.

10. If a distant earthquake generates the tsunami, there may be several hours before the tsunami hits. Will your suggested escape route likely work with several hours of advance warning?

11. If a local major earthquake occurs, it may be less than 30 minutes before a tsunami hits. Will your suggested escape route likely work with less than an hour of advance warning?

12. Given your analyses in Questions 10 and 11 above, are alternative escape routes needed and if so, what alternatives do you suggest for people living, visiting, or working in the Ocean Shores area?

PART D. STORMS AND BARRIER ISLANDS

Storms

The most dramatic changes along coastlines take place during storms. Although hurricanes are dramatic in their power, other storms can also cause much damage. These include storms such as the "pineapple express" of coastal Oregon and Washington and "northeasters" along the East Coast. In both hurricanes and these other storms, strong winds can do much damage to structures. The combination of waves and a rise in water level known as storm surge also has major impacts along the coast. Storm surges during Hurricane Katrina reached nearly 30 feet; when combined with high tides, the runup of water can be even higher. The amount of storm surge is dependent upon air pressure, wind speed, and the near-shore shape of the ocean bottom. Low air pressure and high winds let the water build up higher. Where the sea bottom has a gentle slope, storm surges can build up quite high. Where the sea bottom has an abrupt drop-off, the surges are not likely to be as great.

Think About It

The force of moving water is tremendous. One gallon of water weighs about 8.35 pounds. There are about 7.48 gallons in a cubic foot. This means that each cubic foot of water weighs about 62.5 pounds. A cubic yard of water weighs just slightly less than 1,700 pounds. This means that a wave that is 3 feet high by 3 feet wide, and 100 yards long, will weigh 170,000 pounds. Add the force of motion, and it is easy to see how even smaller waves can pack the punch to knock down houses and easily erode beaches.

Figure 11.12 shows a typical low-lying coast with barrier islands that lie slightly offshore. Although this example is based on Texas, the same processes can occur along other low-lying coasts, such as much of the Gulf of Mexico and Atlantic coasts of the United States.

It is important to note that storms such as hurricanes have winds that rotate in a counterclockwise direction. This means that as a storm approaches a coast, winds in the 12 o'clock to 3 o'clock quadrant of the storm will blow toward the shore, while winds in the 6 o'clock to 9 o'clock quadrant will be blowing offshore. The onshore winds can pile up water into a storm surge, while the offshore winds will relatively lower the water level. So the same storm, where sites are even only a few miles or tens of miles apart, can have dramatically different impacts from surge, waves, and coastal flooding. Study this figure carefully, as it provides the context for the questions that follow.

Hurricanes are rated on the Saffir–Simpson scale. Table 11.3 shows the wind velocities and typical storm surges associated with each magnitude of storm.

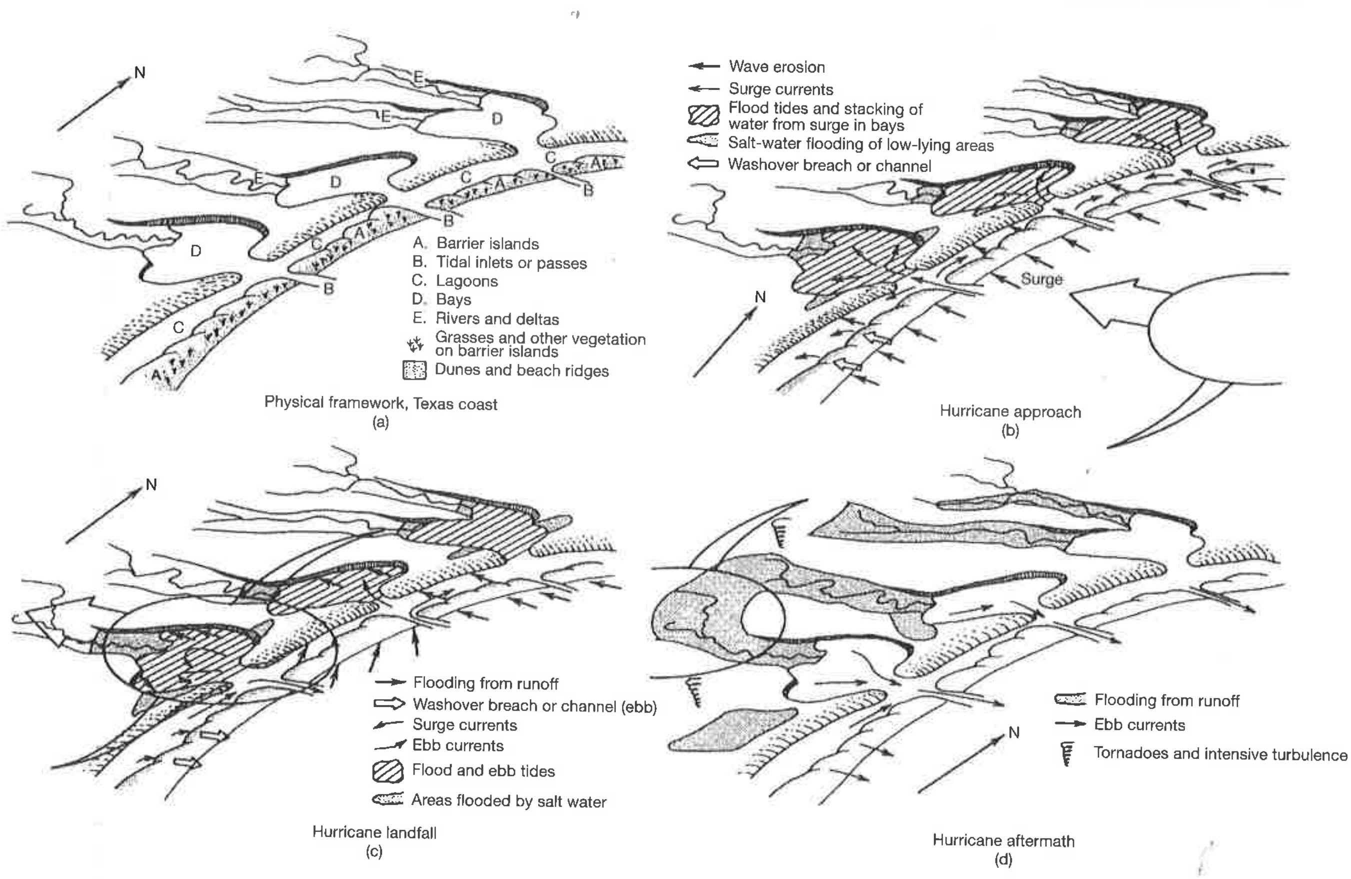


FIGURE 11.12 Impacts of a hurricane as it makes landfall. Figure (a) shows the morphology of the coast. Note that there are no towns shown in this drawing. Figure (b) shows the approach of the storm. The greatest storm surge will be on the north side of the storm in this drawing, as this is where the counterclockwise winds will pile up water the most. Figure (c) depicts landfall conditions. Tremendous amounts of wave erosion continue along the coast, while south of the storm path (in this drawing) ebb currents push water back out to sea. Any houses built along the barrier island, therefore, must be protected not only from waves that come from the sea, but also from currents that flow to the sea from land. Figure (d) shows residual flooding and ebb currents.

(From McGowen et al., 1970)

TABLE 11.3 Saffir–Simpson Hurricane Scale (from http://www.nhc.noaa.gov/aboutsshs.shtml).

Storm Category	Wind Speed Range (in miles per hour)	Typical Storm Surge (in ft)
1	74–95	4–5
2	96–110	6–8
3	111–130	9–12
4	131–155	13–18
5	>155	>18

Barrier Islands

Barrier islands are elongate ridges consisting mainly of sand that extend a few hundred meters to many kilometers along a coast. They have a beach on the ocean side and commonly are capped by sand dunes. Backed by a lagoon, marsh, or tidal flat, these islands are separated by inlets that probably formed during a storm in a wash-over erosion event. Barrier islands are part of a dynamic longshore transport system, migrating by erosion and deposition in response to natural and human factors. In response to changing sediment supply and sealevel rise, barrier islands retreat or decrease in size as their sand is lost to the lagoon or into deeper water offshore. Major changes occur during storm surges that wash over much of an island, causing large structural losses on heavily developed islands. Such losses are not new as revealed by two cases: Hog Island, Virginia, and Isles Dernieres, Louisiana.

In the late 1800s 10-km long Hog Island had a population of about 300, mainly in the town of Broadwater, where there was a "lavish hunting and fishing club ... and 50 houses, a lighthouse, a school, and a church and cemetery." Much of the town was destroyed by a hurricane in 1933, which flooded the island and killed "the protective pine forest." All inhabitants had left by the early 1940s and the town site is now about 400 meters offshore under several meters of water (Williams et al., 1990).

About 120 km southwest of New Orleans, Isles Dernieres is a 32-km long barrier island chain that is "one of the most rapidly eroding shorelines in the world" (Williams et al., 1990). About 500 years ago this area was part of the now abandoned Lafourche delta complex of the Mississippi River. By the mid-1800s the Isles Dernieres were a single wide barrier island, also with a resort community and mature forest. A hurricane destroyed the resort and killed hundreds of people in 1856. Since then the single barrier island was cut by tidal inlets into five islands, which have continued to erode and retreat because of storm erosion and a rise of >1 m in relative sea level (some subsidence occurs). With low relief, some islands are now overwashed by storms and high tides six to eight times per year. Thus they now offer less protection to the wetlands and estuaries behind them than a healthy barrier island would. Between 1887 and 1988, the average erosion rate was 11.1 m/year. Today, the islands continue to decrease in area and migrate landward. These changes help to support the suggestion that Louisiana is losing an acre of coastal land every 24 minutes (O'Malley, 1999). Research continues on this gulfside coastal retreat, which in 1992, the year of Hurricane Andrew, reached 59 m/year.

In the questions for Part D we explore the nature and impacts of hurricanes in the Gulf of Mexico, with examples from the coasts of Texas and New Orleans (Questions 1 and 2) and offshore Louisiana (Questions 3 to 11). At Isles Dernieres, a chain of barrier islands, the focus is on changes to Raccoon Island located at 29° 03′ N, 90° 56′ W, between 1935 and 1994.

QUESTIONS 11, PART D

1. Use Figure 11.13 below, and the data shown in Figure 11.12 and Table 11.3, to analyze the likely impacts of a hurricane on this area.

a. while a category 5 hurricane is still offshore

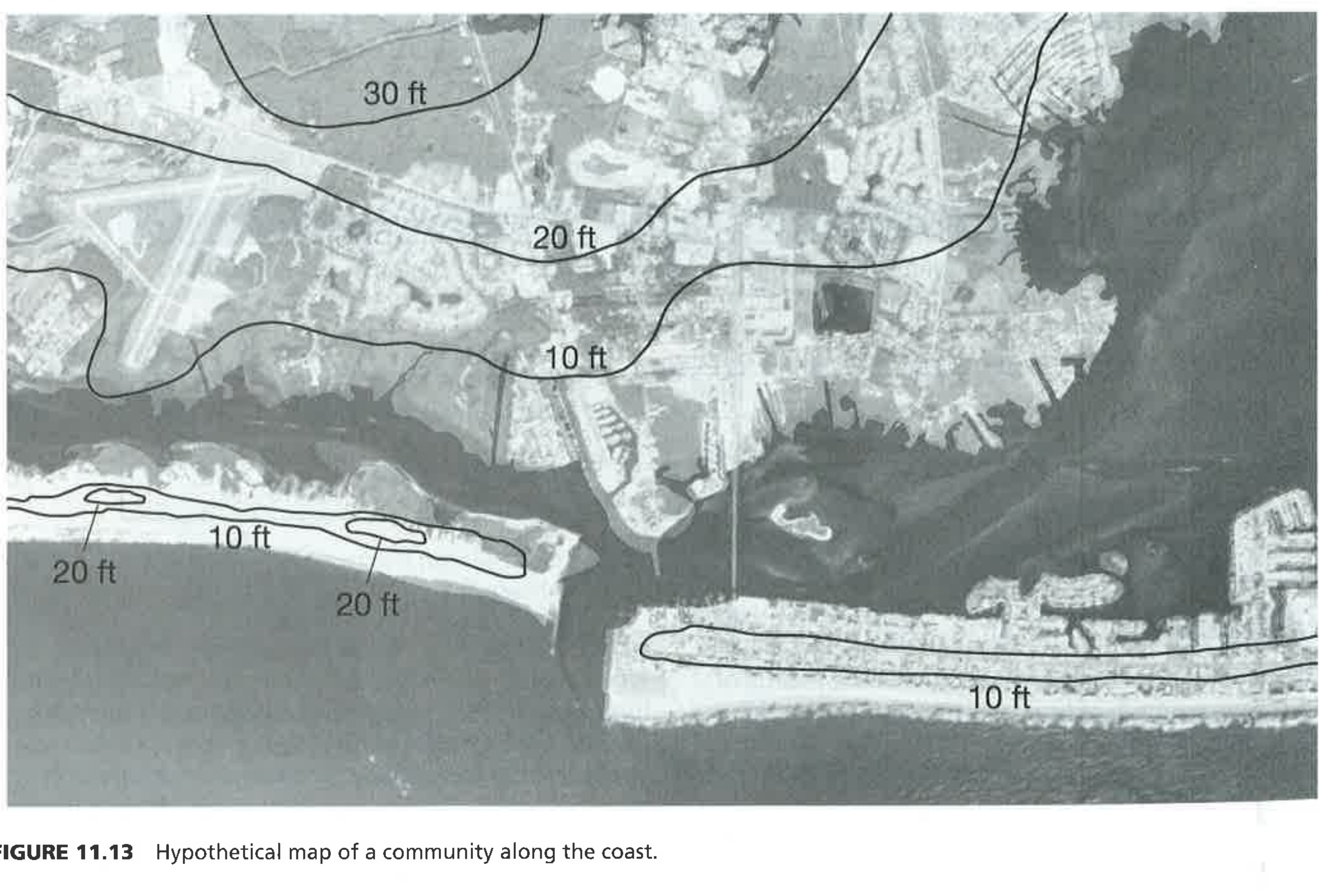


FIGURE 11.13 Hypothetical map of a community along the coast.

b. if a category 2 hurricane hits land east of the town

c. if a category 4 hurricane hits land west of the town

d. after the storm center has passed

2. By 2100, it has been estimated that sea level may rise between 1 and 3 feet.

a. Refer to Figure 11.14 and identify on it additional areas of New Orleans that are likely to be below sea level if a 3-foot rise takes place.

b. What likely impacts from hurricanes could be more severe if a 3-foot rise in sea level takes place?

Examine Figure 11.15a, a map showing changes in Isles Dernieres between 1887 and 1996 (and read the introduction to the barrier islands part of this exercise) to help answer the following. (Note: The Gulf of Mexico is on the south side of the island.)

3. a. How many named islands are there shown at Isles Derniers in 1996? _____ What is the most westerly island?

b. How many major or large islands are shown on Figure 11.15a in 1887?

c. Was Isles Dernieres at one time a single long island?

4. Which of the named islands appear to have lost the most area since 1887?

5. a. In Figure 11.15b (aerial photo mosaic, 1996), identify the following by marking them on the figure:

a sand beach
wetland
spit
shoal

b. What is a pass or coupe?

Figure 11.16 is a compilation of four different editions of the West Derniere, Louisiana, quadrangle, beginning with one

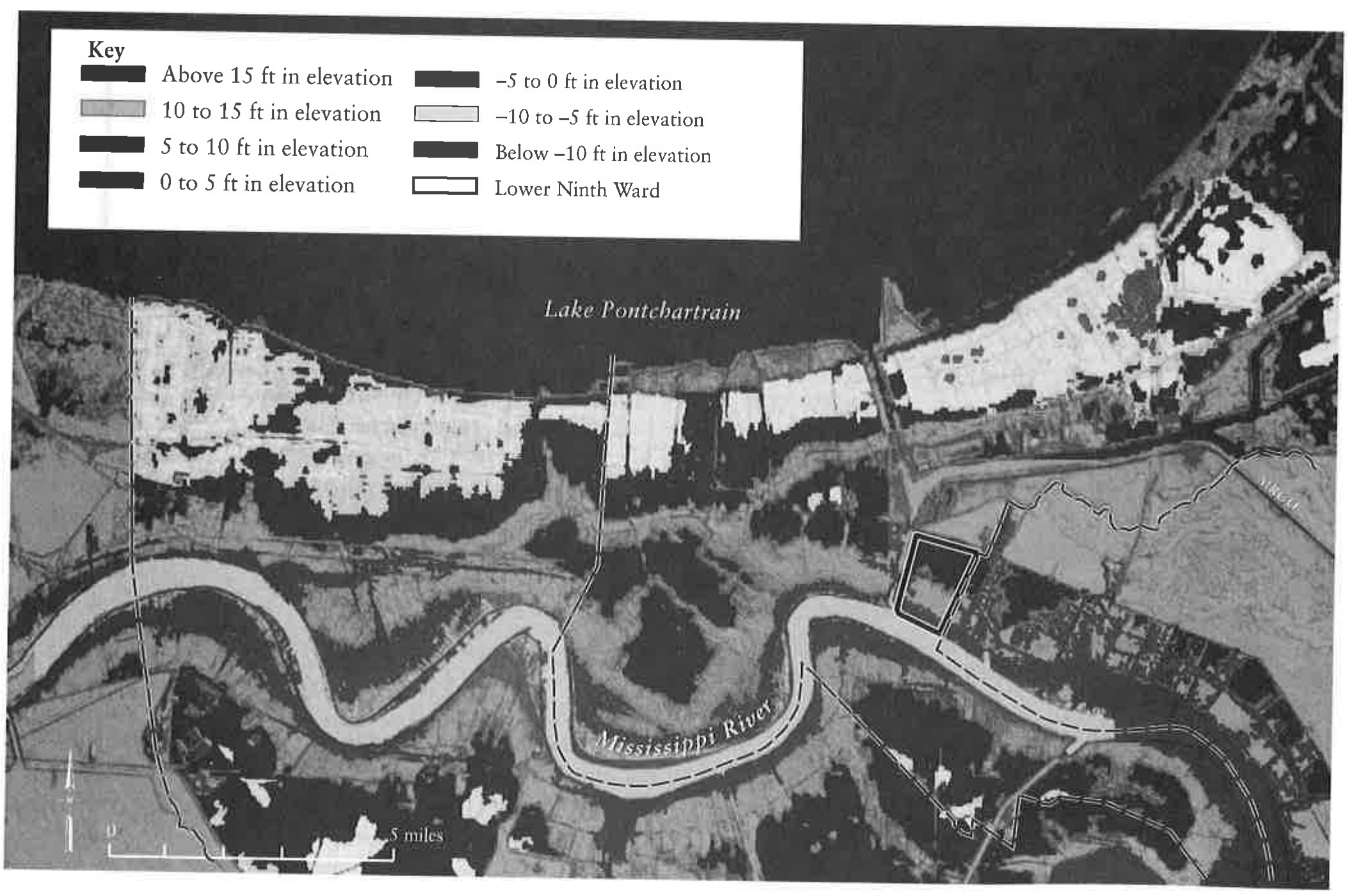
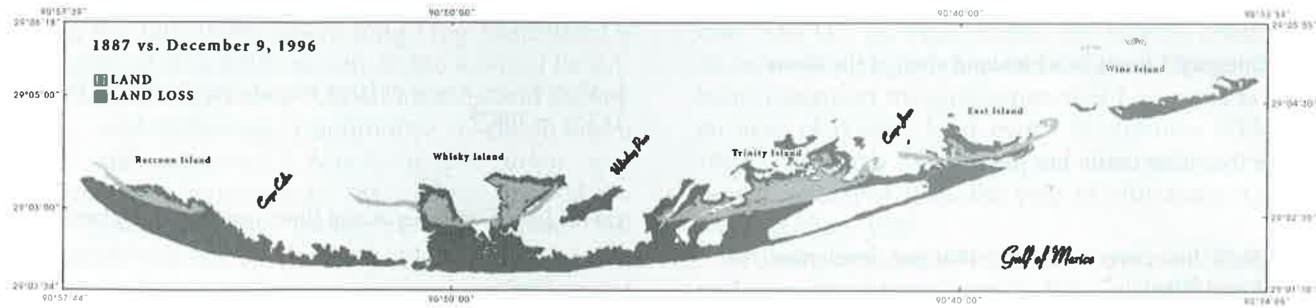


FIGURE 11.14 Topographic map of the New Orleans area. Note that much of the town lies below sea level, and that many of the higher elevations are along levees next to the Mississippi River (From McCulloh, Heinrich, and Good, 2006).

a.



b.

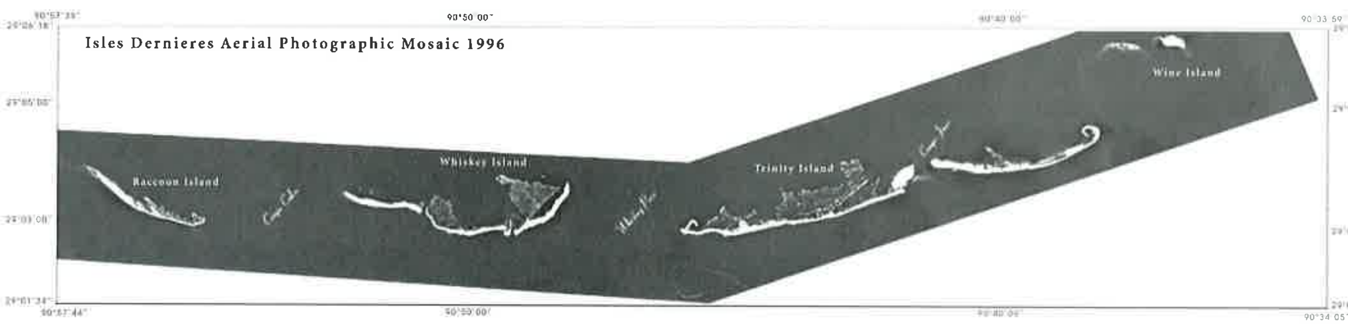


FIGURE 11.15 (a) Coastal change of Isles Dernieres, Lousiana, between 1887 and December 9, 1996, showing land loss and breakup of the island; (b) Aerial photographic mosaic, 1996.

(Adapted from Penland et al., 2003, http://pubs.usgs.gov/of/2003/of03-398/posters/pdf/cont_pdf/id_atlas.pdf)

published in 1935. Note the dashed lines in the 1935 quadrangle that could form a set of equal squares if extended. Each square on the map is numbered and is known as a section. With this set of numbered sections (squares) we have a very good reference system that we can use to trace the changes in this barrier island. Also on this map are named bench marks.

6. a. In the 1935 map (Figure 11.16), what is the section number that contains the word ISLES?

b. What sections contain the word DERNIERES?

c. What is the name of the triangulation point on the west end of the island?

d. What is a section?

e. What is the area of a section? (See the map exercise of this manual.)

f. Write out the abbreviations for T 23 S and R 15 E. (Hint: See the map exercise of this manual.)

7. a. In 1935, what was the maximum length of this island in feet (not including small eastern islands)? (Use a paper edge to measure the map distance and compare with the map scale.)

b. In 1935, what was the maximum width?

c. In 1994, what was the maximum length of this island in feet (not including small eastern islands)?

d. In 1994, what was the maximum width?

8. a. Measured along the boundary between Sections 33 and 32, how many feet has the Gulf side of the island retreated between 1935 and 1994?

b. What is the average rate of retreat? (Show your work.)

9. a. What part of the bayside (N side) of the island showed the most change between 1935 and 1994? (Indicate by Section number and mark on Figure 11.16.)

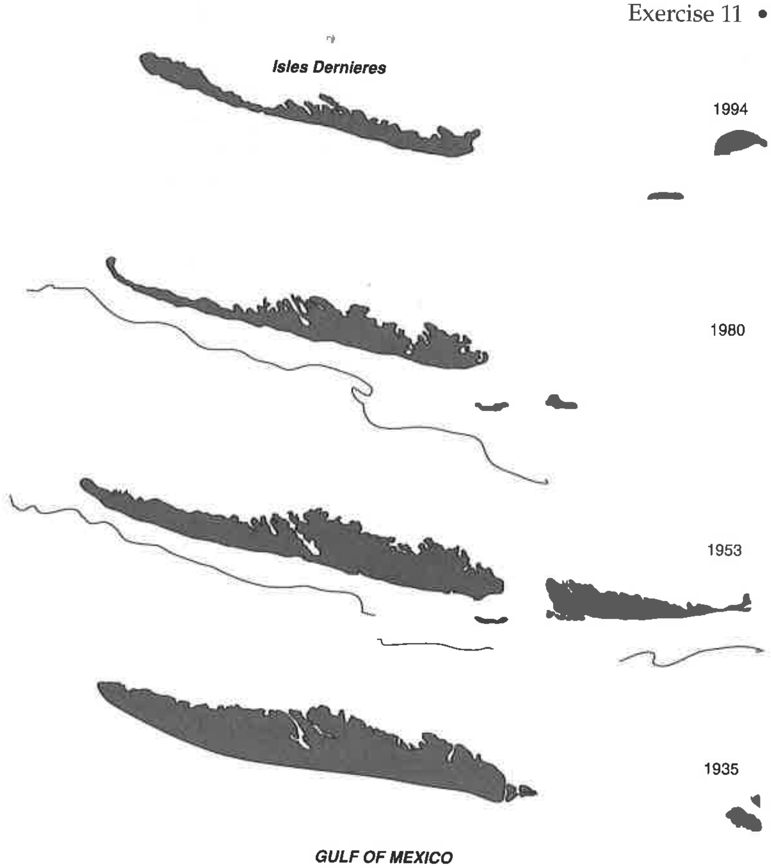


FIGURE 11.16 Compilation from the West Derniere, Louisiana, quadrangles: 1935, 1953, 1980, and 1994 (adjusted to the same scale).

b. What processes contributed to the change?

10. In the 1994 map, what are the materials shown on the island?

11. a. What do you think will eventually happen to the island?

b. Will this have any impact on other areas? Explain your answer.

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