Sea Level Changes and the Texas Coastal Environment

The Bureau of Economic Geology (BEG) a research unit at The University of Texas at Austin developed this lesson to accompany *A Virtual Tour of Texas Gulf Coast Barrier Islands***, a virtual reality computer model. The lesson plan is a collaborative effort between the BEG, the Harte Research Institute (HRI) at Texas A&M University Corpus Christi, and the Texas State Energy Conservation Office.**

Objectives

Students will compare changes in coastal environments, water resources, and air quality with changes in greenhouse gases in the atmosphere, temperature and sea level.

Students will predict the possible environmental response of reduced emissions through energy efficiency, conservation, and the use of alternative energy resources.

Students will develop a plan to reduce greenhouse gas emissions in Texas over the next ten years.

Texas Essential Knowledge and Skills

6.12a,b, 6.14b,c, 7.9b, 7.11b, 7.12a,b, 7.12c, 7.14a,b,c, 8.6c, 8.10a,b, 8.12b,c, 8.14a,c; Biology 12a,b,c,d,e; Environmental Systems 5c,d,e, 8a,b,c,d; Aquatic Science 4a, 5d, 8a,b,c

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Background

Gulf Coast environments respond to the impact of powerful tropical storms, pounding wind and waves, and sea-level rise by shifting inland. To manage and develop the coastal zone wisely, it is vitally important to understand natural processes and to monitor the impacts of development.

Over the past century, ocean tide gauges around the world and satellite measurements have indicated that sea level is rising more rapidly than before. Many scientists think an increase in carbon dioxide (CO_2) in the atmosphere is causing this increase rate of sea-level rise. Carbon dioxide emissions have been on the increase since the beginning of the industrial revolution, which began about 200 years ago. Burning of fossil fuels and a reduction in forests increase greenhouse gases that warm our planet, melt glacial ice, and cause increases in sea level.
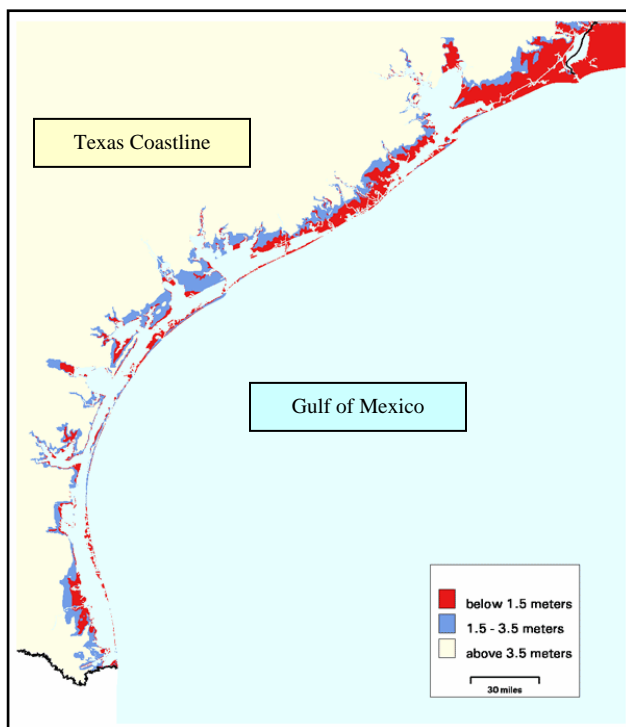

Figure 1. Coastal elevations
Source: www.epa.gov

Sea level is rising more rapidly along the upper Texas coast than worldwide because some coastal lands are sinking. Studies by the Environmental Protection Agency have estimated that along the Gulf Coast 0.30-m (1ft) rise in sea level is likely by 2050. In the next century, a 0.60-m (2 ft) rise is most likely, but a 1.2 m (4 ft) rise is possible. A rise in sea level could cover a substantial amount of land along the Gulf Coast (Fig. 1).

Scientific research concludes that climate change creates problems for coastal environments, drinking water supplies, and air quality in Texas. Although similar temperature changes took place in the past, they occurred over much longer periods. It appears that temperature change and its associated environmental problems may occur faster than the environment and humans can adapt.

Greenhouse Gases
Greenhouse gases are gases that trap heat in the atmosphere. Carbon dioxide and other greenhouse gases enter the atmosphere from natural processes and human activities. For example, animals' exhalations and burning of fuels that contain carbon, such as coal and gasoline increase carbon dioxide in the atmosphere.

The production of energy and the burning of fossil fuels associated with transportation are the leading human sources of CO_2 in the atmosphere (Fig. 2). Electricity generation is responsible for 40 percent of carbon dioxide emissions. Transportation is responsible for 32 percent of carbon dioxide emissions.

Before the Industrial Revolution, CO_2 levels in the atmosphere were 280 ppm (parts per million). By 1958, the level was 315 ppm and today's levels are nearly 380 ppm (Fig. 3). Scientific reports from 2007 show that America's CO_2 emissions have increased 20% since 1990. Scientists are concerned that if there is no cap placed on emissions, they will increase by another 15% by the year 2020. The Intergovernmental Panel on Climate Change (IPCC) predicts conservatively that CO_2 greenhouse gases will increase to 490 ppm by the end of the 21st century. The most drastic predictions have CO_2 at 1260 ppm by 2100.
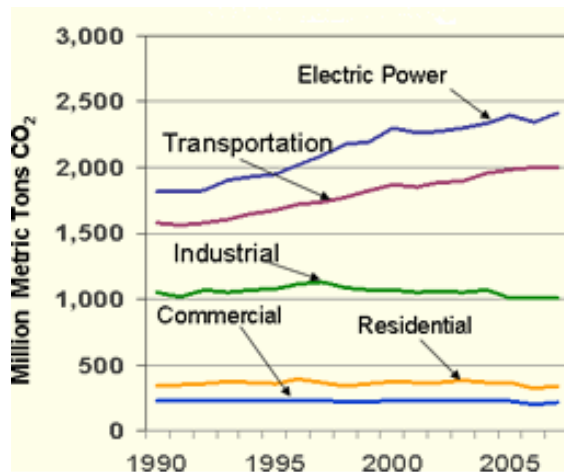

Figure 2. Carbon Dioxide Emissions by Energy-Use
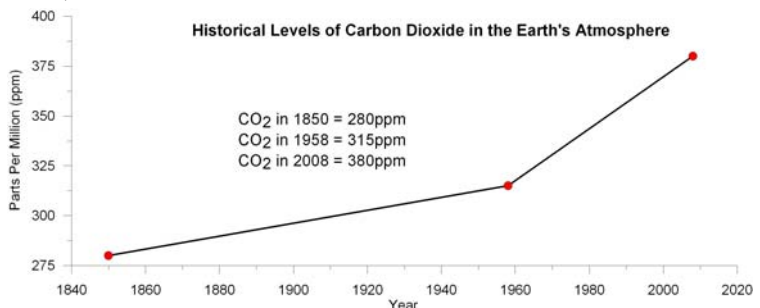*Source: Energy Information Administration 2007*

Figure 3. Historical levels of Carbon Dioxide in the Earth's atmosphere
Source: Intergovernmental Panel on Climate Change

Global Warming

Radiant energy from the sun passes easily through the atmosphere and strikes the surface of Earth. Radiant energy is absorbed and changed into heat through the warming of water, soil and other materials. These materials then re-radiate longer wavelength infrared energy (heat) back out towards space. However, not all the heat escapes. Carbon dioxide and other greenhouse gases in the atmosphere trap and re-radiate heat, thus warming the earth.

Scientists have determined that Earth's temperature has increased by 0.74ºC (1.3ºF) in just over 100 years. In the past 50 years, the temperatures have increased by 0.13 ºC (0.23ºF) each decade. The ten warmest years of this century all occurred in the last 15 years. The IPCC has estimated that Earth's temperatures could continue to increase up to 1.8-4.0 ºC (3.2-7.2 ºF) by 2100.

Sea Level Rise

Sea level is the average height of the ocean between high and low tide. Sea level has fluctuated throughout Earth's history. Causes of global changes in sea level are:
- Expansion or contraction of seawater in response to the addition or subtraction of heat energy
- The melting or growth of snow packs and mountain glaciers
- Changes in the size of major ice caps on Greenland and Antarctica

Global sea level has been rising at a rate of 1.7 mm (.07 in.) per year over the last 100 years. That rate does not seem like much but a 17 cm (6.7 in.) rise in sea level can have a significant impact on low-lying coastal areas. In general, for every 1 cm (0.39 in.) that sea level rises, 1 meter (3.28 ft) of coastal land could be lost. Running various models, scientists have predicted that sea level could rise 18 cm in the next hundred years if greenhouse gases increase. A worst case scenario model predicts a 59 cm (1.9 ft.) sea level rise if greenhouse gas emissions continue to increase at the current rate.

Changes in sea level are calculated based on relative sea level and global sea level changes. Along the Gulf of Mexico coast, changes in land elevation occur through **faulting**, **subsidence**, and **erosion**. According to the tide gauge on Galveston Island, sea level has been rising at a rate of 6.4 mm (0.24 in.) per year over the
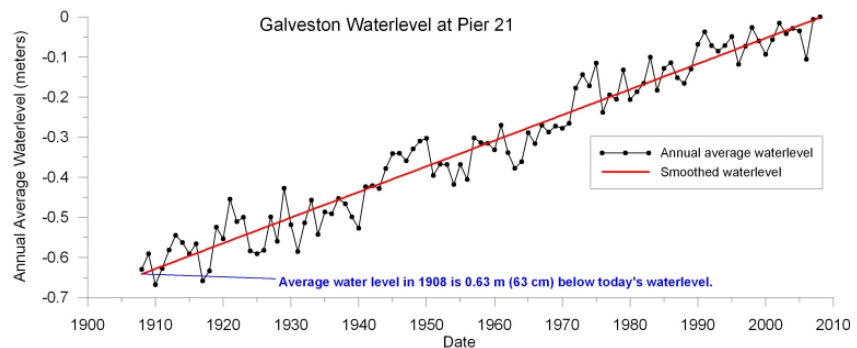

Figure 4. Water level change at Galveston Island from 1908-2007
Source: Texas A&M University Corpus Christi

last 100 years (Fig. 4)!

Effects of Global Warming
There are many effects of global warming. A few of the problems caused by sea-level rise include, but are not limited to, changes in coastal environments, water resources, and air quality.

Coastal Environments
Changes in temperature and precipitation affect coastal environments. As climate warms, water evaporates from the surface of the earth into the atmosphere forming clouds. Clouds' effects on climate are complex. For instance, clouds may increase precipitation and runoff. Changes in rainfall and runoff from upland regions can adversely affect sensitive coastal systems. For example, nutrients from fertilizer could enter the environment from upland areas, and vegetation not accustomed to these nutrients along the coast would need to adapt or perish. Adaptation means the types of vegetation may change. A change or reduction in vegetation could affect animals within the ecosystem, which are dependent on specific vegetation.

As sea ice melts and polar snow cover recedes, some the water is released into the sea. In addition, it causes the Earth to become less reflective, which in turn allows the surface of the Earth, including oceans, to absorb more sunlight and become warmer. Warmer water temperatures will cause water to expand taking up more space in the ocean basins. Melting of ice and warming of the seas are two of the causes of sea level rise. Rising sea levels can accelerate loss of **wetlands** and **estuaries** and eliminate breeding and **foraging habitats**.

The Texas Gulf of Mexico shoreline is over 600-kilometers (373 miles) long. The bay and estuary shoreline of Texas is over 9,400-kilometers (5840 miles) long. Tidal flats and salt marshes border the coastline of the numerous bays and support a rich and diverse ecosystem. Laguna Madre has over 350 square miles of tidal flats that provide nesting areas for sea birds. Marsh shorelines provide critical habitat for shore birds, wading birds, endangered brown pelicans, and other birds (Fig. 5). The Brazoria National Wildlife Refuge is a 43,388-acre coastal estuary system on the Gulf Coast. Coastal estuaries are places where fresh water from rivers mixes with saltwater. Coastal estuaries provide winter habitat for 30,000-40,000 ducks and 40,000 snow geese. About 75 percent of the ducks and geese found in the United States migrate through the Texas coastal wetlands. The salt marshes serve as nursery grounds for young shrimp, crab, and fish. These marshes protect the shorelines from erosion, buffer uplands from flooding, and filter out pollutants. Estuaries also provide many recreational opportunities, such as swimming, boating, fishing, and bird watching.

Coastal wetlands are particularly vulnerable to rising sea level because they are mostly within a few feet of sea level. **Bulkheads** or walls and **levees** along developed coastal areas can keep new wetlands from forming. As sea level rises, wetlands are squeezed between the estuary and the bulkhead. Such a loss would reduce available habitat for

birds, breeding grounds for fish, and would reduce the production of organic materials on which they rely. According to the Environmental Protection Agency, nationwide, a sudden 0.61 m (2 ft.) rise in sea level could eliminate 17-43 percent of US coastal wetlands, even if there are no additional bulkheads or levees erected.

Figure 5. Example of animals, birds, and fish found in Texas coastal wetlands
Source: www.tpwd.state.tx.us

Because of the importance of wetlands to the coastal environment, there have been efforts to remediate wetland loss through marsh restoration projects. The Galveston Island State Park restored marsh habitat looks like a waffle shaped grid in aerial photography (Fig. 6).
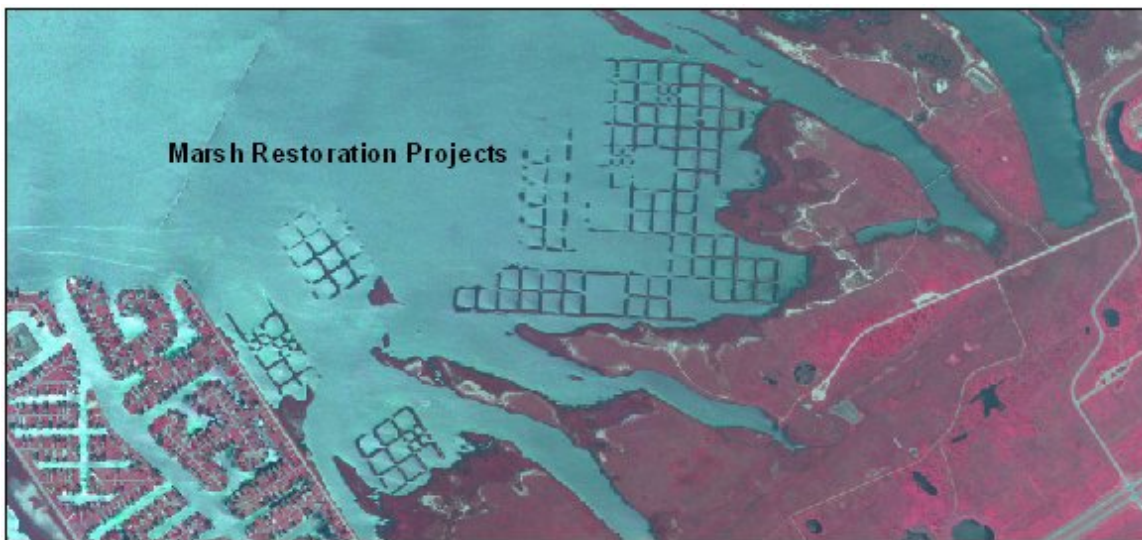

Figure 6. Galveston Island State Park marsh restoration projects
Source: National Agricultural Imagery Program (NAIP) 2005 image

Some of the most vulnerable areas are the **barrier islands** and **spits**. Coastal barriers are generally long narrow islands and spits (peninsulas) with the ocean on one side and a bay or estuary on the other (Fig. 7). Typically, the ocean side of an island ranges from two to four meters above high tide, while the bay side is less than 1 m (3.28 ft.) above high water. Thus, even a 1 m (3.28 ft.) rise in sea level would flood much of a typical barrier island, increasing repair and maintenance costs to ports, roads, beaches, homes, businesses, and other **infrastructure**.
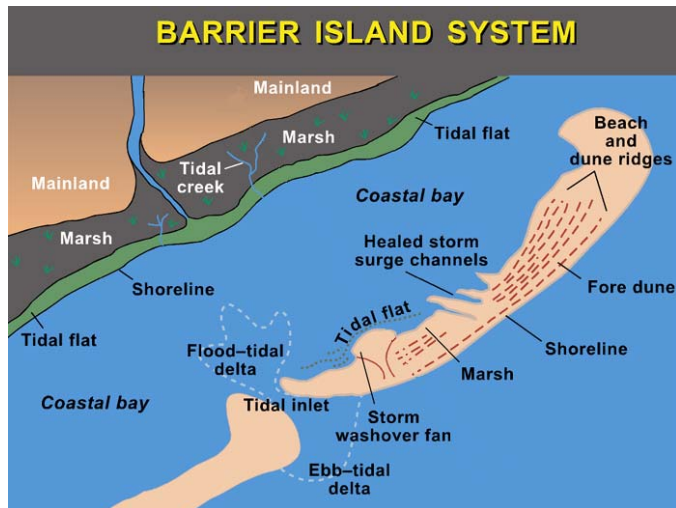

Figure 7. Barrier Island System
Source: University of Texas Bureau of Economic Geology

Relative sea-level rise varies locally based on the rate of land subsidence and erosion. Sea-level rise, along with subsidence and erosion, contributes to shoreline retreat and models predict that Texas shorelines will continue to retreat by 13.12 m (4 ft.) per year. A report by the Federal Emergency Management Agency (FEMA) predicts that a quarter of homes and other structures within 152.4 m (500 ft.) of the U.S. coastline will be lost due to shoreline retreat in the next 60 years.

As sea level rises, coastal areas become more vulnerable to storms and associated floods. A higher sea level raises the flood level making coastal areas more vulnerable to flooding. **Storm surges** could combine with a higher sea level and increase flood levels. For example, a 0.91-m (3ft.) rise in sea level would enable a 15-year storm to flood many areas that today are only flooded by a 100-year storm. This could lead to the loss of coastal wetlands, erosion of beaches and damage to homes, business, roads, causeways, and bridges.

The aquaculture industry in Texas is 11th in the nation. This industry is particularly sensitive to temperature changes, increases in salinity, and the amount of available fresh water. Warmer seas could contribute to the increased intensity, duration, and extent of harmful algal blooms and damage habitat and shellfish nurseries.

Water Resources

Gravity pulls rainwater downward, making its way through **permeable rocks** and around **impermeable rocks**, following a zigzag course until it reaches the water table. Beneath the water table are the water-saturated **aquifers** (Fig. 8). These storehouses of groundwater may be extremely large, stretching out for hundreds of miles.

Figure 8. Example of an aquifer
Source: www.fayettecountygroundwater.com

We drill wells and pump water from the aquifers to serve homes and industries, to supply municipal water systems, and to irrigate crops.

Freshwater resources and the level of the water table, vary with changes in precipitation, temperature, humidity, wind, sunshine, and sea level. With plenty of rainfall, it rises; in dry seasons, it drops and streams and marshes may dry up.

As sea level rises, salt water pushes from the Gulf of Mexico inland and upstream into rivers, bays, wetlands, and aquifers (Fig. 9). This influx raises the water table, increases the salinity of both surface water and ground water, destroys natural vegetation, and contaminates aquifers.
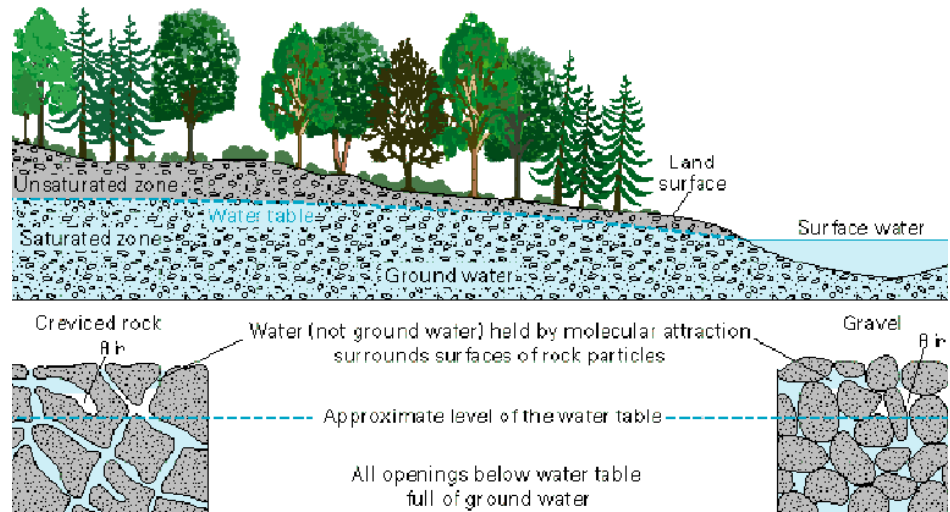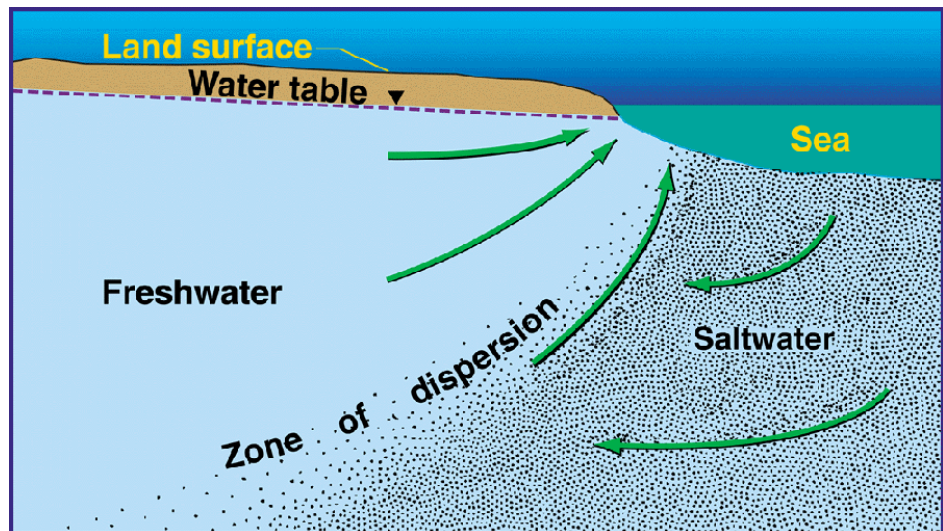

Figure 9. Diagram of saltwater/freshwater interface.
Source: www.water.usgs.gov

Climate and the availability of water influences crops and livestock production in a region. As climate warms, production patterns could shift northward causing significant regional changes. Production of crops such as cotton, rice, and citrus fruits, which grow in the Gulf Coast Region and require irrigation, would suffer from reduced availability of fresh water.

Air Quality
The major contributor to global warming is carbon dioxide, which is a colorless and odorless gas. Carbon dioxide and other greenhouse gases enter the atmosphere from nature and human activities. For example, animals exhale carbon dioxide and burning fuels that contain carbon, such as coal and gasoline, releases carbon dioxide.

In addition to causing sea level to rise, as described earlier, a warming trend is cause for concern about public health. One way that long-lasting extremes and wide fluctuations in weather spread disease is by disturbing relationships between prey and predator. For example, under warmer conditions predators of mosquitoes and rodents may fail to flourish, thus increasing populations of these disease-carrying organisms (Fig. 10).
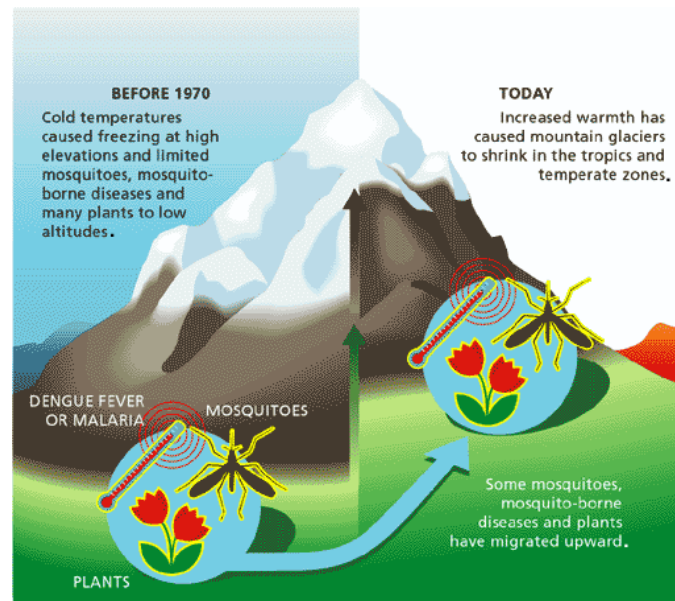

Figure 10. Comparison of environments before 1970 and today
Source: Scientific American (August 2000)

An increase in temperature accelerates ozone formation in the lowest layer of the atmosphere. Higher temperatures mean an increase in the number of "bad ozone" days. Currently, ground-level ozone concentrations exceed national ozone health standards in some areas across the state. The Houston-Galveston area is classified as a severe **nonattainment area**. Ground-level ozone aggravates respiratory illnesses such as asthma, reduces existing lung function, and induces respiratory inflammation.

Solutions
Greenhouse gases that are already in the atmosphere will be there for many years. However, using alternative energy sources and clean energy technologies, reducing deforestation, and restoring forests and wetlands can reduce future buildup of greenhouse gases. Individuals, businesses, and government can reduce greenhouse gas levels through energy efficiency, conservation, and legislation.

PART 1

1. According to the background information, how does carbon dioxide enter the atmosphere?

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    _____

    _____

2. Using the Follet's Island graph showing carbon dioxide levels, what was the level of carbon dioxide in the atmosphere in 1850 and 1958 versus today?

    _____

    _____

    _____

3. Calculate the rate change of carbon dioxide between 1850 and today.
    Rate of change = (CO_2 in 2008 - CO_2 in 1850) ÷ (number of years)

    _____

4. What is the rate change of carbon dioxide between 1958 and today?

    _____

5. What do you think has changed to cause the rate change to differ?

    _____

    _____

6. Look at the tide gauge graph on the Galveston Island scene in the model. What was sea level at Galveston Island in 1908 versus present day?

    _____

7. Calculate the rate of change in the sea level.
    Rate of change = (sea level in 2008 – sea level in 1908) ÷ (number of years)

    _____

8. Project global levels based on above rates of change. You can find carbon dioxide levels on a CO_2 prediction graph in the model (Follet's Island scene). Temperature and sea level predictions can be determined from the model in the Follet's Island scene. You can adjust sea level in 10-year increments to observe how sea level change affects a low-lying barrier island like Follet's Island.

	Carbon Dioxide	Temperature	Sea Level
10 years	_____	_____	_____
20 years	_____	_____	_____
30 years	_____	_____	_____
40 years	_____	_____	_____
50 years	_____	_____	_____
60 years	_____	_____	_____
70 years	_____	_____	_____
80 years	_____	_____	_____
90 years	_____	_____	_____
100 years	_____	_____	_____

9. Describe how increased CO2 emissions modify air quality and impact sea level changes.

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PART 2

10. Look at the Follet's Island scene and mouse over the Terrain button to see the types of wetland environments. What are the typical environments of a barrier island?

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_____

11. Change sea level in the Follet's Island scene by 10-year increments. Which environments are affected by sea level rise first?

_____

_____

12. How many years, according to the model, does it take until the first environments are affected by sea level rise?

_____

13. Explain how the environment you selected in question 11 might be affected by climate change, due to an enhanced greenhouse effect.

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14. Describe the chain of events to the other environments on Follet's Island based on their tolerances and ability to adapt. You may be able to answer this question by observing the changes to the environments due to changing sea level. To view predicted adaptations based on past trends mouse over the Terrain button then click on wetlands to adjust sea level. You may also use the following websites for information to answer this question:
http://www.koshlandscience.org/exhibitgcc/impacts04.jsp
    Science Museum of the National Academy of Sciences looks at impacts of sea level rise on nature.
http://yosemite.epa.gov/OAR/globalwarming.nsf/content/ImpactsCoastalZones.html
    Environmental Protection Agency global warming impacts on coastal zones
http://epa.gov/climatechange/effects/coastal/SLRLandUse.html
    More advanced article from EPA about Greenhouse effect, sea level rise, and land use.

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15. Notice that there are very few impacts to humans on Follet's island other then the beach road and a few houses. Select the Galveston Island scene and click on the green arrow. The image you see is Galveston Island State Park. The Park is mostly natural wetlands, except for the area that looks like a grid. What do you think these grid-like areas are and why are they important?

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_____

_____

_____

16. Change sea level on the Galveston Island wetlands by 10-year increments. Describe the natural and fabricated environments that are impacted by the changing sea level.

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_____

PART 3

17. Your teacher will assign you a Texas coastal county (see Texas Coast scene or Figure 11). What are the present major sources of carbon dioxide in your selected county? For example, the number of vehicles registered (http://www.txdot.gov/apps/discos/default.htm) in the county, power plants, and refineries.

_____

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_____

18. Even if the county assigned by your teacher does not have significant traffic or other polluting factors could the air quality be affected by air pollution in surrounding counties?

_____

19. Some scientist believe the only way to halt global climate change is to return to pre-industrial conditions. How much carbon dioxide would we need to reduce in your area over the next 20 years to return to pre-industrial conditions?

_____

20. Write a 150 word persuasive article on ways and actions you could take to reduce greenhouse gases in your research area. Include energy conservation, renewable energy, and alternative energy measures in your article.
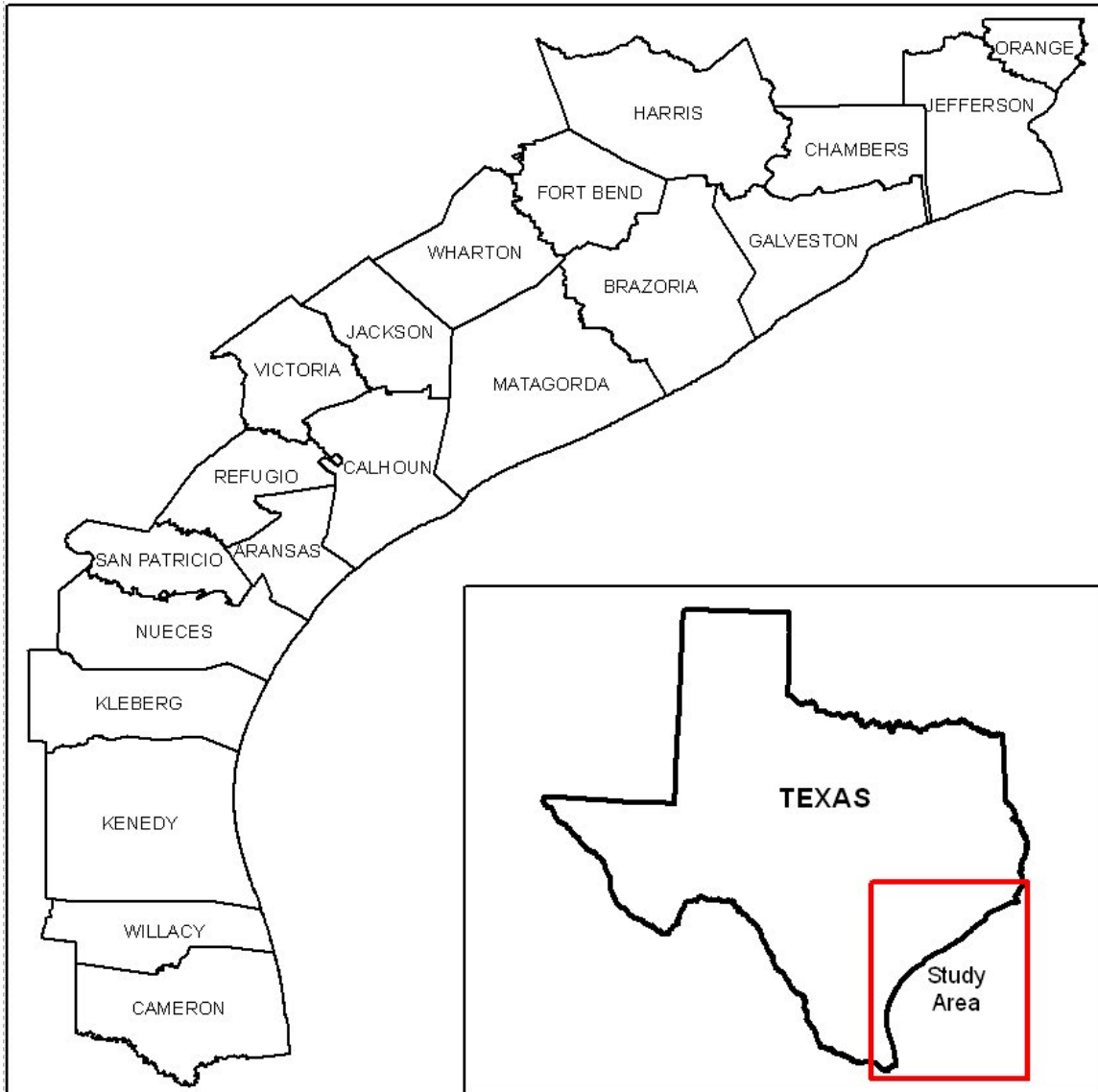
Figure 11. Texas coastal counties
Source: Bureau of Economic Geology

Website Resources

http://www.ipcc.ch/
Intergovernmental Panel on Climate Change
Reviews of the latest literature produced worldwide relevant to the understanding of the risk of human-induced climate change, its observed and projected impacts, and options for adaptation and mitigation.

www.epa.gov/climatechange
U.S. Environmental Protection Agency
General information for younger audiences, which covers weather, climate systems, climate change over time, climate studies, policy options, and games

http://www.usda.gov/
United States Department of Agriculture
The U.S. Climate Change Science Program report assesses the effects of climate change on agriculture, land resources, water resources, and biodiversity in the United States.

www.tceq.state.tx.us
Texas Commission on Environmental Quality
This web site gives point source emissions inventory data on chemical plants, refineries, electric utility plants and other industrial sites by county.

http://www.tpwd.state.tx.us
Texas Parks and Wildlife
Downloadable Texas coastal wetlands species fact sheets

http://www.esrl.noaa.gov/gmd/index.html
NOAA Earth System Research Laboratory, Global Monitoring Division
The Global Monitoring Division monitors long-term records of atmospheric gases, aerosol particles, and solar radiation.

http://www.koshlandscience.org/exhibitgcc/index.jsp
Marian Koshland Science Museum of the National Academy of Sciences
Interactive global warming exhibit

http://www.infinitepower.org/index.htm
Texas State Energy Conservation Office's The Infinite Power of Texas Renewable Energy Education Campaign
Web site with information and resources for teacher and students to learn about renewable energy in Texas

Glossary

Faulting – the process of fracturing and displacement that produces a fault. A *fault* is a fracture (or break in the Earth's surface) along which there has been movement of the sides relative to one another parallel to the fracture. For example, one side of the fault may move up while the other moves down.

Subsidence – sinking or downward settling of the Earth's surface, may be caused by natural geologic processes or by man's activity.

Shoreline erosion – the wearing away of sediments (sand) along the shoreline due to the action of waves, tides, currents, and storms.

Wetlands – are transitional areas of wet land where water is the primary factor controlling the environment and the associated soils, vegetation, and wildlife.

Coastal wetlands – wetlands that occur in coastal environments such as barrier islands or along the margins of bays and estuaries.

Estuary – a partially enclosed coastal body of water or bay that receives fresh water from rivers and streams, as well as saltwater from the sea.

Foraging habitat – the natural environment in which an animal searches for food and other provisions.

Tidal flat – an extensive, nearly horizontal barren tract of land that is alternately covered and uncovered by the tide, consisting of sand and mud.

Marsh – a saturated, poorly drained area, intermittently or permanently flooded, having aquatic and grasslike vegetation.

Salt marshes – a saturated, poorly drained area, intermittently or permanently flooded with saltwater, having aquatic and grasslike vegetation.

Bulkhead – a manmade retaining wall built along shorelines to protect land from erosion.

Levee – an artificial embankment along a watercourse or an arm of the sea to protect land from flooding.

Barrier Island – a long, narrow coastal island separated from the mainland by a lagoon or estuary. It commonly has dunes, vegetated zones, and marshy terrains extending toward the bay. Barrier islands protect the bays and mainland shoreline from ocean waves.

Spit – a long narrow body of sand projecting from the shore into a body of water, similar to a barrier island, but still connected to the mainland. Typically form across the mouth of estuaries and bays.

Infrastructure – the foundation serving as a base for the installation and developments that maintain a community and support its expansion and diversification. For example, water and sewer lines.

Storm surge – an abnormal, sudden rise of sea level along an open coast during a storm, caused primarily by onshore winds, resulting in water piled up against the coast. It is most severe when accompanied by a high tide.

Permeable rocks – rocks that allow water, oil, or gas to move through it.

Impermeable rocks – rocks that are incapable of transmitting fluids.

Aquifer – a body of rock that is sufficiently permeable to conduct ground water and to yield economically significant quantities of water to wells and springs.

Nonattainment area – a locality where air pollution levels persistently exceed National Ambient Air Quality Standards or that contributes to ambient air quality in a nearby area that fails to meet standards.