Chapter 2

Physical and Natural Environment of the Region

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2.1 Introduction

The specific territory covered by the regional assessment encompasses the Gulf Coastal Plains and coastal waters of southern Texas, southern Louisiana, southern Mississippi, southern Alabama, and western Florida **(Fig. 1).** Wetlands are a typical landscape in the Gulf Coast area. Wetlands include areas where the water table is usually at or near the surface or where the land is covered by shallow water. These habitat types are abundant in the Gulf of Mexico. Wetlands may be forested, such as swamps and mangroves, or nonforested, such as marshes, mudflats, and natural ponds. Large areas of nonforested wetlands are found in coastal Texas, Louisiana, and Florida. Recent state estimates of coastal wetlands acreage (both forested and unforested) are: Alabama (121,603 acres); Florida (2,254, acres); Louisiana (3,910,664 acres); Mississippi (64,805 acres); and Texas (412,516 acres) (Ringold and Clark, 1980).

2.2 Physiogeographic Descriptions of the Gulf Coastal States

The physiogeographic descriptions of five Gulf Coastal states in this section are based on information obtained from Duncan, et al, 1995, The World Book Encyclopedia, 1998, and the New Encyclopedia Britannica, 1998.

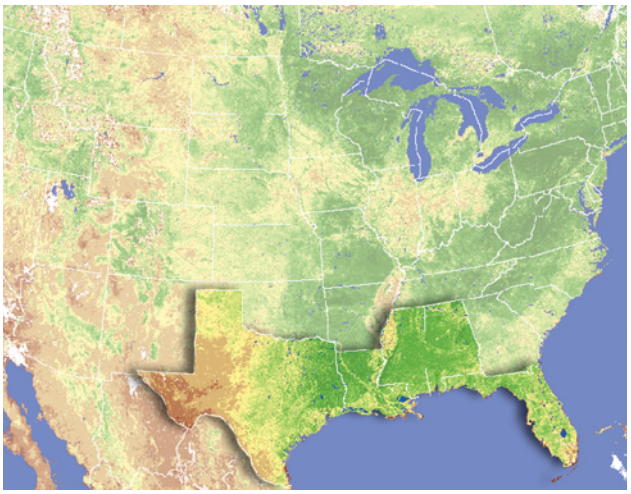

Figure 1. The Gulf Coast region defined by the National Climate Change Assessment.

Alabama

Most of southern Alabama lies less than 500 feet (150 meters) above sea level. The surface of the state rises gradually toward the northeast. Alabama has six main land regions: (1) the East Gulf Coastal plain, (2) the black belt, (3) the piedmont, (4) the Appalachian Ridge and Valley Region, (5) the Cumberland Plateau, and (6) the Interior Low Plateau **(Fig. 2).** The east Gulf Coastal plain is Alabama's largest land region. It covers the entire southern two-thirds of the state, except for a narrow strip of land called the black belt. In western Alabama, the plain extends

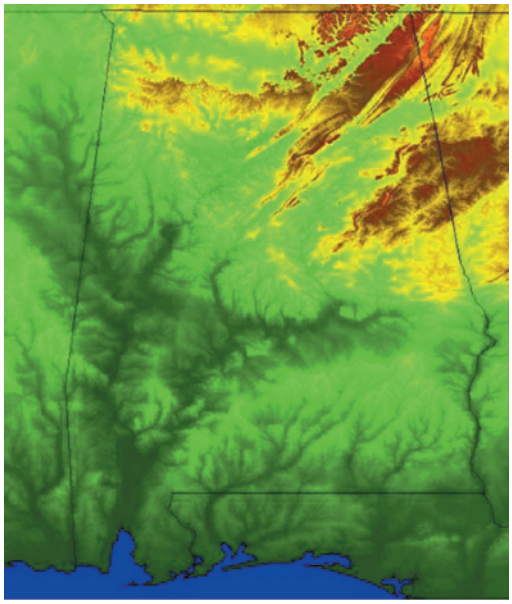

Fig. 2. Alabama territory covered by the Gulf Coast regional assessment.

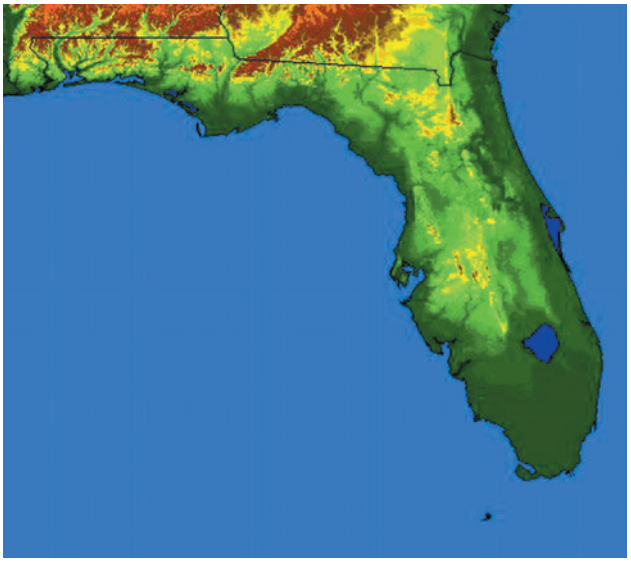

Fig. 3. Florida territory covered by the Gulf Coast regional assessment.

north almost to Tennessee. The plain has several sections. The low, swampy land of the Mobile River Delta makes up the southwestern section. The southeastern part is called the Wiregrass area. It is named for a tough grass that once grew there in pine forests. Today, the Wiregrass area is an important farming region. The northern part of the plain is often called the Central Pine Belt because many pine forests cover its low, rolling hills. In the western part of this section, the soils are gravelly and sandy, and are not good for growing crops.

The black belt is a narrow strip of rolling prairie wedged between the northern and southern parts of the East Gulf Coastal plain. The black belt was named for the sticky black clay soils of its rolling uplands. Early in Alabama history, farmers developed large plantations in this region. Boll weevils came to the black belt in 1915, and damaged the cotton crop. Some farmers then changed from growing cotton to raising livestock.

The piedmont in east-central Alabama, is an area of low hills and ridges separated by sandy valleys. The clay soils of these hills and ridges have been badly eroded. Most of the land is forested. Cheaha Mountain, the highest point in Alabama, rises 2, 407 feet (734 meters) on the northwestern edge of the Piedmont.

The Appalachian Ridge and Valley Region is an area of sandstone ridges and fertile limestone valleys. It lies northwest of the piedmont. The region has coal, iron, oil, and limestone—the three basic minerals used in making iron and steel.

The Cumberland plateau, also known as the Appalachian plateau, lies northwest of the Appalachian Ridge and valley region. The surface varies from flat to gently rolling land. It reaches a height of about 1,800 feet (549 meters) above sea level in the northeast. The land slopes to about 500 feet (150 meters) where it meets the east gulf coastal plain in the southwest.

The interior low plateau lies in the northwestern part of the state. Much of the land is in the valley of the Tennessee River.

Florida

Florida is part of the Atlantic-Gulf Coastal plain, a large land region that extends along the coast from New Jersey to southern Texas. Within Florida, there are three main land regions (1) the Atlantic Coastal plain, (2) the East Gulf Coastal plain, and (3) the Florida uplands **(Fig. 3).**

The Atlantic coastal plain of Florida covers the entire eastern part of the state. It is a low, level plain ranging in width from 30 to 100 miles (48 to 160 kilometers). A narrow ribbon of sand bars, coral reefs, and barrier islands lies in the Atlantic Ocean, just beyond the mainland. Long shallow lakes, lagoons, rivers, and bays lie between much of this ribbon and the mainland.

Big Cypress Swamp and the Everglades cover most of southern Florida. The Everglades include 2,746 square miles (7112 square kilometers) of swampy grassland. Water covers much of this region, especially during the rainy months.

The Florida Keys makes up the southernmost part of the state. These small islands curve southwestward for about 150 miles (241 kilometers) off the mainland from Miami. Key largo is the largest island.

The East Gulf Coastal plain of Florida has two main sections. One section covers the southwestern part of the peninsula, including part of the Everglades and Big Cypress Swamp. The other section of Florida's East Gulf Coastal plain curves around the north edge of the gulf of Mexico across the panhandle to Florida's western border.

The East Gulf Coastal plain is similar to the Atlantic coastal plain. Long, narrow barrier islands extend along the Gulf of Mexico coastline. Coastal swamps stretch inland in places.

The Florida uplands are shaped somewhat like a giant arm and hand. A finger of the hand points down the center of the state toward the southern tip of the peninsula. The uplands separate the two sections of the East Gulf Coastal plain from each other and separate the northern section from the Atlantic Coastal plain.

The uplands region is higher than Florida's other land regions. But its average elevation is only between 200 and 300 feet (61 and 91 meters) above sea level. Lakes are common in the Florida uplands. Many of these lakes were formed in sinkhole-cave-ins where a limestone bed near the surface was dissolved by water action. Pine forests grow in the northern section of the uplands.

The northern part of the Florida uplands extends from the northwestern corner of the state along the northern border for about 275 miles (443 kilometers). Its width varies from about 30 to 50 miles (48 to 80 kilometers). This section has fertile valleys and rolling hills of red clay. The southern part of the Florida uplands is a region of low hills and lakes. It covers an area about 100 miles (160 kilometers) wide and about 160 miles (257 kilometers) long.

Louisiana

Most of Louisiana was once part of an ancient bay of the Gulf of Mexico. The Mississippi and other rivers flowing from the north brought huge amounts of silt to the bay. This action over thousands of years built up the land area to its present size. Louisiana has three main land regions. All are part of the fertile low land that lies along the Gulf Coast of the United States **(Fig. 4.).** These regions are (1) the East Gulf Coastal plain, (2) the Mississippi alluvial plain, and (3) the West Gulf Coastal plain.

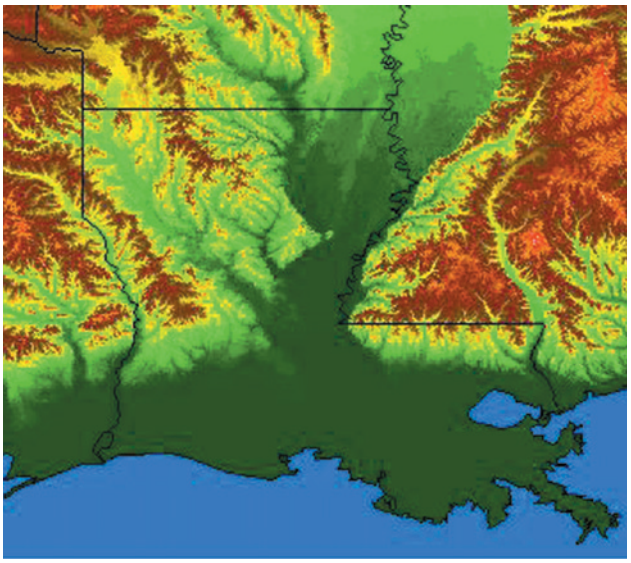

Fig. 4. Louisiana territory covered by the Gulf Coast regional assessment.

The East Gulf Coastal plain in Louisiana covers the area east of the Mississippi river and north of lake Pontchartrain. It rises gradually from marshes in the west and south to low, rolling hills in the north.

The Mississippi alluvial plain lies along the lower Mississippi river. In Louisiana, it reaches from the Arkansas state line to the Gulf of Mexico. Broad, low ridges and hollows parallel the river as it winds down the plain. The high fields atop the ridges are called frontlands. The frontlands slope away from the river to the backlands, which are great stretches of clay and silt. The backlands have several ancient channels of the Mississippi, far from its present course. The Mississippi Delta was formed of silt brought to the river's mouth. It covers about 13,000 square miles (33,700 square kilometers)-about a fourth of Louisiana's total area. The delta has the state's most fertile soil.

The West Gulf Coastal plain includes all Louisiana west of the Mississippi alluvial plain. At the southern end of the plain, low sand ridges called barrier beaches lie along the Gulf of Mexico. Behind these beaches, marshes stretch inland for about 20 miles (32 kilometers). Beneath the marshes and the coastal and offshore waters are large underground formations called salt domes. These domes cap great deposits of salt. Pools of natural gas and petroleum are trapped along the sides of the salt deposits. Sulfur is sometimes found in the top of the domes between the salt and the upper crust.

North of the marshlands, the gently rolling Louisiana prairies-about 60 miles (100 kilometers)

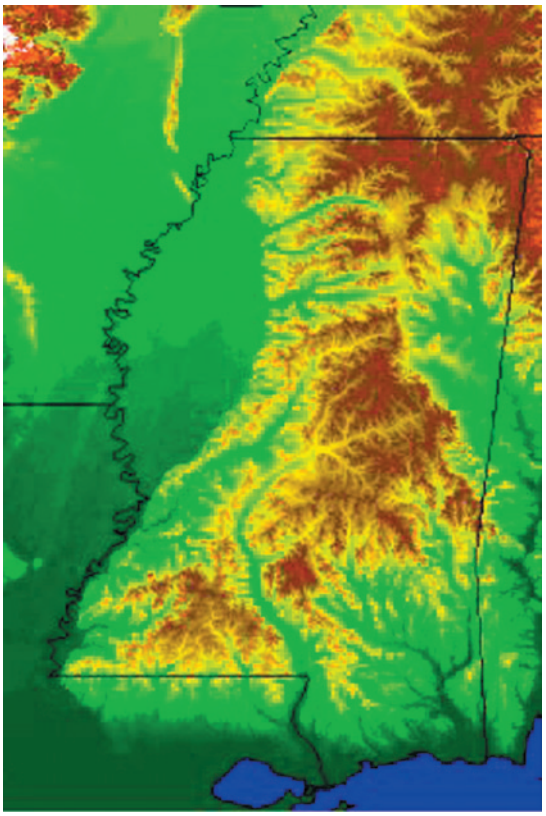

Fig. 5. Mississippi territory covered by the Gulf Coast regional assessment.

wide-reach westward across the plain to Texas. North of the prairies, the land rises gradually as it stretches toward Arkansas. The highest point in Louisiana is 535-foot (163-meters)Driskill Mountain, about 40 miles (64 kilometers) from the Arkansas line.

Mississippi

Mississippi has two main land regions: (1) the Mississippi alluvial plain, and (2) the east Gulf Coastal plain **(Fig. 5).**

The Mississippi alluvial plain covers the entire western edge of the state. It consists of fertile lowlands and forms part of the 35,000-square-mile (90,600-sequare-kilometer) alluvial plain of the Mississippi River. The region is quite narrow south of Vicksburg. North of the city, the plain spreads out and covers the area between the Mississippi and the Yazoo, Tallahatchie, and Cold Water rivers. Floodwaters of the rivers have enriched the soil of the region with the deposits of silt. The fertile soil of the Mississippi alluvial plain is famous for its large cotton and soybean crops. Most Mississippians call this region the Delta.

The east Gulf Coastal plain extends over all the state east of the alluvial plain. Most of the region is made up of low, rolling, forested hills. The coastal plain also has prairies and lowlands. Yellowish-brown loess (soil blown by winds) covers the region in the west. Most Mississippians call these deposits the cane, bluff, or loess hills. The Tennessee River hills rise in northeastern Mississippi. They include the highest point in the state, 806-foot (246-meter) Woodall Mountain. The Pine Hills, often called the Piney Woods, rise in the southeastern part of the region. They are covered largely with longleaf and slash-pine forests.

The main prairie is called the black belt or black prairie because its soil is largely black in color. This long, narrow prairie lies in the northeast section of the state. The black belt stretches through 10 counties. Livestock graze there, and corn and hay grow well on the farmlands of the black belt. Small prairies also lie in the central Mississippi, east of Jackson. Along the Mississippi Sound, lowlands stretch inland over the southern portion of the region.

Texas

Texas has five main land regions. These are, from east to west: (1) the Gulf Coastal plains, (2) the prairie plains, (3) the rolling plains, (4) the Great Plains, and (5) the basin and range region **(Fig. 6).**

The Gulf Coastal plains of Texas are part of the fertile lowland that lies along the entire gulf coast of the United States. They range in elevation from sea level to about 300 feet (91 meters) above sea level. A subtropical region extends along a large part of the coast.

The southernmost part of the coastal plains consists of the fertile Rio Grande Valley. Just north of this valley lies the Middle Nueces Valley, part of the Nueces Plains. The two valleys are famous for their winter vegetables and fruits. The region along the coast from the Rio Grande Valley to Louisiana has rich soils. Cotton and several types of grain thrive in this region.

The northeastern part of the plain is a timberland with thick forests of oak, pine, sweet gum, and other trees. This area is often called the piney Woods. Major lumber and paper companies own most of the land. Farmers in this area raise beef and dairy cattle and poultry. The region has many large mineral deposits

The prairie plains lie west of the forest belt of the coastal plains. The prairie plains feature alternating belts of rugged hills and rolling hills. The rugged

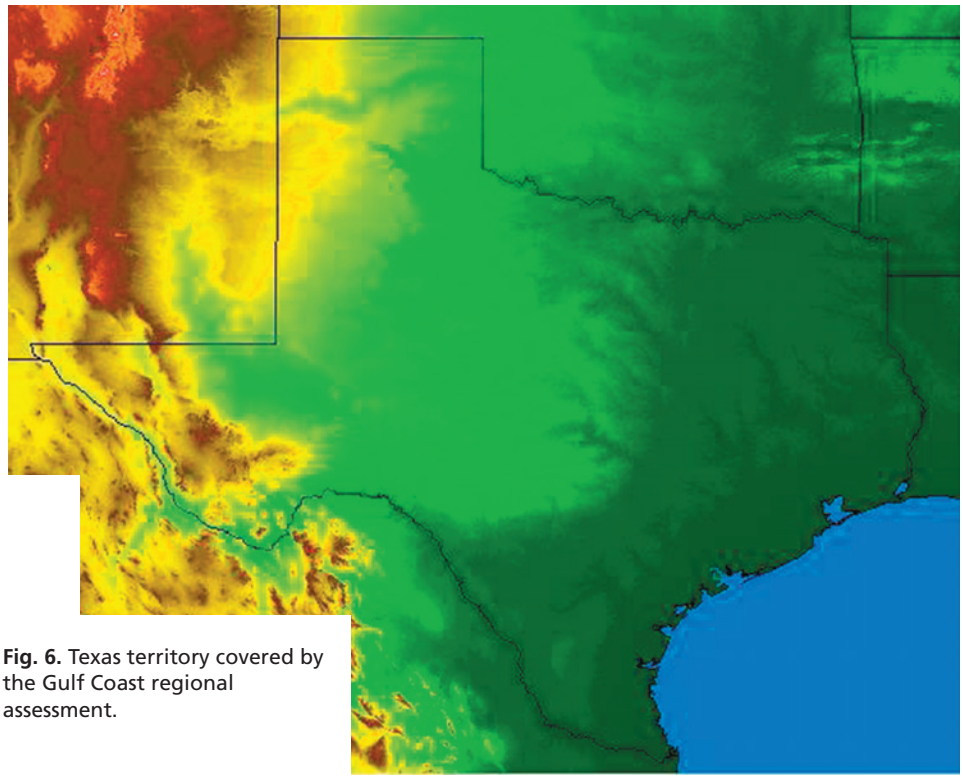

Fig. 6. Texas territory covered by the Gulf Coast regional assessment.

hills are covered with oak and hickory forests. The region includes the fertile Black Waxy prairie. The prairie has rich soils for farming.

The rolling plains are a hilly area west of the prairie plains. The areas' elevation increases as it approaches the Great Plains to the west. The region has scattered belts of fertile farmland and rich petroleum deposits.

The Great Plains reach westward from the prairie plains and the rolling plains into New Mexico. They form part of the series of treeless plains that extends northward through the western United States into Canada. The Great Plains of Texas rise from an altitude of about 700 feet (213 meters) above sea level in the east to over 4,000 feet (1,200 meters) above sea level in the west.

A large part of the Great Plain region lies within the Texas Panhandle, the part of the state that juts northward alongside new Mexico and Oklahoma. The western part of the Panhandle is called the Liano Estacado (staked Plains) or the high plains. This treeless grassland is a high plateau. The Liano Estacado has many irrigated cotton, grain sorghum, and wheat farms. The southern part of this area lies above an underground region called the Permian Basin. The state's largest petroleum and natural gas deposits are in the Permian Basin.

The Edwards Plateau forms the southern part of the Great Plains. Its surface is mainly bare limestone bedrock, but it is dotted with shrubs and sparse grasses. Thick grasses grow in the plateau's river valleys and basins. In the eastern part of the Plateau, the land becomes irregular, forming what is called the Texas Hill Country More sheep and goats are raised in the Edwards Plateau than in any other part of the United States.

The basin and range region, commonly called the Trans-Pecos Region, make up the westernmost part of the Texas. It includes high, partly dry plains that are crossed by spurs of the Rocky Mountains. These spurs include, from north to south, the Guadalupe, Davis, and Chisos Mountains. The peaks that do not form continuous ranges are called Lost mountains. Farmers use the level sections mainly for raising cattle, with some irrigated agriculture on the plains along the Rio Grande. Many beautiful mountain gorges are along the upper Rio Grande, which forms the region's western border. Santa Elena canyon, in Big Bend National Park, is one of the area'smost spectacular gorges.

2.3 Land use

Table 1 and 2 provided summary of land use information of the five Gulf Coastal states.

Table 1 Land Cover/Use, by State: 1992.

[in millions of acres (1,940,000 represents 1,940,000,000)]

States	Total surface area[a]	Non-federal			
		Total	Developed[b]	Rural Land	
				Total	Crop land
United States	1,937.7	1,480.9	91.9	1,389.0	382.0
Alabama	33.1	31.2	2.0	29.1	3.1
Florida	37.5	30.4	4.6	25.8	3.0
Louisiana	30.6	26.4	1.8	24.6	6.0
Mississippi	30.5	28.0	1.3	26.7	5.7
Texas	170.8	163.7	8.2	155.5	28.3

a, includes water area not shown separately.
b, includes urban and built-up areas in units of 10 acres or greater, and rural transportation

Source: U.S. Census Bureau, Statistical Abstract of the United States 1999.

Table 2 National Forest System Land By States: 1997.

[in thousands of acres (e.g., 231,884 represents 231,884,000)]

State Total	Gross area within unit bounaries[a]	National forest system land[b]	Other lands within unit boundaries
United States	231,808	191,785	40,023
Alabama	1,290	665	625
Florida	1,418	1,147	271
Louisiana	1,025	604	421
Mississippi	2,312	1,158	1,154
Texas	1,994	755	1,239

a, Comprises all publicly and privately owned land within authorized boundaries of national forests, purchase units, national grasslands, land utilization projects, research and experimental areas, and other areas.
b, federally owned land within the "gross area within unit boundaries."

Source: U.S. Census Bureau, Statistical Abstract of the United States 1999.

2.4 Water Resources

Table 3 provided summary of water resources information.

Table 3 Land and water area of states and other entities: 1990.

State	Total area		Land area		Water area			
	Sq.mi.	Sq.km.	Sq.mi.	Sq.km.	Total		Inland	Coastal
					Sq.mi.	Sq.km.	Sq.mi.	Sq.km.
United States								
Alabama	52,237	135,293	50,750	131,443	1,486	3,850	968	519
Florida	59,928	155,214	53,937	139,697	5,991	15,517	4,683	1,308
Louisiana	49,651	128,595	43,566	112,836	6,085	15,759	4,153	1,931
Mississippi	48,286	125,060	46,914	121,506	1,372	3,553	781	591
Texas	267,277	692,248	261,914	678,358	5,363	13,890	4,959	404

Source: U.S. Census Bureau, Statistical Abstract of the United States 1999.

Alabama

Navigable rivers flow through almost every part of Alabama. The Mobile River and its tributaries flow south to the Gulf of Mexico. They form the most important river system in the state. The Alabama and the Tombigbee, Alabama's longest rivers, meet about 45 miles (72 kilometers) north of Mobile and form the Mobile River. The Chattahoochee River forms much of the border between Alabama and Geogia. The Tennessee River (Fig. 7) is the most important river in northern Alabama. It flows west across almost the entire width of the state. However, Alabama has no large natural lakes, and dams on rivers have created many artificial lakes.

Florida

Florida has many rivers, such as Escambia river, Yellow river, Apalachicola river, Suwannee river, and more. There are abundant creaks and lakes as well. Among all five Gulf Coastal states, Florida has the largest water area.

Louisiana

The waters of all the rivers in Louisiana find their way to the Gulf of Mexico. The Mississippi, of course, is Louisiana's most important river. Other important rivers in the state include the Atchafalaya, Black, Calcasieu, Ouachita, Pearl, Red, and Sabine.

Mississippi

Mississippi has many rivers and lakes. The nation's most important river, the Mississippi forms most of the state's western border. Its floodwaters, in earlier times, often deposited silt on the land and helped make the land fertile.

The state has several main river basins. The rivers of the western and north-central basin drain into the Mississippi River. These rivers includes the Big Black River and the Yazoo River with its tributaries, the Coldwater Big Sunflower, and Tallahatchie rivers. Rivers of the eastern basin drain into the Gulf of Mexico. They include the Pearl, Pascagoula, and Tombigbee. Many of Mississippi's lakes are artificially created reservoirs.

The Mississippi River has formed many oxbow lakes, mostly north of Vicksburg. Mississippi also has many slow-moving streams called bayous. Some of the bayous connect the lakes with the rivers in the Delta. Others link the inland waterways with the Gulf of Mexico.

Texas

The Rio Grande, Texas' largest river, is one of the longest and most historic rivers in North America. Other Texas rivers include the Brazos, Canadian, Colorado, Guadalupe, Neches, Nueces, Pecos, Red Sabine, San Antonio, and Trinity. Most of the state's rivers flow in a southeast direction into the Gulf of

Mexico. In the dry western parts of Texas, many streams have water only after a rainstorm.

2.5 Soil

Alabama

There are four main soil zones found in Alabama. In the far north, the Tennessee Valley contains the dark loams and red clays that add vivid dashes of color to the landscape when exposed. Farther south lie the varied soils of a mineral belt, and these are succeeded by the rich limestone and marl soils of the Black Belt. Along the coast of Alabama there are sandy loams and deep porous sands.

Louisiana

The soils of Louisiana have been one of the state's priceless resources; nearly one-third of the total land area is covered by the rich alluvium deposited by the overflowing of its rivers and bayous. Muck and peat soils are found within the coastal marshes, while the bottom soils of the Mississippi and Red river valleys are other alluvium and loessial, or windblown, soils. Within the uplands, or hills, there are more mature soils that are less fertile.

Florida

In general, Florida's soil consists of sand, sandy loam, claylike marl, peat, and muck, but more than 300 soil types have been mapped. Six broad soil-vegetation regions may be described.

Texas

There is immense variation in the types of Texas soil. The Piney Woods region of east Texas has a gray and tan topsoil that covers the red subsoil usually within a foot or two of the surface. The soil along the upper and middle Texas coast is black clay or loam, with lighter-coloured sandy soil on coastal islands, bars, and spits. The soil of the southern Texas coast and inland to the Rio Grande is sandy, like that of east Texas, but is less eroded and leached.

The Blackland Prairie, a belt of fertile black clay to the west of the Piney Woods, extends southwesterly from the Red river to San Antonio. The soil of the Grand Prairie region, just to the west of the Blackland Prairie, is more rocky and resistant to erosion.

The Cross Timbers, a forest region with light-colored, slightly acid, sandy loam soil, stretches across the prairies of northern Texas, enclosing part of the Grand Prairie. Red sandy and dark clay soils are found in the Llano Basin, in the center of the state. The Edwards Plateau has thin, stony soil with a limestone bedrock.

Most of the soils of the western North Central Plains are red or tan-colored and sandy, but some black clay is found in the region. The High Plains, just to the west, has dark brown to reddish clay loams, sandy loams, and sands. In the Trans-Pecos region are found reddish brown sandy soil in the mountains and grayish brown to reddish brown clay soil in the basins.

The rich fertility of the soils first attracted settlers to Texas. Much of the soil was lost through wasteful farming and ranching practices in the 19th and the early 20th centuries, but since the 1930s efforts by federal and state governments have done much to promote soil conservation in the state.

2.6 Coastline

Alabama

Alabama's general coastline extends for 53 miles (85 kilometers) along the gulf of Mexico. The tidal shoreline, which includes small bays and inlets, is 607 miles (977 kilometers) long.

Mississippi

Mississippi has a coastline of 44 miles (71 kilometers) along the Gulf of Mexico. With bays and coves, it has a total shoreline of 359 miles (578 kilometers). The largest bays include Biloxi, St. Louis, and Pascagoula. The nation's longest sea wall protects about 25 miles (40 kilometers) of coastline between Biloxi and Point Henderson at Pass Christian. Other coastal towns include Bay St. Louis, Gulfport, and Ocean Springs Deer Island is near the month of Biloxi Bay, and a chain of small islands lies off the coast. They include Cat, Horn Ship, and Petit Bois islands. Mississippi Sound separates them from the mainland.

Louisiana

Louisiana has a general coastline of 397 miles (639 kilometers) along the Gulf. But the marshy coast has been made extremely uneven by silt deposits. As a result, Louisiana's tidal shoreline-including bays, offshore islands, and river months- is 7,721 miles (12,426 kilometers) long. Salt water from the Gulf of Mexico enters the coastal waters through canals. It kills many of the freshwater marsh plants that help hold coastal soils in place, and as a result, large amounts of these soils are washed away. About 50

square miles (130 square kilometers) of Louisiana's coastal land erodes annually.

Florida

The coastline of Florida is 1,350 miles (2,173kilometers) long divided into Atlantic Coast and the Gulf Coast. The Atlantic coast has 580 miles (933 kilometers) of shoreline. The Gulf coast is 770 miles (1,240 kilometers) long.

Texas

The general coastline of Texas is 367 miles (591 kilometers) long along the Gulf. The tidal shoreline, including bays, offshore islands, and river mouths, is 3,359 miles (5, 406 kilometers) long. A series of narrow sand bars, enclosing shallow lagoons, lies along the Texas coast. These sand bars help protect the coast from ocean storms and huge, destructive waves called tsunamis. The Texas coast has 27 artificially created ports, that were once filled by silt left by the many streams emptying into the Gulf of Mexico. When they were filled by silt, only small vessels could use them. By removing the silt and deepening the harbors, engineers built 12 deepwater pots and 15 ports for barges and small ships.

2.7 Current Stresses

The following regional key sectoral issues were identified by the Gulf Coast Regional Workshop (Ning and Abdollahi, 1999, USGCRP, 1998a)

2.7.1 Coastal Ecosystems

The potential impacts of climate change are of great practical concern to those interested in Gulf Coast region's **wetland** resource. The Northern Gulf Coast area is of greatest risk in the U.S. because of its low-laying habitats with easily eroded substrates. The IPCC and the World Meteorological Organization (IPCC, 1997 and WHO, 1996) have identified coastal wetland as an ecosystem most vulnerable to direct, large-scale impacts of climate change, primarily because of their sensitivity to increase in sea-level rise.

The Gulf Coast is a region prone to rapid subsidence of an order of magnitude greater than the Atlantic and Pacific coastal zones. The Governor of Louisiana's representative at the workshop referred to this region as the "Poster Child of Vulnerability". Accelerated **sea-level rise** of any predicted rate, high or low, will only exacerbate the impacts of the existing rate of sea-level rise on this highly vulnerable coastal region.

Gulf Coast ecosystems continue to be impacted by stresses of altered **watershed dynamics** and **flood** control measures. Changing climate conditions which impact flow regimes in other regions (such as the Upper Mississippi River watershed) are also felt along the Gulf Coast. Gulf Coast states have experienced an increase in total annual rainfall during this century. This increase is associated with more intense rainfall events, which alter both the timing and delivery of freshwater to coastal wetlands and estuaries. The State Climatologist for Louisiana stated that intense spring rainfall events have doubled in frequency since 1971, while the number of summer events during that period were half as frequent. In addition to these climatic changes, **flood control measures** and impoundment alter surface water flows and impede the sediment flux that is necessary to sustain the development of river deltas. The extraction of freshwater for municipal purposes and irrigation, along with landscape fragmentation in the coastal zone has altered the balance of freshwater and tidal flows. Several Gulf Coast estuaries and wetlands are slated for engineered restorations (e.g. fresh water diversions along the lower Mississippi River and the Everglade's surface water restoration).

Rising sea level and deteriorating landforms allow **saltwater to intrude** further inland and to mix with surface and groundwater supplies. Changing the salinity patterns of Gulf Coast wetlands threatens stability of freshwater ecosystems and survival of two important shellfish resources — oysters and shrimp. Fertilizers, herbicides, and pesticides applied on agricultural crops in watersheds that feed coastal marshes and estuaries also pose a real concern. The cumulative impact of water removal and replacement, whether for municipal or industrial purposes, involves a reduction in the quality of water interring downstream wetlands. Urban floodwaters that are pumped across levees also introduce significant contaminants of unknown fate into adjoining wetlands.

Frontal passages and hurricanes account for most of the acute effects that lead to coastal changes of barrier islands and wetlands. Even relatively mild winter storms create fetch dynamics in coastal bays and estuaries that can cause significant impacts.

The invasion of non-indigenous species of flora and fauna alters the structure and balance of coastal systems to the exclusion, in some cases, of native species. The **loss of habitat** for resident wildlife is also of concern. The Gulf Coast spans the transition zone between temperate and sub-tropical climates

and species distribution, which adds to its biological diversity as a region. Climate changes and conditions may foster the rate of spread of exotic species. Some notable exotic species include *Melaleuca, Salvinia,* Water hyacinth, Eurasian millfoil, Brazilian pepper, Chinese tallow tree, gecko, and zebra mussel.

2.7.2 Forests

Climate variability is already a prime stress and is related to the many summer storms of both sub-tropical and convection driven origin. Forests are affected by numerous thunderstorms of high intensity as well as tropical storms and the associated high winds. The high rainfall during short periods associated with these storm leads to **flooding** and waterlogged soils. Plant growth is impacted. Reduced root growth and increased incidence of windthrow are not uncommon problems.

Along the coast and for some distance inland, **sea-level rise** is a major problem in the region. Natural sea-level rise is a product of warming temperatures and thermal expansion. Apparent sea-level rise is aggravated by subsidence caused from the organic soils and the losses of sediment influx as drainage patterns have been altered for human use in coastal areas. Sea-level rise exacerbates drainage of rivers and streams resulting in flooding and **saltwater intrusion** that severely alter the coastal ecosystems. Freshwater swamps are being killed by saltwater intrusion and bottomland hardwoods are being killed by alteration of flood timing and duration. Changes in species composition, changes in wetland boundaries, and complete loss of terrestrial ecosystems to open water areas have occurred. Such changes have also been associated with increased numbers of pests and success of new pests in the region.

Although high rainfall is common, the Gulf Coast region also experiences its share of **droughts.** Droughts in recent years have caused much damage and loss of productivity. Plants growing in waterlogged soils have restricted root systems and once the soils begin to dry out, plants are unable to extract sufficient water from the soil. Wildland ecosystems under water stress often lead to insect and disease infestations, with a concomitant increase in the frequency and severity of wildfires. The release of sequestered carbon through uncontrolled wildfire can lead to major air pollution and to the buildup of radiatively important gases and particles in the atmosphere. In the summer, high temperatures provide additional stress through increased plant respiration, reduced photosynthesis, and direct-heat-caused injury. In the winter, temperature fluctuation and the sudden onset of freezing temperatures result in biological miscues and loss of productivity. The negative impacts on flower and fruit production are most noticeable.

Ozone and other **air pollutants** are problems in many areas of the Gulf Coast region. Foliar damage, reductions in photosynthesis, and associated reductions in growth have been shown to occur. These problems are becoming more serious in the Gulf Coast region.

2.7.3 Water and Air Quality

The Gulf Coast shares a number of stresses that are currently creating problems for coastal areas due to a high rate of population influx and development along the coast. Many of the health stresses in the region relate to **contamination** of the marine environment as a result of development, agriculture (nitrogen flow), and **industrial pollution,** such as benzene and other organic chemicals from oil refining. This is of particular concern because the Gulf Coast has the highest concentration of petrochemical companies in the nation. Pollutants in water are a major problem in the region. With the potential of sea level rise, health is threatened by petrochemical plants. In addition to the chemicals released by the petrochemical companies, the Mississippi River carries the chemical pollutants of the Central U.S. to the Gulf Coast region. Extraction, refining, and transport of oil and petrochemicals all carry risks for the health of humans, wildlife and ecosystems. Extreme rains and flooding can enhance run-off of nutrients, pollutants and microorganisms. Heavy rains and high nutrient levels can increase algae blooms and add to the **"hypoxic zone"** in the Gulf of Mexico, currently the size of New Jersey.

In addition, there were a number of disease events in Florida in 1997, which affected both humans and plants. These included St. Louis encephalitis around Orlando and three crop pests: medfly in Dade county, citrus canker sore and tomato leaf virus carried by whiteflies.

The growth of major cities and the effects of this growth on air quality are major health concerns in the Gulf Coast region. Large cities such as Houston and New Orleans have major problems with air pollution, particularly tropospheric ozone (O_3). Pollution stagnation, such as occurred in Baton Rouge in 1990 and 1995, is dangerous and may be exacerbated by increased temperatures. Poor air quality contributes

to health endpoints such as heat shock, asthma, respiratory disease, and allergies.

When air quality is bad, people often stay inside of the house where the air quality is worse than outside of the house. In addition, when temperatures increase, more people use air conditioners, adding to the pollution problems.

Diversion of water to serve the growth of the human population in large cities is a potential threat to the availability of clean water in the Gulf Coast region. The large population growth in Atlanta is currently threatening Gulf Coast water quality. Similarly, population growth and the diversion of water are also threatening the water quality of the Rio Grande River. To assess this problem, it is important to monitor key water systems and to determine the purpose for which water is being used.

2.7.4 Fisheries

Increased variability in precipitation has the potential to greatly impact coastal fisheries by affecting freshwater inflow to estuaries, which in turn would affect flushing rates, the location of the freshwater-saltwater interface, and the quality of coastal estuarine nursery areas for fish and shellfish. Further inland, increased variability in precipitation has the potential to negatively impact riverine fish resources.

Fishermen of the Terrebonne Fishermen's Organization expressed concerns about **coastal erosion and the loss of coastal marsh habitat,** which, in Louisiana, is mainly attributable to subsidence of deltaic deposits of the Mississippi River, and human alteration of coastal marsh. They are concerned that sea level changes associated with global climate change will exacerbate the current problems of coastal erosion. Even small rates of sea-level rise take on a special significance in coastal Louisiana.

There is currently little public understanding of the importance of coastal water and habitat quality to coastal fisheries. Coastal habitat quality is affected by factors like industrial and metropolitan development along the coastal zone, tourism and recreation, inland land use (natural vegetation cover versus agriculture or silviculture, fertilizer and pesticide use, animal husbandry, etc.), and atmospheric and hydrologic deposition of pollutants (e.g., inorganic nitrogen) from industry located far inland. The extent to which climate change will exacerbate or ameliorate stresses on fisheries associated with changes in coastal water and habitat quality depends on future trends of coastal zone development. Some sense of the minimum amount of undisturbed coastal habitat and minimally disturbed coastal habitat buffer needed to sustain current fisheries must be gained in order to project habitat needs under climate change scenarios.

In 1997 Louisiana fisheries contributed roughly $20 billion to the gross national product, employing about a million people. Marsh and other coastal habitats on which coastal fisheries depend play an important role as nursery grounds for many commercially important fish and shellfish species. Other commercially important fishes, whose life histories are not directly tied to coastal habitats, are dependent on fish and shellfish produced in coastal habitats.

All aquatic organisms have particular ranges of physiological tolerance to factors like temperature, salinity, pH and dissolved oxygen. In general, species are found only in habitats that meet all of their requirements for survival, growth, and reproduction. These requirements often differ with different life history stages (eggs, larvae, and adults), particularly in marine and estuarine species. A change to warmer water temperature in the Gulf of Mexico, for example, has the potential to restrict the zone of inhabitance of temperate adapted species (northward movement in the Northern Gulf of Mexico is limited by the coastline) and shift the zone of more tropical adapted species northward.

The same may be said for fishes in inland freshwater stream and lake habitats along the Gulf Coast. The species are generally temperature adapted, so any warming, or tendency toward warmer extremes than at present, has the potential to restrict their natural range. The ability of any of these species to migrate north or south is dependent on the range of stream sizes the species normally inhabits, and the presence of barriers to dispersal such as dams or natural physiographic features.

A critical problem in trying to predict how global climate change might impact populations of both coastal and inland fisheries is that very little is known about the specific tolerances and life history requirements of many of the species involved. Life history information is being gathered for many of the commercially important species by agencies such as the National Marine Fisheries Service and state fisheries departments. However, the information is not being gathered in a coordinated way, with a view toward future climate change. In cases where key life history information is being gathered (e.g., in the course of routine shrimp, ichthyoplankton and groundfish surveys), important information on conditions of capture is not being recorded or archived, the collec-

tions are not being precisely referenced as to geographic position, and the collections are not being archived. We need a comprehensive interagency review of information needs related to impacts of global climate change on coastal fisheries, a better coordination of ongoing fishery surveys with proper attention to the quality of the information being gathered, and improved databasing and archiving of information collected.

2.7.5 Commerce, Industry and Energy

Industries of the region can be divided into two broad categories: primary industries and support industries. Primary industries with the most impact on the economies of the Gulf Coast region (in no particular order) are oil and gas, agriculture and forestry, tourism and entertainment, fisheries and aquaculture, chemical, manufacturing, port transfer and shipping. A number of support industries with important roles in the region (in no particular order) are insurance, finance, real estate, construction, medical and health, public sectors, military, government, and retail.

Current climatic and non-climatic stresses can be related to the relevant industries. Some of these influences originate within the region, while others have global dynamics. Some general "stresses" are coastal land loss, saltwater intrusion, population growth, and education/training of the general population and available workforce. Specific effects on the primary industries include the following:

a. Oil and gas

Clearly, global energy markets, international emissions agreements, and national policy are major forces in shaping the demand for oil and gas products, and the ultimate mix of fuels used to meet the nation's energy needs. Also, the current age and inefficiency of capital equipment is one important stress in this industry as well as in the chemical and manufacturing industries. Weather plays a substantial role in determining demand for, hence the price of, various fuels. Another major stress on the oil and gas industries is the frequency and magnitude of major storms. In such cases, drilling activities in the Gulf are curtailed. While this stress is currently thought to play only a minor role, future increases in storm intensity and frequency associated with climatic change could be important.

b. Agriculture and forestry

Agriculture is particularly sensitive to climate variability and extremes. The dates of the first and last frosts dictate planting and harvesting schedules. Shifts in the length of growing season can benefit or harm agriculture. Some crops will likely benefit from the enhanced CO_2 and increased air temperatures. There may even be opportunities for double cropping (i.e., two growing seasons each year). The expected drying of the soil and increased magnitude of heavy precipitation events, on the other hand, may be damaging to the agricultural industry.

c. Tourism and entertainment

Weather in the Gulf Coast region has an important influence on tourism. For instance, it is generally known that the month of August can be quite hot and humid, discouraging tourists and encouraging residents to travel out of the region. The role of weather in tourism, however, is a two-way street. Many of the tourists visiting the region in winter months are from the northeast. If winters in the northeast are less severe, there will be less incentive for these individuals to flee to the south. Another important influence on tourism is the perception of health threats. One example is the recent outbreak of encephalitis in central Florida, that resulted in the evening closings of the Disneyworld parks. Even very small outbreaks of infectious disease can have major impacts on tourism.

d. Fisheries and aquaculture

Wetland loss is a current issue of great importance to the fisheries and aquaculture industries. If natural subsidence is enhanced by sea-level rise, these industries may be severely impacted. There are also salinity issues associated with the interface between the coastal salt water and the brackish and fresh water marshes.

e. Chemical

While the chemical industry is generally not significantly impacted by climate, it relies on the oil and gas industries for much of its raw materials, and is also subject to the policy actions of local governments which often act to limit emissions. Environmental activism is also playing a more pronounced role, as the activist groups grow and become more vocal about their environmental concerns. Vocal public opposition to the proposed Shintech PVC plastics plant in Louisiana is one of the examples.

f. Port transfer and shipping

This industry depends upon port access that in some cases may be affected by river flow rates, sedimentation, and the need for dredging. Ship traffic can also be significantly impacted by severe storms.

2.8 Potential Futures

2.8.1 Climate Change and Sea Level Raise

Rising global temperatures are expected to raise sea level, and change precipitation and other local climate conditions. Changing regional climate could alter forests, crop yields, and water supplies. It could also threaten human health, and harm birds, fish, and many types of ecosystems.

There are five major physical impacts of sea-level rise: (1) erosion; (2) inundation; (3) salinization; (4) increased flooding and storm damage; and (5) rising water tables (Nicholls et al., 1994). Sea-level rise does not act in isolation and these impacts can be offset or reinforced by other factors such as sediment availability, or changing freshwater runoff. It is also important to recognize that the coastal zone will evolve due to processes other than sea-level rise. Therefore, when examining potential impacts of sea-level rise for planning purposes, it is important to consider all coastal processes (Stive et al., 1990).

Rising sea level is gradually inundating wetlands and lowlands; eroding beaches; exacerbating coastal flooding; threatening coastal structures; raising water tables; and increasing the salinity of rivers, bays, and aquifers (Barth and Titus, 1984). The areas most vulnerable to rising seas are found along the Gulf of Mexico and the Atlantic Ocean south of Cape Cod. Although there also are large low areas around San Francisco Bay and the Fraser delta (British Columbia), most of the Pacific coast is less vulnerable than the Atlantic and Gulf coasts.

Coastal marshes and swamps generally are found between the highest tide of the year and mean sea level. Coastal wetlands provide important habitat and nourishment for a large number of birds and fish found in coastal areas. Wetlands generally have been able to keep pace with the historic rate of sea-level rise (Kaye and Barghoorn, 1964). If sea level rises more rapidly than wetlands can accrete, however, there will be a substantial net loss of wetlands (Titus, 1986; Park et al., 1989).

Coastal development is likely to increase the vulnerability of wetlands to rising sea-level. In many areas, development will prevent the wetland creation that otherwise would result from the gradual inundation of areas that are barely above today's high-water level (Titus, 1986, 1988). In Louisiana, flood control levees, navigation infrastructure, and other human activities have disabled the natural processes by which the Mississippi delta otherwise could keep pace with rising relative sea level; as a result, Louisiana currently is losing about 90 km^2 (35 mi^2) of wetlands per year (Gagliano et al., 1981; Penland et al., 1997).

Louisiana is expected to experience the greatest wetland loss from rising sea level, although most of these losses are predicted to occur even with the current rate of relative sea-level rise. A 50-cm rise in sea level would cause a net loss of 17 – 43% of the wetlands, even if no additional bulkheads or dikes are erected to prevent new wetland creation. The table presents estimated losses in U.S. wetlands by region.

The dry land within 1m above high tide includes forests, farms, low parts of some port cities, communities that sank after they were built and that now are protected with levees, parts of deltas, and the bay sides of barrier islands. Major port cities with low areas include Miami, and New Orleans. New Orleans' average elevation is about 2m below sea level.

The most economically important vulnerable areas are recreational resorts on the coastal barriers-generally long and narrow islands of spits (peninsulas) with ocean on one side and a bay on the other-of the gulf coasts. Typically, the ocean front block is 2-5m above high tide; the bay sides often are 0.5m above high water. Rising sea level tends to cause narrow islands to migrate landward through the overwash process (Leatherman, 1979).

Changing climate generally is increasing the vulnerability of Gulf Coast areas to flooding both because higher sea level raises the flood level from a storm of a given severity and because rainstorms are becoming more severe in many areas. It also is possible that hurricanes could become more intense, thus producing greater storm surges. The IPCC (1996) concluded, however, that the science currently is inadequate to state whether or not this is likely to occur. Many Gulf Coastal areas currently are protected with levees and seawalls. Because these structures have been designed for current sea level, however, higher storm surges might overtop seawalls, and erosion could undermine them from below (National Research Council, 1987). In areas that are drained artificially, such as New Orleans, the increased need for pumping could exceed current pumping capacity (Titus et al., 1987).

Higher sea level and more intense precipitation could combine synergistically to increase flood levels by more than the rise in sea level alone in much of coastal Louisiana and Florida. The direct effect of higher sea level also could be exacerbated throughout the coastal zone if hurricanes or northeasters become more severe-a possibility that has been suggested but not established (IPCC, 1996).

Rising sea level also enables saltwater to penetrate farther inland and upstream in rivers, bays, wetlands, and aquifers. Saltwater intrusion would harm some aquatic plants and animals and threaten human uses of water. Increased drought severity, where it occurs, would further elevate salinity. Higher salinity can impair both surface and groundwater supplies. If saltwater were able to reach farther upstream in the future, the existing intakes would draw salty water during droughts. Louisiana's coastal wetlands are disappearing at the rate of 25 square miles per year — equal to 16,000 acres annually. In this century, the state of Louisiana lost between 600,000 and 900,000 acres of valuable coastal vegetative wetlands. Estimates reveal that another 600,000 acres will be lost between now and the year 2040. A commitment to establish cost-effective coastal restoration projects is essential if Louisiana's costal wetlands are to be saved.

The aquifers that are most vulnerable to rising sea level are those that are recharged in areas that currently are fresh but could become salty in the future. The South Florida Water Management District already spends millions of dollars each year to prevent the aquifer from becoming salty (Miller et al.,

Table 4 Regional and national wetland losses in the U.S. for the trend and 1-m global sea-level rise scenarios (% loss of current area).

	Current Wetland Area		1-m Shore Protection Policy		
Region	**(mi^2)**	**Trend**	**Total[a]**	**Developed[a]**	**None[a]**
Northeast	600	7	16	10	1[d]
Mid-Atlantic	746	-5	70	46	38
South Atlantic	3,814	-2	64	44	40
South/Gulf Coast of Florida	1,869	-8	44	8d	7[d]
Louisiana[b]	4,835	52	85	85	85
Florida Panhandle, Alabama, Mississippi, And Texas	1,218	22	85	77	75
West Coast[c]	64	-111	56	-688	-809
United States	13,145	17	66	49	50
Confidence Intervals					
95% Low	-	9	50	29	26
95% High	-	25	82	69	66

a The "total" scenario implies that all shorelines are protected with structures; hence, as existing wetlands are inundated, no new wetlands are formed. "Developed" implies that only areas that are currently developed will be protected; "no protection" assumes that no structures will be built to hold back the sea.

b Evaluation of management options currently contemplated for Louisiana (e.g., restoring natural deltaic processes) was outside the scope of this study.

c This anomalous result is from small sample size. The impact on nationwide results is small.

d Results are not statistically significant; sampling error exceeds estimate of wetlands lost.

Source: Titus et al., 1991, and USEPA website at
http://www.epa.gov/globalwarming/publications/reference/ipcc/chp8/america13.html

1992). A second class of vulnerable aquifers consists of those in barrier islands and other low areas with water tables close to the surface, which could lose their freshwater lens entirely (IPCC, 1990).

Finally, rising sea level tends to make some agricultural lands too saline for cultivation. In areas where shorefront lands are cultivated, the seaward boundary for cultivation often is the point where saltwater penetrates inland far enough to prevent crops from growing. As sea level rises, this boundary penetrates inland-often rendering farmland too salty for cultivation long before inundation converts the land to coastal marsh (Toll, 1997).

regions, have resulted in increased salinity in wells because when freshwater is drawn down saltwater can then intrude into the aquifers. An increase in sinkhole formation has also been associated with large groundwater withdrawals. Showed warmer and drier conditions occur, particularly if accompanied by rising sea levels, they could compound the problems of high demand for water and low availability. Lower water levels and higher temperatures could also impact water quality by concentrating pollutants.

Table 5 Loss of dry land from sea-level rise (95% confidence interval, mi^2).

	Rise in Sea Level (cm)			
	Baseline	**50**	**100**	**200**
If no shores are protected	NR	3,300-7,300	5,100-10,300	9,200-15,400
If developed areas are protected	1,500-4,700	2, 200-6,100	4,100-9,200	6,400-13,500

(NR=not reported) Source: Titus *et al.*, 1991.

2.8.2 Climate Change and Its Potential Impacts to Five Gulf Coastal States (USEPA, 1999)

Alabama

Coasts

Alabama has a 600-mile tidally influenced shoreline along the Gulf of Mexico. The shoreline consists of a low-lying coastal plain, narrow barrier islands, forested swamps, and low terraces. Along much of the Florida Panhandle and Alabama Gulf Coast, sea level already is rising by approximately 9 inches per century, and it is likely to rise another 20 inches by 2100.

Water resources

In a warmer climate, runoff is likely to be reduced primarily because of higher temperatures, increased evaporations, and changes in precipitation. Reduced runoff and the resulting lower groundwater levels, especially in the summer, could affect the availability of water to satisfy Alabama's growing and competing needs for municipal, industrial, irrigation, and recreational uses of water. Large groundwater withdrawals in the coastal zones of Baldwin and Mobile counties, which include the Mobile Bay and Gulf Shores

Forests

In Alabama, longleaf and slash pine forests could expand northward and replace some of the loblolly and shortleaf pine forests. Wetter conditions would favor expansion of southern pine forests, as well as oak and hickory forests and the gum and cypress forests found along the Gulf Coast. In contrast, under drier conditions, 40 – 70% of forests in the east –central part of the state could be replaced by grasslands and pasture. Warmer and drier conditions could increase the frequency and intensity of fires, which could result in increased losses to important commercial timber areas. Even warmer and wetter conditions could stress forests by increasing the winter survival of insect pests.

Ecosystem

Alabama is located at the intersection of several geographic areas, and it's ancient and complex geological terrain is home to a variety of ecosystems, ranging from the Appalachians in the north to the coastal plain in the south. Although it ranks 29th of all the states in area, it is the nation's fourth in terms of plant and animal species richness. With 235,000 miles of waterways spanning three major river basins (the Mobile, Tennessee, and Apalachicola), it's aquatic biodiversity is particularly notable. Freshwater fauna in the rivers and Streams include 52% of North American's known freshwater turtles (of these, 22%

are endemic to the state), 38% (41% endemic) of freshwater fishes, 60% (34% endemic) of freshwater mussels, and 43% (77% endemic) of all gill-breathing snails. The Cahaba River, Alabama's longest free-flowing river, is home to 131 species of fish, the greatest diversity for any river of its size on the continent. Habitat for warm water fish could be reduced by hotter temperatures. Alabama's coastline may be small in comparison to other Gulf Coast States, but over 500 species of marine mollusks have been found in the coastal sands and waters of Alabama. Climate Changes could exacerbate threats to coastal and freshwater ecosystems. For example, warmer air temperatures could lead to reduced stream flow and warmer water temperatures, which would significantly impair reproduction of fish and other animals and favor the spread of exotic species that exhibit a high tolerance for extremes environmental conditions. The low-lying Mississippi Delta is particularly vulnerable to the effects of sea level rise – inundation of coastal lands, intrusion of saltwater into coastal freshwater ecosystems, and increases in erosion rates and storm damage resulting from increase storm frequency. If rainfall increases, runoff along the Gulf Coast and the rate of estuarine flushing are expected to increase, leading to reduced yields in shrimp and other species favoring high salinities. Higher runoff rates and outflow into the Gulf of Mexico could increase nutrient loads and alter water temperatures, exacerbating the already serious eutrophication and hypoxia.

Florida

Coasts

Along much of the Florida coast, the sea level already is rising 7-9 inches per century. Because of local factors such as land subsidence and groundwater depletion, sea level rise will vary by location. The sea level in this area is likely to rise 18-20 inches by 2100. As sea level rises, coastal areas in Florida, particularly wetlands and lowlands along the Gulf and Atlantic coasts, could be inundated. Adverse impacts in these areas could include loss of land and structures, loss of wildlife habitat, accelerated coastal erosion, exacerbated flooding and increased vulnerability to storm damage, and increased salinity of rivers, bays, and aquifers, which would threaten supplies of fresh water.

Water resources

A critical factor in Florida's development, especially in southern Florida, has been water. Competing demands for water – for residences, agriculture, and the Everglades and other natural areas – are placing stresses on south Florida's water resources. Although south Florida receives an annual average of 60 inches of rain, annual evaporation sometimes can exceed this amount. Rainfall variability from year to year is also high, resulting in periodic droughts and floods. Higher temperatures increase evaporation, which could reduce water supplies, particularly in the summer. Saltwater intrusion from sea level rise also could threaten aquifers used for urban water supplies. These changes could further stress south Florida's water resources.

Forests

The mixed conifer/hardwood forests found in the northern and panhandle sections of Florida are likely to retreat northward. These forests eventually could give way to wet tropical forests such as tropical evergreen broadleaf forests and dry tropical savanna. These changes would be accompanied by a reduction in forest density. The dry tropical savanna of the Florida peninsula could become more of a seasonal tropical forest with a corresponding increase in forest density. The potential dieback of forests along the Gulf coast could adversely affect forest-based recreation and commercial timber.

Ecosystems

Southern Florida has natural national treasures in the Big Cypress Swamp, the Everglades, and the Keys. These three ecosystems are interlined and have a common history. The Big Cypress Swamp is part of the broad, shallow river moving fresh water south into the Everglades. The keys mark the last outposts of the Everglades lands. Once hummocks of higher vegetation set in a prehistoric swamp, they have maintained themselves against the rising sea. Mangroves on their perimeters collect silt and organic material, building a barricade secure against all but the most severe hurricane winds and tides. In the Everglades and Big Cypress Swamps, there is a strong contrast between the seasons. From early spring well into autumn, they have ample rainfall, averaging 50 inches per year. Winter is a time of drought and fire, and saltwater penetrates farther inland.

Already stressed by water diversions, non-native species of plants and animals, and the natural phenomena of drought, flood, and storms, these ecosystems will be stressed further by climate change. A 20-inch sea level rise would cause large

losses of mangroves in southwest Florida. Increase salinity, resulting from rising saltwater into the Everglades from Florida Bay, also would damage freshwater ecosystems containing sawgrass and slough. Communities of wet prairie also would decline with the rise in sea level. Climatic conditions in central Florida may become suitable for subtropical species such a Gumbo-limbo, now confined to subtropical hummocks in the southern part of the peninsula and the Keys. Theoretically, under projected climate change, such species could be found as far north as Gainesville and Jacksonville, but agricultural and urban development will likely preclude such a progression.

Louisiana

Coasts

At Grand Isle, Louisiana, relative sea level is rising by 41 inches per century mostly due to land subsidence, and is likely to rise another 55 inches by 2100. Louisiana currently is losing coastal wetlands at a more rapid rate (approximately 25 square miles a year) than any other coastal state or region in the United States. Louisiana's low-lying delta coastal wetlands are a unique case — these wetlands receive large deposits of sediment from the outflow of the Mississippi River. These deposits provide wetlands with a natural defense against the effects of sea-level rise.

However, because the land surface is subsiding faster than sedimentation is occurring, Louisiana wetlands could be flooded extensively even by relatively changes in sea level. A 1 – 3 foot increase in sea level over the next century is projected to submerge at least 70% of Louisiana's remaining salt marshes. Even freshwater marshes located far inland may convert to brackish or salt marsh.

Water resources

Most of Louisiana drains to the lower Mississippi and Red rivers, both of which have headwaters thousands of miles from their mouths. Stream flow in these rivers is affected mostly by conditions outside Louisiana's borders. Because much of the runoff of the Red and Mississippi rivers comes from areas where there is little snowfall, stream flow is affected by changes in precipitation and temperature. Summer flows of these rivers could be reduced by the increased evaporation that would occur in a warmer climate. The part of Louisiana that is not in the Red or Mississippi river basins is drained by smaller rivers and streams that flow directly to the Gulf of Mexico.

Forests

With changes in climate, the extent and density of forested areas in Louisiana could change little or decline by 5 – 15%. Hotter, drier weather could increase wildfires, particularly in the important timber producing regions in the northern part of the state. In some areas, the types of trees dominating Louisiana forests are likely to change. Longleaf and slash pine densities could increase, as would the extent of cypress and gum dominated forests in southeastern Louisiana. Loblolly and shortleaf pines would continue to thrive over much of the state; however, drier conditions could result in increased areas of grassland and savanna in the western part of the state.

Ecosystem

Louisiana's Mississippi river delta contains the largest wetlands in the nation. These coastal wetlands support 30% of national commercial fish and shellfish harvests. They are also the winter home of 20 – 25% of the ducks that frequent ponds in North America. These wetlands are among the most commercially and ecologically productive in the United States. The coastal marshes in Louisiana generate over $2 billion worth of commercial species such as oysters, crabs, fish and shrimp each year. They also are an invaluable buffer against storm surges.

Louisiana is already losing many of its wetlands because levees and other structures along the Mississippi River prevent soil deposition. Sea level rise most likely will accelerate wetland loss. Reducing important habitats for migratory birds, crayfish, sport fish, and other species. Some warm water fish species such as black crappie could lose all of their habitat in Louisiana as a result of the effects of climate change. In addition, spotted sea trout, oyster larvae, pinfish, and flounder would lose much, if not all, of their habitat.

Mississippi

Coast

Mississippi coast has a 360-mile tidally influenced shoreline along the Gulf of Mexico. The shoreline consists of a low-lying coastal plain, narrow barrier islands, and low terraces. At Pass Christian, sea level already is rising by 5 inches per century, and it is

likely to rise another 15 inches by 2100. Possible responses to sea level rise include building walls to hold back the sea, allowing the sea to advance and adapting to it, and raising the land and structures (e.g., by replenishing beach sand, elevating Houses and infrastructure). Each of these responses will be costly, either in out-of-pocket costs or in land and structures.

Water resources

Declining groundwater levels are a matter of concern throughout the state. Increased rice irrigation and fish farming in the northwestern Delta region have reduced groundwater levels in the Mississippi alluvial aquifer. Increased municipal and industrial withdrawals in the metropolitan Jackson area, along the Gulf Coast, and in northeastern Mississippi also have lowered groundwater levels. Additionally, in the southern half of the state, saline water has begun to intrude into freshwater aquifers because of declining groundwater levels along the coast as well as from saline waste water injection into oil-field production zones. Warmer and drier conditions, particularly if accompanied by sea-level rise, could compound these types of problems due to higher water demand and lower flows.

Warmer temperatures could lead to reduce stream flow and warmer water temperatures, which would significantly impair reproduction of fish and other animals and favor the spread of exotic species that exhibit a high tolerance for extreme environmental conditions.

Forests

About 55% of the land area of Mississippi is covered with forests, including bottomland hardwoods, pine woods, and oak-hickory forests. In Mississippi, longleaf and slash pine forests could expand northward and replace loblolly and shortleaf pine forests if the climate changes as predicted. Wetter conditions would favor expansion of southern pine forests as well as oak and hickory forests and the gum and cypress forests found along the Gulf Coast. In contrast, under drier conditions, 50-75% of forests in the east-central part of the state could be replaced by grasslands and pasture.

Ecosystem

Most of Mississippi is made up of habitats associated with either the coastal plain or the Mississippi Delta. The coastline is separated from the Gulf of Mexico by a shallow sound and is paralleled by a series of barrier islands. The Mississippi flatlands in the alluvial plain attract hundreds of thousands of migrating snow geese, Canada geese, and ducks in the winter. Wetlands play a major role in basin hydrology and serve as wildlife habitats.

The low-lying Mississippi Delta is particularly vulnerable to the effects of sea level rise—inundation of coastal lands, intrusion of saltwater into coastal freshwater ecosystems, increase in erosion rates and storm damage with increasing wave force and storm frequency. If runoff along the Gulf Coast increases, estuarine flushing rates would increase, leading to reduced yields in shrimp and other species favoring high salinities. Increasing runoff rates and outflow into the Gulf of Mexico could increase nutrient loads and alter water temperatures, exacerbating already serious eutronphication and low oxygen levels. Loss of coastal wetlands and marshes with rapid sea level rise would reduce estuarine health because many estuarine species depend on wetlands as nursery areas and source of organic matter.

Texas

Coasts

The Texas coastline is over 1,400 miles long. The coastline is composed of wind tidal flats, sandy marshes, salt marshes, and beaches. About 75% of the ducks and geese found in the United States move through the Texas coastal wetlands. The salt marshes provide a home for oysters and clams, and serve as nursery grounds for young shrimp, crab, and fish. These marshes protect the shorelines from erosion and also act as a purification system by filtering out many pollutants added to the waters by human activities. At Galveston, sea level already is rising by 25 inches per century, and it is likely to rise another 38 inches by 2100. Brown shrimp catch in the U.S. Gulf Coast could fall 25% with only a 10-inch rise in sea level.

Water resources

Several major river basins lie in part, or entirely, within Texas. Most of the state is drained by several south-flowing rivers, including the Neches, Trinity, Brazos, Colorado, San Antonio, and Nueces. Western Texas drains into the Rio Grande or its major tributary, the Pecos River. Unless increased temperatures are coupled with a strong increase in rainfall, water could become more scarce. A warmer and dryer climate would lead to greater evaporation, as much as a 35% decrease in streamflow, and less water for

recharging groundwater aquifers. Increased rainfall could mitigate these effects, but also could contribute to localized flooding. Additionally, climate change could give rise to more frequent and intense rainfall, resulting in flash flooding.

Forests

With changes in climate, the extent and density of forested areas in east Texas could change little or decline by 50-70%. Hotter, drier weather could increase wildfires and the susceptibility of pine forests to pine bark beetles and other pests, which would reduce forests and expand grasslands and arid shrublands. With increased rainfall, however, these effects could be less severe. In some areas, the types of trees dominating Texas forests would change; for example, longleaf and slash pine densities could increase in the deciduous forests of east Texas.

Ecosystems

The coasts wetlands, which support important fisheries and provide vital wildlife habitat, are also vulnerable to climate change. For example, Brazoria National Wildlife Refuge, a 43,388 acre coastal estuarine and coastal prairie habitat on the Gulf Coast, provides winter habitat for 30,000 – 40,000 ducks and 40,000 snow geese. The refuge also contains about 4,000 acres of native coastal systems, and sea level rise would accelerate loss of wetlands and estuaries, eliminating breeding and foraging habitat for commercial, game, and threatened and endangered species.

The vast area within Texas includes a great diversity of ecosystems, from forests to grasslands to semiarid shrublands to extensive coastal and inland wetlands. In land-based Texas, climate change could weaken and stress trees, making them more susceptible to pine bark beetle outbreaks. Semi-arid grasslands and shrublands are very sensitive to changes in rainfall season and in the amount of rainfall, and could be affected adversely by warmer, drier conditions.

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