CHAPTER 16
SOUTHEAST

by James G. Titus

FINDINGS

Global climate change could diminish the extent of the region's forests, reduce agricultural productivity and increase the abandonment of farms, diminish fish and shellfish populations, and increase electricity demand. Approximately 90% of the national coastal wetland loss and two-thirds of the national shoreline protection costs from sea level rise could occur in the Southeast. The impacts on rivers and water supplies are uncertain.

Agriculture

- Southeastern agriculture is generally more vulnerable to heat stress than to freezing, so the adverse impacts of more hot days would more than offset the beneficial impact of a longer growing season.

- As a result of climate change alone, yields of soybeans and corn would vary from no change in the cooler regions to up to a 91% decrease in warmer areas, even if rainfall increases.

- A preliminary assessment suggests that when the direct effects of CO 2 are included, yields might increase in parts of the region if climate also becomes wetter. If climate becomes drier, yields could decrease everywhere in the region. However, our understanding of the direct effects of CO_2 fertilization is less certain than our understanding of the impacts of climate change. Increased CO_2 could also affect weeds, but these impacts were not analyzed.

- If rainfall decreases, irrigation will become necessary for farming to remain viable in much of the region.

- The range of such agricultural pests as potato leafhoppers, sunflower moths, and black cutworms could move north by a few hundred kilometers. This would most likely result in increased use of pesticides.

- Considering various scenarios of climate change and CO_2, the productivity of southeastern agriculture could decline relative to northern areas, and 10 to 57% of the region's farmland could be withdrawn from cultivation. This analysis did not consider whether new crops would be introduced. The decline in cultivated acreage may tend to be concentrated in areas where farming is only marginally profitable today. A reduction in agriculture could hurt farm-related employment and the regional economy.

Forests

- There may be a significant dieback in southern forests. Higher temperatures and drier soils may make it impossible for most species to regenerate naturally and may cause forests to convert to shrub terrain or grassland. The decline in the forests could be noticeable in 30 to 80 years, depending on the site and scenario. Southern noncoastal areas, such as Atlanta and Vicksburg, may have particularly large reductions. The moist coastal forests and the relatively cool northern forests may survive, although with some losses.

- The forest industry, which is structured around currently valuable tree species, would have to either relocate or modify its planting strategies.

- Historically, abandoned farms have generally converted to forests. If large portions of the Southeast lose the ability to naturally generate forests, much of the region's landscape may gradually come to resemble that of the Great Plains.

Water Supplies

Because the winter accumulation of snow plays a negligible role in determining riverflow, our inability to predict whether rainfall will increase or decrease makes it difficult to say whether riverflows will increase or decrease.

- The limited number of hydrologic studies conducted in the Southeast further prevents us from making any definitive statement about the regionwide implications for rivers.

- Decreases in rainfall could disrupt navigation, drinking water availability, recreation, hydropower, powerplant cooling, and dilution of effluent, while increased rainfall could exacerbate the risk of flooding.

- For the scenarios used in this report, changes in operating rules for managed water systems would allow current water demands to be met in most instances.

- The Southeast generally has ample groundwater supplies. The potential implications of increased irrigation on groundwater need to be examined.

Sea Level Rise

- A 1-meter rise in sea level by the years 2100 would inundate 30 to 90% of the region's coastal wetlands and flood 2,600 to 4,600 square miles of dryland, depending on the extent to which people erect levees to protect dryland from innundation. If current river management practices continue, Louisiana alone would account for 40% of national wetland loss, and developed areas could be threatened as soon as 2025.

- Holding back the sea by pumping sand or other measures to raise barrier islands, and protecting mainland areas with bulkheads and levees, would cost approximately $42 to $75 billion through the year 2100 for a 1-meter rise.

Marine Fisheries

- Gulf coast fisheries could be negatively affected by climate change. A loss of coastal wetlands due to sea level rise could eliminate the critical habitats for shrimp, crab, and other commercially important species. Temperatures in the gulf coast estuaries may exceed the thermal tolerances for commercially important finfish and shellfish, such as shrimp, flounder, and oysters. Oysters and other species could be threatened by the increased salinity that will accompany sea level rise. Some species, such as pink shrimp and rock lobster, could increase in abundance.

Electricity Demand

The annual demand for electricity in the Southeast could rise by 14 to 22 billion kilowatthours (kWh), or 2 to 3%, by 2010 and by 100 to 197 billion kWh, or 7 to 11%, by 2055 as a result of increased temperature.

By 2010, approximately 7 to 16 gigawatts (GW) could be needed to meet the increased demand, and by 2055, 56 to 115 GW could be needed -- a 24 to 34% increase over baseline additions that may be needed without climate change. The cumulative costs could be $77 to $110 billion by 2055.

Policy Implications

- Federal laws constrain the U.S. Army Corps of Engineers and other water resource managers from rigorously considering tradeoffs between may nonstatutory objectives of federal dams in the Southeast, including recreation, water supply, and environmental quality. Increased flexibility would improve the ability of these agencies to respond to and prepare for climate change.

- Given the potential withdrawals of acreage from agriculture, the potential for growing tropical crops needs to be examined.

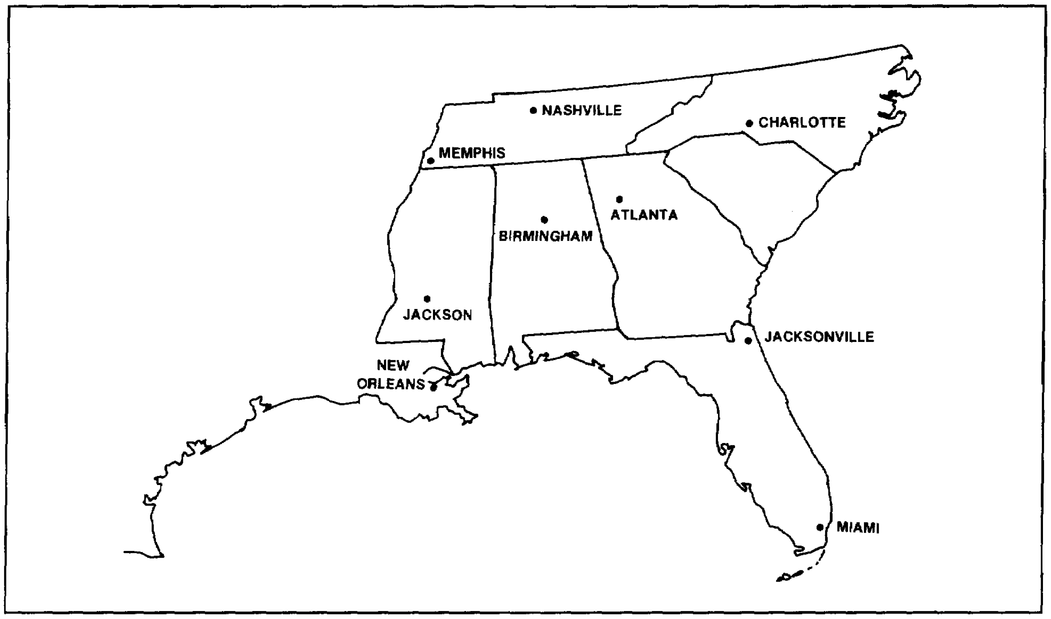


Figure 16-1. Southeast region.

- Strategies for now being evaluated by the Louisiana Geological Survey and the U.S. Army Corps of Engineers to address coastal wetland loss in Louisiana should consider a possible sea level rise of 0.5 to 2.0 meters. measures that would enable this ecosystem to survive would require major public works and changes in federal navigation and riverflow policies. Because of the decades required to implement necessary projects and the prospect that much of the ecosystem would be lost by 2030 even without climate change, these programs need to proceed expeditiously.

- Given the potentially important impacts on forests, private companies as well as agencies such as the U.S. Forest Service and state agencies may wish to assess the potential for large losses of southern forests and the implications for research and management strategies.

CLIMATE AND THE SOUTHEAST

The climate and the coastal zone of the Southeast are among the chief factors that distinguish the southeastern United States from the rest of the nation[1]. The warm temperatures, abundant rainfall, and generally flat terrain gave rise in the 17th century to a strong agricultural economy with a distinctive regional culture. The combination of a benign climate and 60% of the nation's ocean beaches continues to attract both tourists and new residents to the southeastern coastal plain. Florida, for example, is the nation's fastest growing state and will be the third largest by the year 2000 (Meo et al., Volume J).

CLIMATE-SENSITIVE RESOURCES OF THE SOUTHEAST

Water Resources

When statewide averages are considered, each of the seven states in the Southeast receives more rainfall than any other state in the continental United

[1]Except for the discussion of the economic implications for agriculture, the term "Southeast" refers to the study area shown in Figure 16-1: North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Tennessee, and the coastal zones of Louisiana and Texas.

States (although parts of some western states receive more). Moreover, the rivers of the Southeast drain over 62% of the nation's lands; the Mississippi River alone drains 38% of the nation (Geraghty et al., 1973).

The Southeast supports 50,000 square miles of bottomland hardwood forests (Mitch and Gosselink, 1986)[2], which are periodically flooded areas that offer winter habitat for migratory birds such as ducks, geese, and songbirds. Bass, catfish, and panfish are found in the slow-moving rivers, and trout inhabit the fast-moving mountain streams.

Dams have been constructed along most of the region's major rivers. Although private parties have built a few dams, most of the major projects were built by the U.S. Army Corps of Engineers, the Tennessee Valley Authority, and other federal agencies. In general, the statutory purposes of these reservoirs have been to ensure a sufficient flow of water during droughts, to prevent floods, and to generate electricity. The non-statutory objectives of environmental quality, recreation, and water supply also are considered in the operation of dams.

Dam construction has created large lakes along which people have built houses, hotels, and marinas. These dams generate 22.2 billion kilowatthours (kWh) per year, approximately 7% of the region's power requirements (Edison Electric Institute, 1985). In general, the reservoirs have sufficient capacity to retain flood surges and to maintain navigation flows during the dry season. The one notable exception is the Mississippi River: levees and land-use regulations are the main tools for preventing flood damages; although the Mississippi's base flow usually is sufficient to support navigation, boats ran aground on many stretches of the river during the drought of 1988.

In Florida, which accounts for 45% of water consumption in the Southeast, groundwater supplies about half the water used by farms and 85% of the water used for residential and industrial purposes. For the rest of the Southeast, groundwater supplies most water for agricultural and rural uses but only 30% for public supplies (see Meo et al., Volume J).

[2]This measure includes Mississippi, Arkansas, Louisiana, Texas and Virginia.

Atlanta and some other metropolitan areas obtain their water supplies from federal reservoirs; however, even the many cities that do not still may benefit from federal and federal/state water management. For example, New Orleans obtains its water from the Mississippi River. Without the Old River Control Structure in Simmesport, Louisiana, which prevents the river from changing its course to the Atchafalaya River, the New Orleans water supply would be salty during droughts. Although Miami obtains its water from the Biscayne Aquifer, some coastal wells would be salty without the efforts of the U.S. Army Corps of Engineers and the South Florida Water Management District to recharge the aquifer with supplemental freshwater from canals and Lake Okeechobee.

The various uses of water often conflict with each other. Hydroelectric power generators, lakefront residents, and boat owners benefit when water levels are maintained at high levels. However, high water levels make flood control more difficult, and municipal uses, navigation, hydropower, and environmental quality require that water be released during the dry season, which adversely affects recreation.

Estuaries

Over 43% of the fish and 70% of the shellfish harvested in U.S. waters are caught in the Southeast (NOAA, 1987). Commercially important fishes are abundant largely because the region has over 85% of the nation's coastal wetlands; over 40% are in Louisiana alone.

Most of the wetlands in the Southeast are less than 1 meter above sea level. The wetlands in Louisiana are already being lost to the sea at a rate of 50 square miles per year because of the interaction of human activities and current rates of relative sea level rise resulting from the delta's tendency to subside 1 centimeter per year. (This problem is discussed in greater detail below.)

Summer temperatures in many of the gulf coast estuaries are almost as warm as crabs, shrimp, oysters, and other commercially important fishes can tolerate (Livingston, Volume E). Winter temperatures along the gulf coast are almost warm enough to support mangrove swamps, which generally replace marshes once they are established; mangroves already dominate the Florida coast south of Fort Lauderdale.

Beach Erosion and Coastal Flooding

The Southeast has 1,100 miles of sandy ocean beaches, many of which are found on low and narrow barrier islands. The Atlantic coast is heavily developed, while much of the gulf coast is only now being developed. In part because of their vulnerability to hurricanes, none of Mississippi's barrier islands has been developed, and only one of Louisiana's barrier islands is developed at present. Because much of Florida's gulf coast is marsh, it is still largely undeveloped.

All eight coastal states are experiencing coastal erosion. Along developed coasts, recreational beaches have narrowed, increasing the vulnerability of shorefront structures to storms. In Louisiana, some undeveloped barrier islands are eroding and breaking up. Elsewhere, narrow barrier islands are keeping pace with sea level rise by "overwashing" (i.e., rolling over like a rug) in a landward direction, while wide islands and mainland coasts have simply eroded. The coastal states of the Southeast are responding by holding back the sea in some areas and by adapting to erosion in others.

The two greatest natural disasters in U.S. history resulted from floods associated with hurricanes in Galveston, Texas, and Lake Okeechobee, Florida, in which over 8,000 people drowned. After the Mississippi River overflowed its banks and inundated most of coastal Louisiana in the 1930s, Congress directed the U.S. Army Corps of Engineers to initiate a major federal program of flood control centered around the Southeast. Nevertheless, flood waters often remain over some low areas in Louisiana and Florida for several days after a major rainstorm.

Hurricanes continue to destroy recreational development in at least a few ocean beach communities almost every year in the Southeast. The region presently experiences the majority of U.S. coastal flooding and probably would sustain the worst increases in flooding as a result of global warming. Unlike the Northeast and Pacific coasts, this region has wide low-lying coastal plains and experiences several hurricanes annually. Florida, Texas, and Louisiana account for 62% of the $144 billion of private property insured by the Federal Flood Insurance Program (see Riebsame, Volume J).

Agriculture

In the last few years, droughts and heat waves have caused crop failures in many parts of the Southeast. Unlike much of the nation, cold weather generally is not a major constraint to agricultural production, except for Florida's citrus industry.

Although cotton and tobacco were once the mainstays of the Southeast's economy, agriculture now accounts for only 1% of the region's income (U.S. Department of Commerce, 1986). Since World War II, substantial amounts of farmland have been withdrawn from agriculture, and much of thus land has been converted to forest. The cotton crop has been largely lost to the irrigated Southwest, and although tobacco remains profitable, it is grown on only 500,000 acres. However, in the last few decades, southeastern farmers have found soybeans to be profitable; this crop now accounts for 45% of all cultivated land in the Southeast. Corn continues to account for 5% of southeastern agriculture U.S. Department of Commerce, 1982). Table 16-1 compares annual revenues by state for various crops.

Forests

The commercial viability of southeastern forests has increased greatly since World War 11, primarily as a result of the increased use of softwoods, such as pines and firs, for plywood and for applications that once required hardwood. Because this transition coincided with lower farm prices and declining soils in the piedmont foothills of the Southeast, many mountain farms have been converted to forests. However, in the last 10 years, 7 million acres of coastal plain forests have been converted to agriculture (Healy, 1985).

Approximately 45% of the nation's softwood (mostly loblolly pine) and 50% of its hardwood are grown in the region. Forests cover 60% of the Southeast, and 90% of forests are logged. Oak-hickory covers 35%, and pine covers another 33% of commercial forests. Only9% of the southeastern forests are owned by federal and state governments, and 18% are owned by the forest industry. In contrast, 73% of the forests are owned by farmers and other private parties (Healy, 1985).

Table 16-1. Annual Revenues by State for 33% of commercial forests. Only 9% of the Various Crops (thousands of 1986 southeastern forests are owned by federal and state dollars)

Crop	Value
Corn for grain	
Alabama	856,550
Florida	31,493
Georgia	203,931
Mississippi	22,600
North Carolina	324,789
South Carolina	104,333
Tennessee	193,687
Cotton	
Alabama	145,540
Florida	8,112
Georgia	97,325
Mississippi	449,630
North Carolina	30,944
Tennessee	109,610
Sugarcane for sugar and seed	
Florida	369,899
Tobacco	
Florida	NA
Georgia	NA
North Carolina	NA
South Carolina	NA
Tennessee	NA
Peanuts for nuts	
Alabama	133,930
Florida	48,600
Georgia	472,645
North Carolina	122,941
South Carolina	5,882
Soybeans	
Alabama	140,719
Florida	31,036
Georgia	179,676
Mississippi	365,018
North Carolina	196,673
South Carolina	125,214
Tennessee	230,373

NA= Not Available.
Source: U.S. Department of Agriculture (1987).

Indoor and Outdoor Comfort

The southeast is one of the few areas that spends as much money on air-conditioning as heating. Figure 16-2 shows temperatures throughout the Southeast for the months of January and July. Even in January, about half the region experiences average temperatures above 50°F. Thus, with the possible exception of the cool mountains of Tennessee and North Carolina, a global warming would increase the number of days during which outdoor temperatures would be unpleasantly hot much more than it would reduce the number of unpleasantly cold days.

PREVIOUS STUDIES OF THE IMPACTS OF CLIMATE CHANGE ON THE SOUTHEAST

Most studies examining the impact of global warming on the Southeast have focused on sea level rise. Recent efforts have addressed other topics. Several dozen researchers presented papers on other global warming impacts on the Southeast at a 1987 EPA conference held in New Orleans (Meo, 1987). Their papers suggested that agricultural yields would decline, forest species would shift, and that coastal and water supply officials should start to plan for the consequences of global warming.

Flooding

Leatherman (1984) and Kana et al. (1984) applied flood-forecasting models to assess potential increases in flooding in Galveston, Texas, and Charleston, South Carolina. For the Galveston area, a 90-centimeter (3-foot) rise would increase the 100-year floodplain by 50%, while a 160-centimeter (5.2-foot) rise would enable the 100-year storm to overtop the seawall erected after the disaster of 1900. For the Charleston area, a 160-centimeter rise would increase the 10-year floodplain to the area currently covered by the 100year floodplain.

Gibbs (1984) estimated that the economic impact of a 90-centimeter rise by 2075 could be as great as $500 million for Galveston and over $1 billion for Charleston. However, he also estimated that the adverse impacts of flooding and land loss could be cut in half if the communities adopted measures in anticipation of sea level rise. Titus (1984) focused on decisions facing

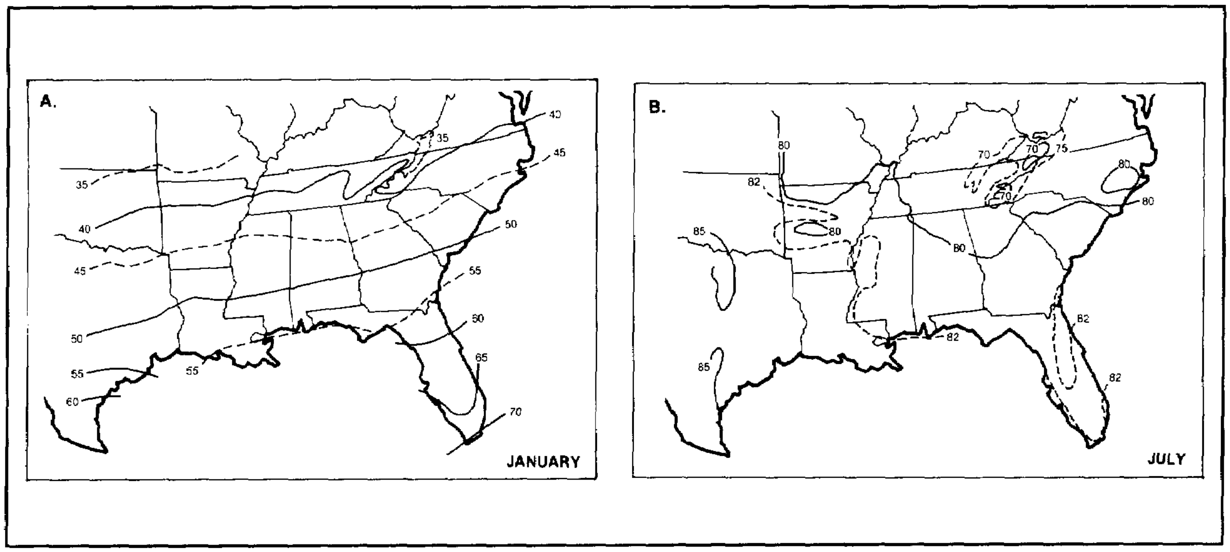


Figure 16-2. Typical temperatures in the Southeast: (A) January, (B) July.

Sullivans Island, South Carolina, in the aftermath of a storm. He concluded that rebuilding $15 million in oceanfront houses after a storm would not be economically sound if future sea level rise is anticipated, unless the community is prepared to continuously nourish its beaches.

Wetlands

Kana et al. (1986) surveyed marsh transects and estimated that 90- and 160-centimeter (3.0- and 5.2-foot) rises in sea level would drown 50 and 90%, respectively, of the marsh around Charleston, South Carolina. Armentano et al. (1988) estimated the Southeast would lose 35 and 70% of its coastal wetlands for respective rises of 1.4 and 2.1 meters, assuming that developed areas are not protected.

Infrastructure

The Louisiana Wetland Protection Panel (1987) concluded that a rise in sea level might necessitate substantial changes in the ports and shipping lanes of the Mississippi River to prevent the loss of several thousand square miles of coastal wetlands. Titus et al. (1987) showed that a reconstructed coastal drainage system in Charleston should be designed for a 1-foot rise in sea level if the probability of such a rise is greater than 30%. Linder et al. (1988) found that warmer temperatures would require an electric utility company to substantially increase its generating capacity.

CLIMATE CHANGE STUDIES IN THIS REPORT

Table 16-2 and Figure 16-3 illustrate the studies undertaken as part of this effort. Few resources had previously been applied to examining the various impacts of climate change for the Southeast. Models of coastal erosion, coastal wetland loss, agricultural yields, forest dynamics, and electricity consumption were sufficiently refined, so that it was possible to inexpensively apply them to numerous sites and develop regional assessments. Louisiana, which accounts for half of the region's wetlands, has been the subject of previous studies. It is discussed following the studies for this report.

By contrast, the impacts on water resources and ecosystems required more detailed site-specific studies, and it was not possible to undertake such case studies for a large number of watersheds or ecosystems. Therefore, our analysis was limited to representative case studies. For water resources, we picked (1) the Tennessee Valley, because it is the largest managed watershed in the region; and (2) Lake Lamer, because it serves Atlanta, the region's second largest city. In both cases, we were able to identify researchers who were already familiar with the area. The sole aquatic ecosystem studied in depth was Apalachicola Bay, picked because the estuary had already been the subject of the most comprehensive data collection effort in the Southeast.

Table 16-2. Studies of the Southeast

Regional Studies

- Impacts on Runoff in the Upper Chattahoochee River Basin - Hains, C.F. Haines, Hydrologist, Inc. (Volume A)
- Projected Changes in Estuarine Conditions Based on Models of Long-Term Atmospheric Alteration - Livingston, Florida State University (Volume E)
- Policy Implications of Global Climatic Change Impacts Upon the Tennessee Valley Authoriy Reservoir System, Apalachicola River, Estuary and Bay and South Florida - Meo, Ballard, Deyle, James, Malysa, and Wilson, University of Oklahoma (Volume J)
- Potential Impacts on Climatic Change on the Tennessee Valley Authority Reservoir System -Miller and Brock, Tennessee Valley Authority (Volume A)
- Impact of Climate Change on Crop Yield in the Southeastern U.S.A. - Peart, Jones, and Curry, University of Florida (Volume C)
- Methods for Evaluating the Potential Impacts of Global Climate Change - Sheer and Randall, Water Resources Management, Inc. (Volume A)
- Forest Response to Climate Change: A Simulation Study for Southeastern Forests - Urban and Shugart, University of Virginia (Volume D)

National Studies That Included Southeast Results

- The Economic Effects of Climate Change on U.S. Agriculture: A Preliminary Assessment - Adams, Glyer, and McCarl, Oregon State University (Volume C)
- National Assessment of Beach Nourishment Requirements Associated with Accelerated Sea Level Rise - Leatherman, University of Maryland (Volume B)
- The Potential Impacts of Climate Change on Electric Utilities: Regional and National Estimates -Linder and Inglis, ICF Inc. (Volume H)
- The Effects of Sea Level Rise on U.S. Coastal Wetlands -Park and Trehan, Butler University and Mausel and Howe, Indiana State University (Volume B)
- Potential Effects of Climatic Change on Plant-Pest Interactions - Stinner, Rodenhouse, Taylor, Hammond, Purrington, McCartney, and Barrett, Ohio Agricultural Research and Development Center (Volume C)
- Assessing the Responses of Vegetation to Future Climate Change: Ecological Response Surfaces and Paleoloocal Model Validation - Overpeck and Bartlein, Lamont-Doherty Geological Observatory (Volume D)
- An Overview of the Nationwide Impacts of Rising, Sea Level - Titus and Greene, U.S. Environmental Protection Agency (Volume B)
- The Cost of Defending Developed Shorelines Along Sheltered Waters of the United States from a Two Meter Rise in Mean Sea Level - Weggel, Brown, Escajadillo, Breen, and Doheny, Drexel University (Volume B)

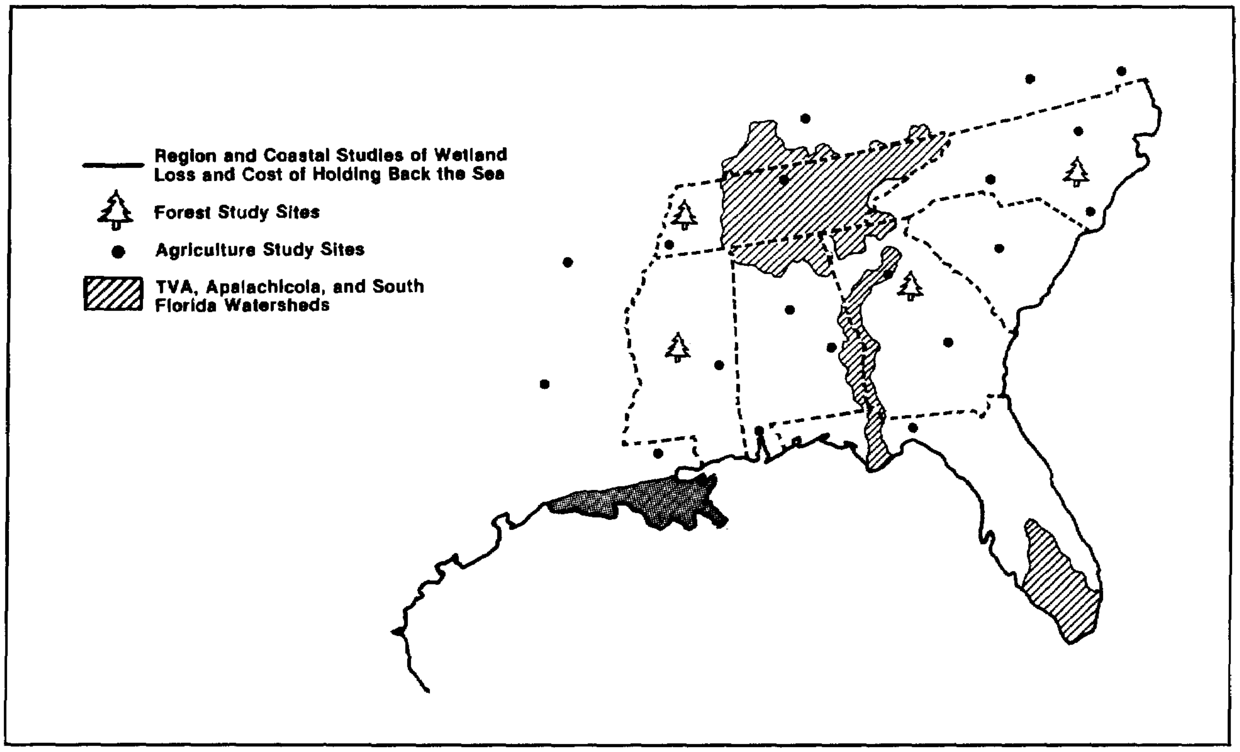


Figure 16-3. Overview of studies of the Southeast.

SOUTHEAST REGIONAL CLIMATE CHANGE SCENARIOS

Figure 16-4 illustrates the scenarios of future climate change from general circulation models. Table 16-3 shows the more detailed seasonal changes.

Table 16-3 illustrates how the frequency of mild days during the winter and the frequency of very hot days during the summer might change under the Goddard Institute for Space Studies (GISS) doubled CO_2 scenario. As explained in Chapter 4: Methodology, these estimates used average monthly changes in temperature and assumed no change in variability. Under this scenario, the number of days per year in which the mercury would fall below freezing would decrease from 34 to 6 in Jackson, Mississippi; from 39 to 20 in Atlanta; and from 41 to 8 in Memphis. The number of winter days above 70°F would increase from 15 to 44 in Jackson, from 4 to 14 in Atlanta, and from 5 to 24 in Memphis.

Of the nine cities shown, only Nashville has summer temperatures that currently do not regularly exceed 80°F. However, the number of days with highs below 80°F would decline from 60 to 34. Elsewhere, the heat would be worse. The number of days per year above 90°F would increase from 30 to 84 in Miami, from 17 to 53 in Atlanta, and from 55 to 85 in New Orleans. Memphis, Jackson, New Orleans, and Jacksonville, which currently experience 0 to 3 days per year above 100°F, would have 13 to 20 such days (Kalkstein, Volume G).

RESULTS OF SOUTHEASTERN STUDIES

Coastal Impacts

A number of national studies for the report presented results for the effects of climate change on the southeastern coast. Leatherman estimated the cost of maintaining recreational beaches. Park et al. and Weggel et al. examined the impacts on wetland loss and shoreline defense, and used their results to estimate the regionwide cost of raising barrier islands. The projected

Table 16-3. The GISS Doubled $_{CO2}$ Scenario: Frequency of Hot and Cold Days (°F)

Location	Number of winter days with:				Number of summer days with:					
	Daily low <32		Daily high >70		Daily high <80		Daily high >90		Daily high >100	
	HIST[a]	$2x_{CO2}$	HIST[a]	$2x_{CO2}$	HIST[a]	$2x_{CO2}$	HIST[a]	$2x_{CO2}$	HIST[a]	$2x_{CO2}$
Atlanta, GA	38.3	20.5	4.2	13.6	10.0	2.2	17.1	53.3	0.6	4.2
Birmingham, AL	35.5	8.1	7.1	30.7	4.5	0.4	34.1	72.5	1.5	10.7
Charlotte, NC	42.1	23.8	3.4	9.9	11.9	3.7	23.1	56.5	0.1	5.9
Jackson, MS	33.5	5.9	15.3	43.5	0.8	0.2	55.1	83.1	2.0	19.5
Jacksonville, FL	9.3	1.7	34.6	49.6	2.3	0.3	46.4	81.3	0.6	14.1
Memphis, TN	41.2	8.1	5.2	23.6	4.9	0.7	50.5	74.8	2.6	19.1
Miami, FL	0.2	0.0	72.9	82.7	0.6	0.0	29.8	83.5	0.0	2.5
Nashville, TN	42.5	15.4	0.3	8.6	60.4	33.7	10.5	20.2	0.3	3.5
New Orleans, LA	14.9	3.5	24.9	39.5	0.9	0.1	55.4	84.9	0.3	13.5

HIST[a] = Historic.
Source: Kalkstein (Volume G).

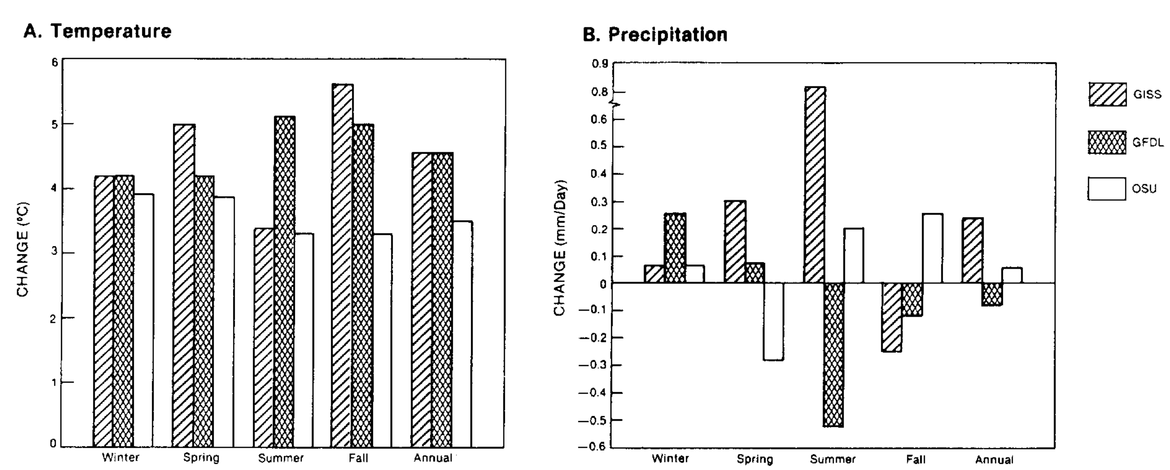


Figure 16-4. $2xCO_2$ less $1XCO_2$ climate scenarios for the Southeast: (A) temperature, and (B) precipitation..

rise in sea level would cause shorelines to retreat, exacerbate coastal flooding, and increase the salinity of estuaries, wetlands, and aquifers. (For a discussion of the rationale, methods, and nationwide results of these studies, see Chapter 7: Sea Level Rise.)

Coastal Wetlands

Park et al. (Volume B) examined 29 southeastern sites to estimate the regionwide loss of coastal wetlands for a variety of scenarios of future sea level rise. Their analyses included such societal responses as providing structural protection for all shorelines (total protection), protecting areas that are densely developed today (standard protection), and allowing shorelines to adjust naturally without coastal protection (no protection).

Figure 16-5 illustrates their estimates for the year 2100 for the various scenarios of sea level rise and coastal defense. Even if current sea level trends continue, 25% of the Southeast's coastal wetlands will be lost, mostly in Louisiana. Excluding Louisiana:

- current trends imply a loss of 15%;
- a 50-centimeter rise could result in a loss of 35 to 50%, depending on how shorelines are managed;
- a 100-centimeter rise could result in losses of 45 to 68%; and
- a 200-centimeter rise implies losses of 63 to 80%.

Park et al. estimated losses of 50, 75, and 98% for Louisiana under the three scenarios. However, they did not consider the potential for mitigating the loss by restoring the flow of river water into these wetlands; no model exists that could do so (Louisiana Wetland Protection Panel, 1987). Titus and Greene estimated statistical confidence intervals illustrated in Table 16-4.

Total Coastal Land Loss

Park et al. also estimated total land loss, including both wetlands and dryland. Most of the land loss from a rise in sea level would occur in Louisiana. A 50-centimeter (20-inch) sea level rise would result in the loss of 1,900 to 5,900 square miles of land, while a 200-centimeter rise would inundate 10,000 to 11,000 square miles.

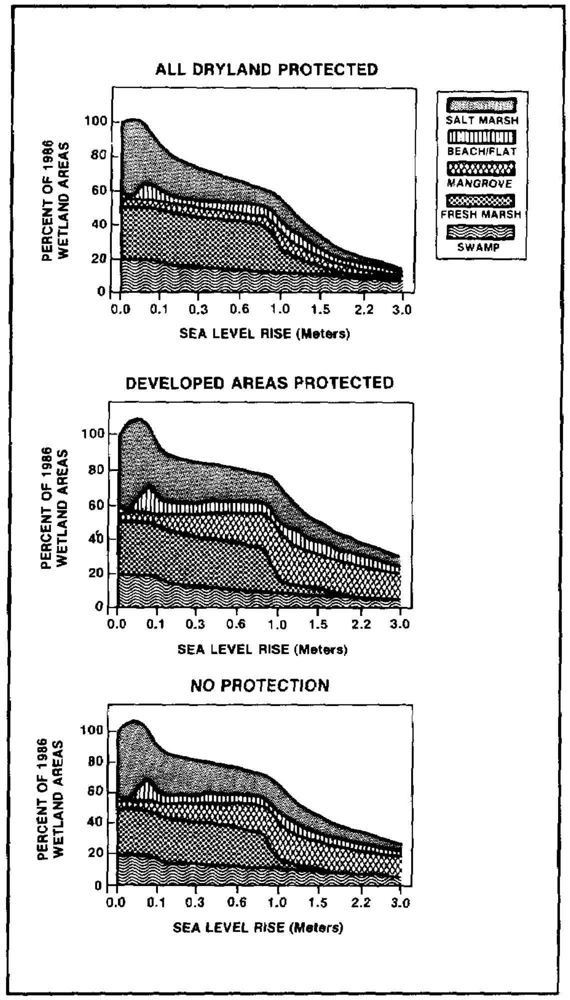


Figure 16-5. Wetlands loss in the Southeast for three shoreline protection options (Park et al., Volume B). (NOTE: These numbers are different from those in Table 16-4 because they include nonvegetated wetlands, i.e., beaches and flats.)

Cost of Protecting Recreational Beaches

In Volume B, Leatherman notes that the projected rise in sea level would threaten all developed recreational beaches. Even a 1-foot sea level rise would erode shorelines over 100 feet throughout the Southeast. Along the coasts of North Carolina and Louisiana, the erosion would be considerably greater. Because the distance from the high tide line to the first building is rarely more than 100 feet, most recreational beaches would be lost, unless either the buildings were removed or coastal protection measures were undertaken.

Table 16-4 illustrates Leatherman's estimates of the cost of protecting recreational beaches by pumping sand from offshore locations. (See Table 7-3 for state-by-state results). A 1-meter rise in sea level could imply almost $20 billion in dredging costs, with Texas spending $8.5 billion and Florida and Louisiana each spending over $3 billion.

Using constant unit costs (except for Florida), Leatherman estimated that a 2-meter rise could only double the total cost to $43 billion. Titus and Greene estimated that if the unit costs of sand increased, 1- and 2-meter rises could cost $30 and $74 billion, respectively. They also estimated that the respective costs of rebuilding roads and utilities on barrier islands could be $5 to 9 billion, $10 to 40 billion, and $60 to 75 billion for the three scenarios.

Cost of Protecting Calm-Water Shorelines

While Leatherman focused only on the open ocean coast, Weggel et al. estimated the regionwide costs of holding back the sea in developed sheltered and calm-water areas. Weggel et al. estimate that about $2 billion would be spent to raise roads and to move structures, and $23 billion would be spent to erect the necessary levees and bulkheads for a 2meter rise. Table 16-4 shows confidence intervals estimated by Titus and Greene, which imply a total cost of $42 to 75 billion for a 1- meter rise. The combined cost is $68 to 83 billion. These estimates do not include the costs of preventing flooding or of protecting water supplies.

Table 16-4. Summary of Results of Sea Level Rise Studies for the Southeast (billions of dollars)

Response	Baseline	50-cm rise	100-cm rise	200-cm rise
Developed areas are protected				
Land lost				
Dryland lost (mi^2)	1,300-3,700	1,900-5,500	2,600-6,900	4,200-10,100
Wetlands lost (%)[a]	11-22	24-50	34-77	40-90
Cost of coastal defense		19-28	42-75	127-174
Open coast				
Sand	3	10-15	19-30	44-74
Elevated structures	negligible[b]	5-9	10-40	60-75
Sheltered shores	negligible[b]	2-5	5-13	9-41
All shores are protected				
Land lost				
Dryland lost (mi^2)				
Wetlands lost (%)[a]	0	0	0	0
No shores are protected	0	38-61	47-90	68-93
Land lost				
Dryland lost (mi^2)	N/A	2,300-5,900	3,200-7,600	4,800-10,800
Wetlands lost (%)[a]	N/A	22-48	30-75	37-88

[a] "Wetlands" refers to vegetated wetlands only; it does not include beaches or tidal waves.
[b] Costs due to sea level rise are negligible.
Source: Titus and Greene (Volume B).

Tennessee Valley Authority Studies

The Tennessee Valley Authority (TVA) was created in 1933 to spur economic growth in an area previously considered to be one of the nation's poorest. Geographically isolated by the Appalachian Mountains, the region lacked electricity and roads, and the Tennessee River could not provide reliable transportation because it flooded in the spring and dried to a trickle during the summer. By creating the TVA, Congress sought to remedy this situation by harnessing the river to provide electricity, to prevent the flooding that had plagued Chattanooga, and to ensure sufficiently stable riverflows that would permit maintenance of a 9-foot-deep navigation channel.

The region administered by the TVA covers 40,000 square miles and includes parts of seven states. In the last half century, the TVA has coordinated the construction of 43 major dams along the river and its tributaries, many of which are shown in Figure 16-6. The system provides power to over 7 million people and contains 675 miles of navigable waterways with annual commercial freight of 28 million tons. The lakes created by the dams have over 10,000 miles of shorelines, which generate 75 million visits each year and along which people have invested $630 million, boosting the region's annual economy by $400 million (Miller and Brock, Volume A).

To assess the potential impacts of climate change, Miller and Brock conducted a modeling study of the water resource implications, and Meo et al. examined the policy implications for the TVA.

<u>TVA Modeling Study</u>

Methods

Miller and Brock used the TVA's "Weekly Scheduling Model," which the Agency currently uses in setting the guidelines for its operations, to assess the impacts of climate change. This linear programming model selects a weekly schedule for managing each reservoir in the TVA system by sequentially satisfying the objectives of flood control, navigation, water supply, power generation, water quality, and recreation. Miller and Brock used this model to simulate reservoir levels, riverflows, and hydropower generation for wet and dry scenarios, derived from the runoff estimates from the GISS doubled CO_2 model run.

TVA was unable to use a hydrologic model to estimate runoff for this study. Instead, they sought to use the runoff estimates from general circulation models. Unfortunately, the OSU and GFDL models estimate that there is no runoff today, which would not permit derivation of a scenario. Therefore, the GISS runoff estimates were used as the "wet scenarios." Based on Rind (1988), the dry scenario simply assumed that the change in runoff would be the inverse of the change assumed in the wet scenario. Therefore, a TVA study should be viewed as an assessment of the system's sensitivity to climate change, not as the literal implications of particular general circulation models.

Miller and Brock assessed the potential impacts of climate change on flood levels in Chattanooga, Tennessee, using a model that had been developed to estimate the constraints on weekly tributary releases. They also estimated the potential implications for water quality in the Upper Holston Basin of the valley, using a reservoir water quality model, a riverflow model, and a water quality model that TVA has used in the past to determine the environmental constraints affecting riverflow.

<u>Limitations</u>

Because the riverflow scenarios were not based on hydrologic analysis, conclusions cannot be drawn regarding the sensitivity of riverflow to climate change; a more thorough study should apply a basinwide hydrologic model to the region. A key limitation for the flood analysis was that EPA assumed that every storm in a given month would result in a change in riverflow proportional to the change in monthly runoff rather than incorporating potential changes in flood frequency and intensity. (For climate change scenarios, see Chapter 4: Methodology.) Finally, the study assumed that TVA would not mitigate impacts by changing its operating rules for the reservoirs in response to climate change.

<u>Results</u>

Reservoir levels

Figure 16-7 shows the estimates of the changes in reservoir levels in the Norris Reservoir for the wet and dry scenarios. Currently, water levels are typically

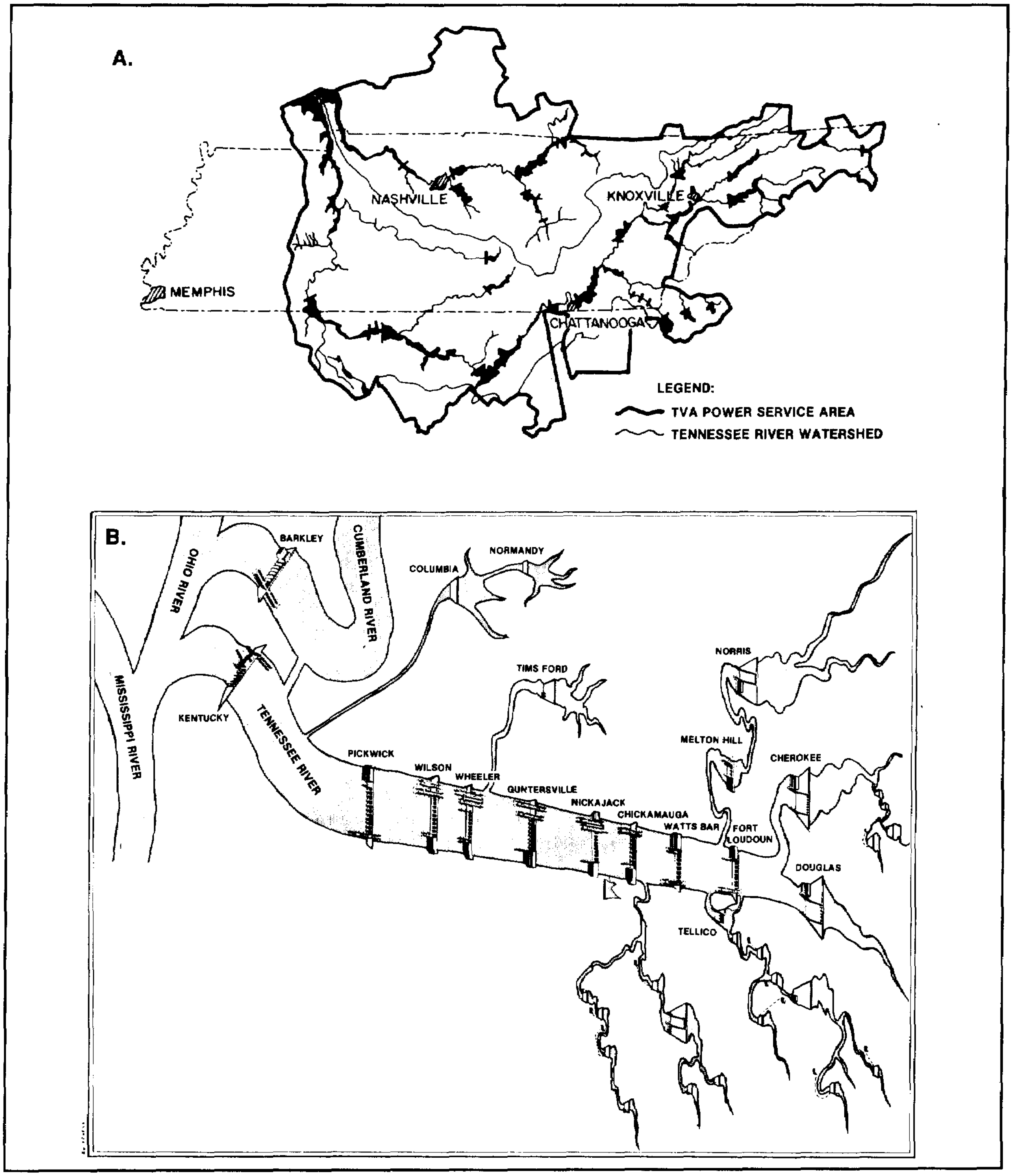


Figure 16-6. (A) Map of the TVA region, and (B) schematic of the TVA reservoir system (Miller and Brock, Volume A).

above 1,010 feet (NGVD) from early May to early August. Under the wet scenario, the water would generally be above this level from early April to early September; during the driest years (1%), the water levels would be similar to the current normal level between May and October. In the dry scenario, water levels would never exceed 1,005 feet in a typical year, and even during the wettest years (1%) they would barely exceed the current normal condition between April and September.

Changes in lake levels of this magnitude would have important implications for recreation in the Tennessee Valley, which is supported by facilities worth over $600 million. Even today, recreation proponents are concerned with reservoir levels dropping during some summers. Miller and Brock found that the wet scenario would largely eliminate current problems with low lake levels; in contrast, the dry scenario would make these problems the norm.

Water Quality

Miller and Brock found that a drier climate could also create environmental problems. Lower flows would reduce the dilution of municipal and industrial effluents discharged into the river and its tributaries. Moreover, because water would generally remain at the bottom of reservoirs for a longer period of time, the amount of dissolved oxygen could decline; this would directly harm fish and reduce the ability of streams to assimilate wastes. Miller and Brock concluded that the water supplies from TVA would probably be sufficient, but that TVA could experience operational difficulties and customer dissatisfaction due to degraded water quality. During extended low-flow conditions, wastes would have increased opportunities to backflow upstream to water supply intakes.

Flooding

Although a drier climate could exacerbate many current problems facing TVA, a wetter climate could create difficulties, particularly the risk of flooding, in matters that are currently under control. Miller and Brock found that in the wet scenario, during exceptionally wet years, storage would be inadequate at the tributary reservoirs; this condition could result in uncontrolled spillage over dams. A high probability of flooding would also exist at Chattanooga. Miller and Brock examined the levels of the five worst floods of the last 50 years at Chattanooga, which did not overflow the banks of the Tennessee River or flood the city. However, under the wet scenario, two of the floods would overtop the banks. The worst flood could reach a level of 56.3 feet and cause over $1 billion in damages; the second worst could reach a level of 46 feet and cause over $200 million in damages (see Figure 16-8).

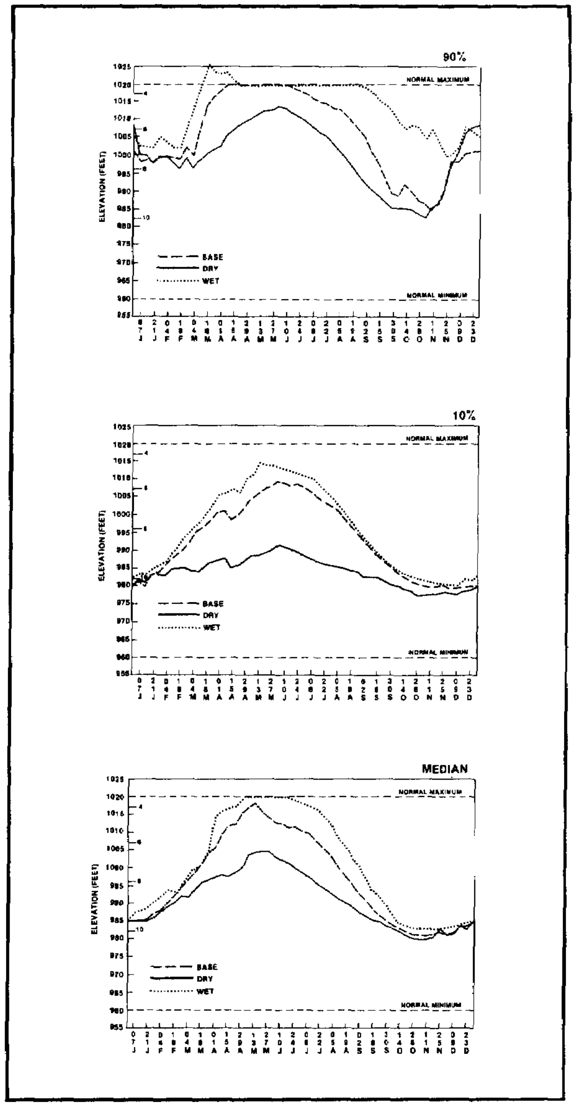


Figure 16-7. Water levels in Norris Reservoir under climate scenarios: (A) 10% wet test years; (B) median; and (C) 10% driest years (adapted from Miller and Brock, Volume A).

Flooding could be reduced if operating rules were modified to keep water levels lower in reservoirs on tributaries (although this would diminish the hydropower benefits from a wetter climate). However, changes in operating rules would not be sufficient to protect Chattanooga from being flooded during a repeat of the worst storm, because rainfall would be largely concentrated over the "mainstem" reservoirs, which do not have substantial flood-control storage.

Power Generation

Miller and Brock calculated that the wet and dry scenarios imply, respectively, an annual increase of 3.2megawatt-hours (16%, $54 million per year) and a decrease of 4.6 megawatt-hours (24%, $87 million per year), given current capacity and operating rules.

Climate change could also have an impact on fossil-fuel powerplants. If river temperatures become warmer, they will require additional dilution water. Although sufficient water would be available if the climate became wetter, meeting minimum flow requirements would be more difficult if climate became drier. Miller suggested that the most feasible operational change would be to cut back power generation at fossil-fuel powerplants during periods of low flow. However, hydropower production would also be reduced during periods of low flow, so cutting back production might not be acceptable. One alternative would be to construct cooling towers, which would eliminate discharges of hot water, at a capital cost of approximately $75 million.

<u>Tennessee Valley Policy Study</u>

Meo et al. (Volume J) analyzed the history, statutory authority, and institutional structure of the TVA to assess the ability of the organization to respond to climate change. Their analysis relied both on the available literature and on interviews with a few dozen officials of TVA and states within the region. They divided the possible responses of TVA into two broad categories: (1) continuing the current policy of maximizing the value of hydroelectric power, subject to the constraints of flood control and navigation; and (2) modifying priorities so that power generation would be subordinated to other objectives if doing so would yield a greater benefit to the region. They concluded that if the climate became wetter, current policies would probably be adequate to address climate change because the only adverse effect would be the risk of additional flooding, which is already a top priority of the system.

If climate became drier, on the other hand, existing policies might be inadequate, because they require power generation to take precedence over many of the resources that would be hardest hit. Although they expect that the TVA will be more successful at addressing future droughts, Meo et al. found that during the 1985-86 drought, falling lake levels impaired recreation and reduced hydropower generation, forcing the region to import power while five powerplants sat idle. Meo et al. point out that groundwater tables are falling in parts of the region, in part because numerous tributaries recharge the aquifers whenever water is flowing but are allowed to run dry when water is not being released for hydropower. They suggest that even without climate change, the deteriorating groundwater quality and availability are likely to lead a number of communities to shift to surface water supplies in the coming decades, adding another use that must compete for the water that is left over when the demands for power have been met. Even with current climate, they contend, the TVA should assess whether other uses of the region's water resources would benefit the economy more. If climate becomes drier, the need for such a reevaluation will be even more necessary.

Studies of the Impacts on Lake Lanier and Apalachicola Bay

Figure 16-9 shows the boundaries of the 19,800-square-mile Chattahoochee- Flint Apalachicola River Basin. The U.S. Army Corps of Engineers and others who manage the Chattahoochee River as it passes through Lake Lamer on its way to the Apalachicola estuary and the Gulf of Mexico face many of the same issues as those faced by the TVA. However, they also are managing the water supply of Atlanta, the second largest city in the Southeast, and the flow of water into an estuary that supports the most productive fishery in Florida (U.S. Department of Commerce, 1988).

A number of researchers were involved in EPA's assessment of the potential implications of climate change for this watershed. A study of Lake Lamer and a study of the implications for the fish in Apalachicola Bay are discussed in the following sections of this chapter.

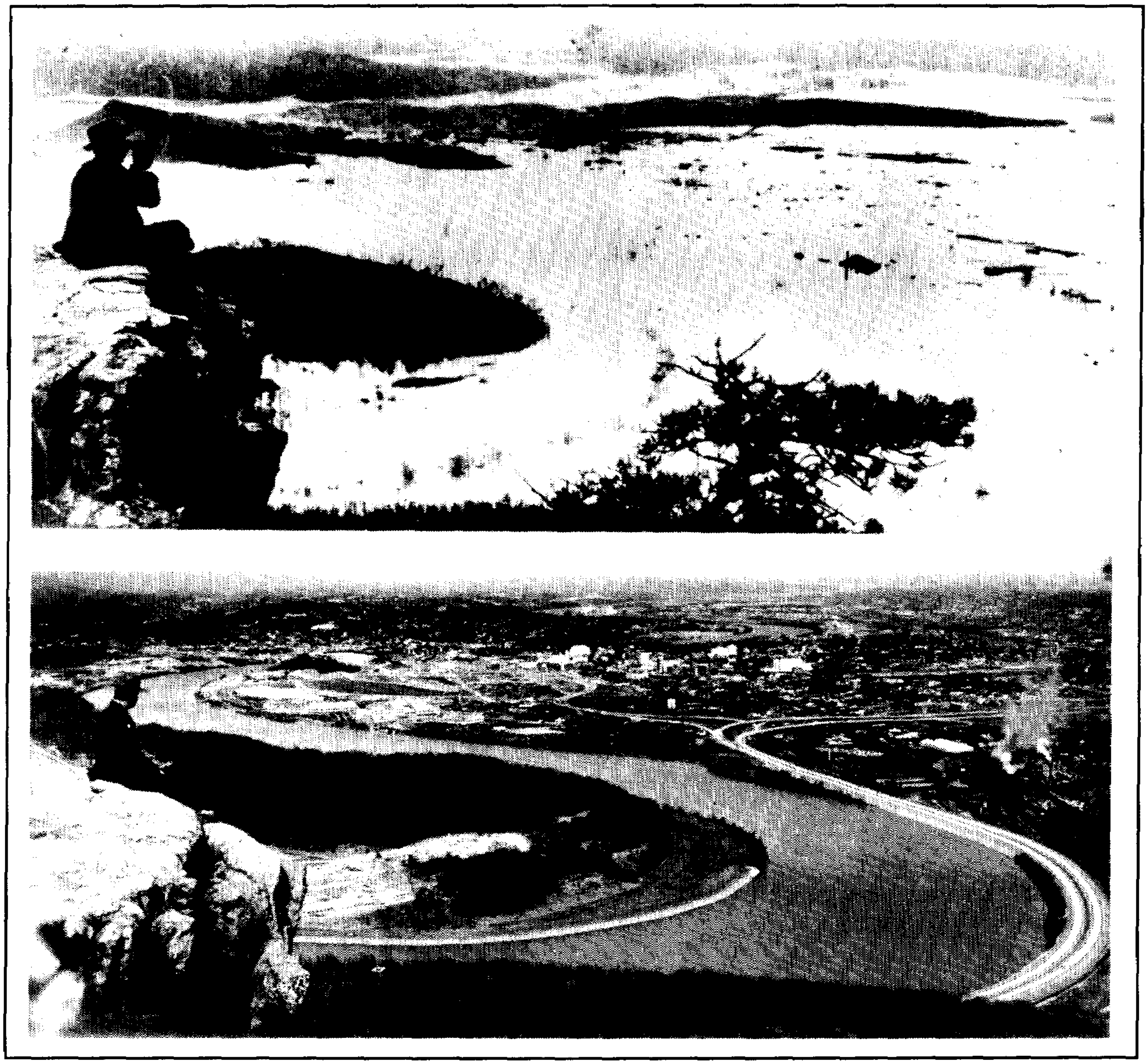


Figure 16-8. Chattanooga was vulnerable to flooding until the TVA system of dams was constructed. The upper photo shows the 1867 Flood, with water levels similar to those projected by the Miller and Brock under the wet scenario (Miller and Brock, Volume A).

Lake Lanier

Lake Lanier, located 30 miles northeast of Atlanta, is a source of water for the city and nearby jurisdictions. Federal statutes require the U.S. Army Corps of Engineers to manage Lake Lanier to provide flood control, navigation, and hydropower. Nevertheless, the lake is also managed to meet nonstatutory objections such as recreation, minimum flows for environmental dilution, and water supply.

Since Lake Lanier was dammed in 1957, the statutory objectives of flooding and navigation have been met; annual hydropower generation has been 134

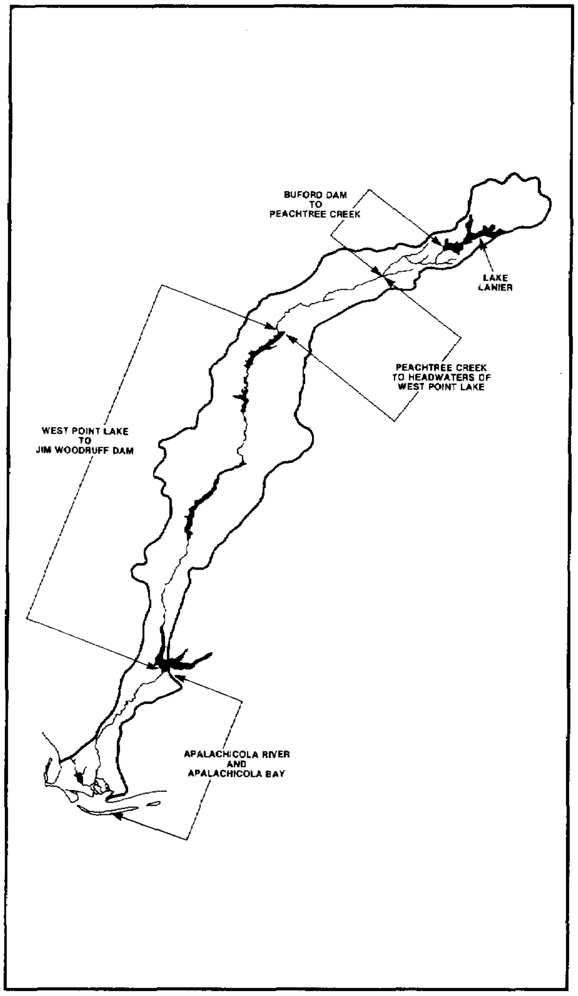


Figure 16-9. Drainage area of the Apalachicola-Chattahoochee-Flint River system.

MWH[3], equal to 2% of today's power requirements for Atlanta; and the releases of water have fulfilled the additional minimum flow needed to dilute the effluents from sewage treatment plants.

During the last two decades, the lake's shoreline has been substantially developed with marinas, houses, and hotels. To a large degree, the residents have become accustomed to the higher water levels that prevailed from the 1970s through 1984. Droughts from 1985 to the present, however, have lowered lake levels, disrupting recreation. In the summer of 1986, navigation for recreational boats located downstream of the lake was curtailed because of minimal releases from the lake. In 1988, Atlanta imposed water-use restrictions, with the objective of cutting consumption by 10 to 20%. A bill has been introduced to add recreation to the list of statutory purposes (HR-4257).

Runoff in the Chattahoochee River Basin

Study Design. Hains estimated runoff in the Chattahoochee River Basin and the flow of water into Lake Lanier for the three scenarios. He calibrated the Sacramento hydrology model developed by the National Weather Service (Burnash et al., 1973) to the conditions found in the watershed of the upper Chattahoochee River. He then generated scenarios of riverflow for the baseline climate and the GCM scenarios.

Limitations. The Sacramento model was designed primarily for flood forecasting, not base flow. In addition, the model was calibrated using the data on evaporation of water from pans, which is not perfectly correlated with evapotranspiration, and these data came from a nearby watershed.

Since the analysis was based on scenarios of average monthly change, it did not consider potential changes in variability of events such as floods. The analysis did not incorporate changes in vegetation, which could affect runoff.

Results. As with the Tennessee River, the major climate models disagree on whether the Chattahoochee watershed would become wetter or drier with an effective doubling of greenhouse gases. Hains estimated that under the wetter GISS scenario, the average annual riverflow of the Chattahoochee River would increase by 13%; the drier OSU and GFDL models imply declines of 19 and 27%, respectively, as shown in Figure 16-10. The GISS scenario implies slight decreases in winter flow and increases the rest of the year. Under the GFDL scenario, these substantial decreases were estimated throughout the year, with almost no flow in late summer. The OSU scenario also shows reductions, but the reduction is greatest during the flood season (February to May) and negligible

[3]Personal communication from Harold Jones, Systems Engineer, Southeast Power Administration, Department of Energy, September 12, 1988.

during the dry season (late summer/early fall).

Management of Lake Lanier

Study Design. Sheer and Randall (Volume A) examined the implications for water management of the riverflow changes estimated by Hains. They modified a monthly water balance model/operations model previously applied in southern California for the lake, based on current operating rules for the reservoir. For the first set of runs, the model assumes that (1) minimum flows are maintained for navigation and environmental dilution at all times, (2) lake levels are kept low enough to prevent flooding, (3) historic rates of consumption continue, and (4) peak hydropower generation is maximized. To ensure that the assumptions adequately reflect the actual decision rules used by water managers, Sheer and Randall reviewed the rules with local officials from the U.S. Army Corps of Engineers, the Atlanta Regional Council, and others responsible for managing the water supply. In a second set of runs, they examined the impacts of climate change under alternative operating rules that assume recreation is also a statutory objective.

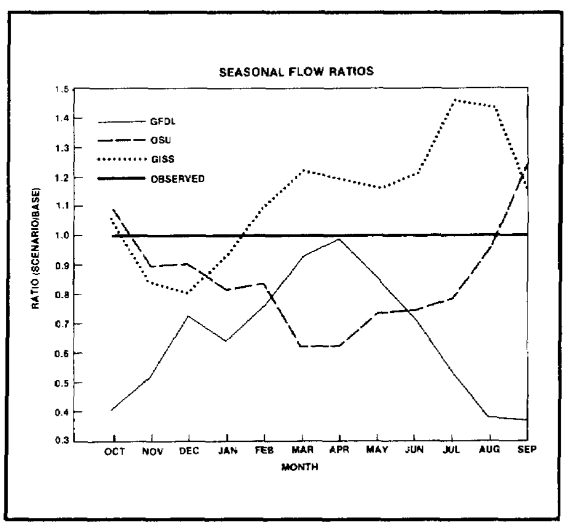


Figure 16-10. Ratios of flow under doubled CO_2 scenarios to base case in Upper Chattahoochee River.

Limitations. Sheer and Randall did not consider changes in demand for water due to climate change or population growth; thus, it produces high estimates of future water availability under all scenarios. Moreover, the results were not compared with historic lake levels.

Results. Figure 16-11 shows the Sheer and Randall estimates of lake levels; Figure 16-12 shows quarterly hydropower production. Under the relatively wet GISS scenario, annual power production could increase by 9%. The higher streamflows in this scenario would still be well below those that occasionally occurred before Lake Lamer was closed; hence, no significant threat of flooding would exist for a repeat of the climate of 1951-80. Under the relatively dry GFDL scenario, however, power production could drop 47%, and lake levels would be likely to drop enough to substantially disrupt recreation. This scenario assumes that Atlanta would continue to take as much water as it does currently (allowing for growth would increase water supply problems).

Sheer and Randall also examined the implications of making recreation a statutory objective. Although it would be possible to maintain lake levels, Atlanta's water supply would be threatened. With the current climate, strict enforcement of such a policy would result in Lake Lanier supplying no water to metropolitan Atlanta for 8 months of every 30 years. Although under the GISS scenario this would be reduced to 1 month, under the dry GFDL scenario, Atlanta would have to use an alternative source of water 1 to 3 months each summer.

Implications. Climate change combined with population growth may require water managers to reexamine the tradeoffs between the various uses of the Chattahoochee River and Lake Lanier. A number of local water officials who met with Sheer suggested that an appropriate response to changing water availability might be to relax minimum flow requirements for navigation and environmental quality. They reasoned that minimum flows for environmental purposes are based on the assumption that sewage treatment plants are discharging at their maximum rates and that temperatures are high, conditions that are usually not met. They also argued that little is accomplished by maintaining minimum flows for navigation because ship traffic is light in the lower Chattahoochee. Others argued, however, that it would be unwise to assume that minimum flows could be decreased because future growth may increase the need for dilution of effluents, and warmer temperatures would speed biological activity. The likely impacts of climate change on Apalachicola Bay may also increase the need to

Figure 16-11. Lake Lanier elevation (September) under doubled CO_2 scenarios (Sheer and Randall, Volume A).

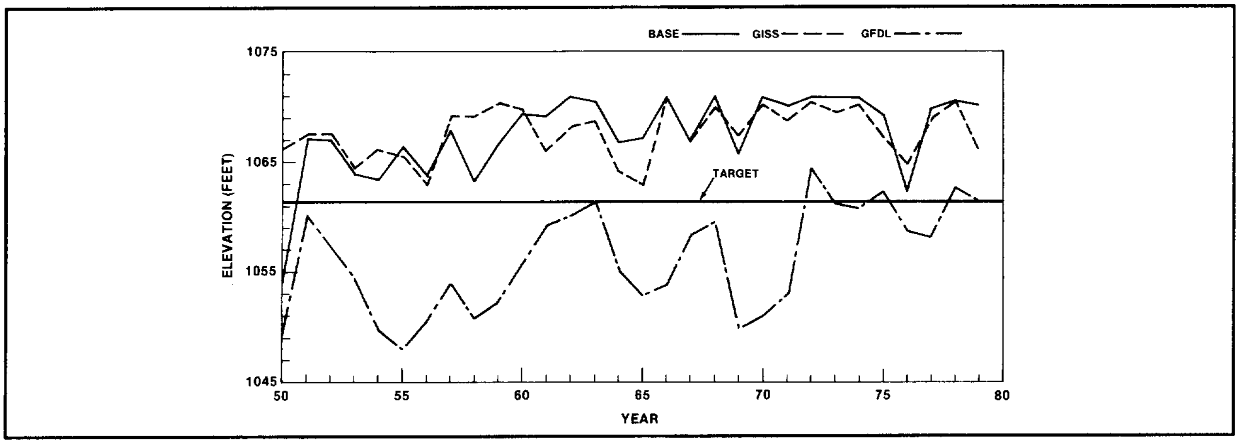
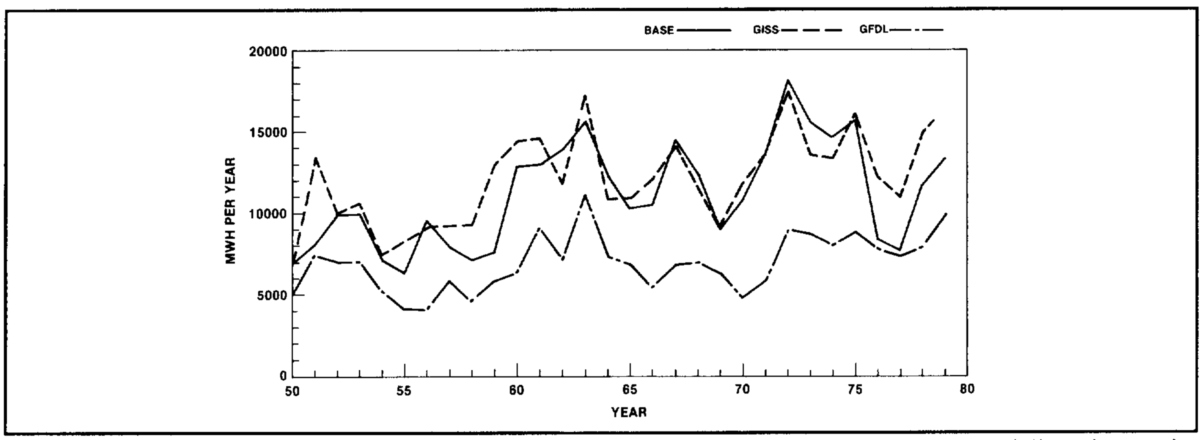


Figure 16-12. Lake Lanier power generation under doubled CO_2 scenarios (Sheer and Randall, Volume A).



maintain minimum flows.

Apalachicola Bay

Apalachicola Bay supports hundreds of commercial fishermen; over 80% of Franklin County earns a livelihood from the bay (Meo et al. Volume J). The contribution of fishing to the area was estimated at $20 million for 1980, representing 90% of Florida's oyster harvest and 10% of its shrimp harvest. This figure is projected to grow to $30 to $60 million by 2000.

Although the state has purchased most of the land that is not part of a commercial forest, economic pressures on forestry companies to sell land for coastal development are increasing. In 1979, the National Oceanic and Atmospheric Administration created the Apalachicola National Estuarine Sanctuary to prevent development from encroaching into this relatively pristine estuarine environment.

The biology of the Apalachicola Bay estuary may be affected by higher temperatures, higher sea levels, and different flows of water into the Apalachicola River. Hains estimated the flow of the Apalachicola River, and Park et al. estimated wetland loss due to sea level rise. Livingston used both of these results and the temperature change scenarios to evaluate the potential impacts on the bay's fish populations.

Sea Level Rise

The methods of Park et al. for estimating wetland loss are described in Chapter 7: Sea Level Rise.

They estimated that a 1-meter rise in sea level would inundate approximately 60% of the salt marshes in Apalachicola Bay, and that mangrove swamps, which are rarely found outside southern Florida today, would replace the remaining salt
marsh. Table 16-5 illustrates their estimates.

Apalachicola Riverflow

Study Design. Hains estimated the impact of climate change on riverflow, using a regression model, which is simpler than the Sacramento model he used for the Chattahoochee River analysis. The regression expressed the logarithm of riverflow as a function of the logarithms of precipitation and evapotranspiration for a few weather stations located in the basin.

Limitations. Hains' procedure greatly oversimplified the relationships between the causal variables and riverflow, ignoring the impacts of reservoir releases and the failure of the relationships to fit the simple log-linear form. These results should be interpreted as an indication of the potential direction of change.

Results. Figure 16-13 illustrates Hains' estimates of average monthly flows for the Apalachicola estuary. Annual riverflow would decrease under all scenarios, although it would increase in the summer and fall for the GISS and OSU scenarios, respectively.

Figure 16-13. Doubled CO_2 flow into Apalachicola Bay (Hams, Volume A).

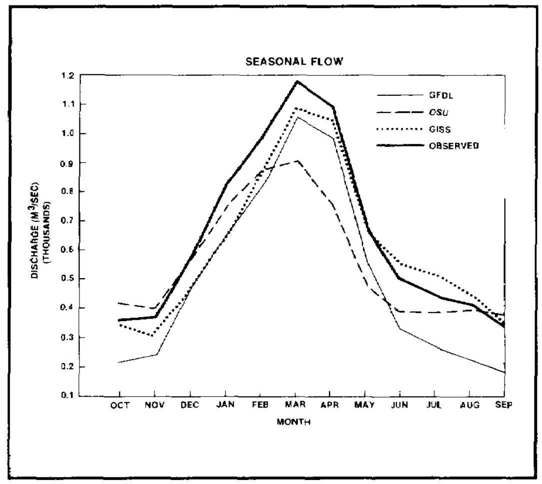


Table 16-5. Remaining Coastal Wetlands in Apalachicola Bay in the Year 2100 (hectares)

Area	1987	Current area sea level rise	50-cm rise	100-cm rise	200-cm rise
Swamps	9.46	6.71	6.26	5.47	4.16
Fresh marsh	1.46	1.27	1.17	1.00	0.25
High marsh	1.19	0.37	0.04	0.04	0.02
Low marsh	3.42	2.33	0.39	0.06	0.03
Mangrove	0	0	3.06	2.13	1.80
Total wetlands	15.53	10.68	10.92	8.70	6.26

Source: Park et al. (Volume B).

Fish Populations in Apalachicola Bay

Study Design. Using data from the literature on the tolerance of various species to warmer temperatures, Livingston estimated the number of months in a typical 30-year period during which the estuary would be too hot for these species and extrapolated this information to estimate reductions in populations.

Hydrologic modeling was not used to estimate the combined impacts of sea level rise and changing riverflow on salinity. Instead Livingston used historic data to estimate regression equations relating riverflow to salinity and salinity to populations of some commercially important seafood species.

Limitations. There is no historical record by which to estimate the impact of warmer temperatures on the Apalachicola (or any other) estuary. Livingston did not model the relationships between various aquatic species or how they would change. He did not consider how fmfish and shellfish might adapt to climate change, and he was unable to estimate the impact of wetland loss on populations of finish and shellfish.

The limitations in Hains' estimates of riverflow do not significantly affect the results of Livingston's study because riverflow was only one of several variables to be considered. The uncertainties surrounding changes in rainfall probably dwarf any errors due to Hains' simplified hydrology, and higher temperatures and sea level rise appear to be more important.

Results. The results of this study suggest a dramatic transformation of the estuary from subtropical to tropical conditions.

Warmer temperatures. Livingston concluded that warmer temperatures would have a profound effect on seafood species in the estuary because many species cannot tolerate temperatures much above those that currently prevail. Figure 16-14 compares the number of months in a 6-year period (based on 1971-76) in which temperatures exceed a particular level for the current climate and the GISS and GFDL scenarios, with known thresholds for major commercial species.

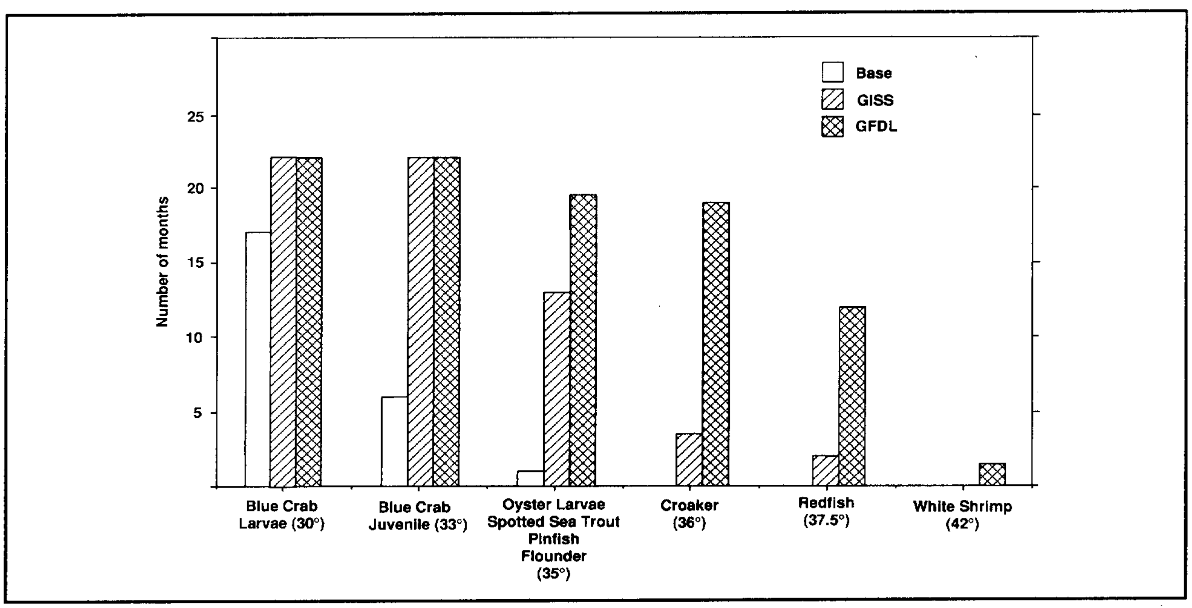


Figure 16-14. Months in a 6-year period during which temperatures (°C) would be too high for selected species under doubled $_{CO2}$ scenarios (Livingston, Volume E).

Livingston concluded that crabs, shrimp, oysters, and flounder could not survive in the estuary with the warming estimated in the GISS and GFDL scenarios, which imply close to 100% mortality for blue crab larvae and juveniles. The GFDL scenario could cause over 90% mortality for spotted sea trout, oyster larvae, panfish, and flounder. The mortality under the milder GISS scenario would be only 60%.

Although Livingston concludes that the oysters would probably be eliminated, he cautions that shrimp and other mobile species might adapt by fleeing the estuary for cooler gulf waters during the summer. However, such a flight would leave them vulnerable to predators.

Increased salinity. Although sea level rise and warmer temperatures seem likely to substantially reduce the productivity of the estuary, the probable impact of precipitation changes is less clear. If riverflow in the Chattahoochee declines, it would combine with sea level rise to increase salinity concentrations in the estuary. Livingston concluded that oysters are the most vulnerable to increases in salinity because oyster drill and other predators, as well as the disease MSX, generally require high salinities. Livingston estimated losses of 10 to 35% for oysters, blue crabs, finfish, and white shrimp under the GFDL scenario because of salinity increases alone.

Sea level rise. Livingston also concluded that the loss of wetland acreage would have important impacts on the estuary. Table 16-6 shows Livingston's estimates of losses in particulate organic carbon, the basic source of food for fish in the estuary. Sea level rise between 50 and 200 centimeters would reduce available food by 42 to 78%. A proportionate loss in seafood populations would not necessarily occur, since organic carbon food supplies are not currently the constraining factor for estuarine populations. However, wetlands also are important to larvae and small shrimp, crabs, and other species, serving as a refuge from predators. A rise in sea level of a meter or more could lead to a major loss of fisheries.

Despite the adverse impacts on shellfish and flounder, a number of species might benefit from global warming. For example, Livingston points out that pink shrimp could become more prevalent. Moreover, some finfish spend their winters in Apalachicola Bay and occasionally find the estuary too cold. Other species such as rock lobster that generally find the waters too cold at present may also be found in the estuary in the future.

Implications. Based on Livingston's projections, Meo et al. (Volume J) used current retail prices of fish to estimate that the annual net economic loss to Franklin County could be $5 to $15 million under the GFDL scenario, $1 to $4 million under GISS, and $4 to $12 million under the OSU scenario.

Livingston's results should not be interpreted to mean that fishing will be eliminated from Apalachicola Bay. The extent to which commercially viable tropical species could replace the species that are lost was not estimated.

Table 16-6. Projected Changes of the Net Input of Organic Carbon (metric tons per year) to the Apalachicola Bay System for Various Scenarios of Sea Level Rise

Factor	Fresh wetlands	Seagrass	Salt marshes	Phytoplankton	Total
Current scenario for 2100	30,000	27,200	46,905	233,280	337,385
Baseline sea level rise	26,100	28,700	23,500	144,640	222,940
0.5-meter rise	24,000	28,800	4,690	71,450	128,940
1.0-meter rise	21,300	30,100	940	58,790	111,130
2.0-meter rise	4,980	31,035	780	15,160	51,955

Source: Livingston (Volume E).

Agriculture

Agriculture in the Southeast will be affected directly by changes in climate and indirectly by changes in economic conditions and pests. This section presents results from a crop modeling study of yield changes by Peart et al., and regional results from national studies of agricultural production shifts by Adams et al. (Volume C) and of impacts of changes in pest populations by Stinner et al. (Volume C).

Crop Modeling Study

Study Design

Peart et al. (Volume C) used the crop models CERES-Maize (Jones and Kiniry, 1986) and SOYGRO (Wilkerson et al., 1985) to estimate the impacts of climate change on yields of corn and soybeans for 19 sites throughout the Southeast and adjacent states. Agricultural scientists have used these models for several years to project the impacts of short-term climatic variations. They incorporate the responses of crops to solar radiation, temperature, precipitation, and soil type, and they have been validated over a large range of climate and soil conditions in the United States and other countries.

The major variable not considered by these and other existing agricultural models is the direct "fertilization effect" of increased levels of atmospheric carbon dioxide. Peart et al., therefore, modified their models to consider both the increased rate of photosynthesis and the increased water-use efficiency that corn and soybeans have exhibited in field experiments (see Chapter 6: Agriculture).

Limitations

The analysis of combined effects is new research and will need further development and refinement. The model runs use simple parameters for CO effects, assume higher atmospheric concentration of CO 2 than are predicted, and probably overestimate the beneficial impact on crop yields. The direct effects of CO_2 in the crop modeling study results may be overestimated for two reasons. First, experimental results from controlled environments may show more positive effects of CO_2 than would actually occur in variable, windy, and pest-infested (weeds, insects, and diseases) field conditions. Second, because other radiatively active trace gases, such as methane, also are increasing, the equivalent warming of a doubled CO 2 climate may occur somewhat before an actual doubling of atmospheric CO_2. A level of 660 ppm CO_2 . was assumed for the crop modeling experiments, while the CO_2 concentration in 2060 is estimated to be SSS ppm Hansen et al., 1988) (see Chapter 6: Agriculture).

The study assumed that soils were relatively favorable for crops, with low salinity or compaction, and assumed no limits on the supply of all nutrients, except nitrogen. The analysis considers neither change in technology nor adverse impacts due to changes in storm frequency, droughts, and pests and pathogens.

Results

Soybean Yields. Table 16-7 illustrates the results of the soybean model for 13 nonirrigated sites in the study area, as well as Lynchburg, Virginia, a colder site included for comparison purposes.

The relatively wet GISS and relatively dry GFDL scenarios imply very different impacts on yields. In the GISS scenario, the cooler sites in Georgia and the Carolinas mostly show declines in soybeans yields of 3 to 25%, and the other sites show declines of 20 to 39%, ignoring CO_2 fertilization. When the latter effect is included, the Atlantic Coast States were estimated to experience gains of 11 to 39%, and the other states could vary from a 13% drop in Memphis to a 15% gain in Tallahassee. (Tennessee fares worse than the North Carolina sites at similar latitudes because its grid cell does not receive as favorable an increase in water availability.)

By contrast, the dry GFDL scenario results in very large drops in soybean productivity, with all but one site experiencing declines greater than 50% and eight sites losing over 75%, considering only the impact of climate change. Even when CO_2 fertilization is considered, all but four sites experience losses greater than 50%.

Corn Yields. The two scenarios differ in a similar fashion for nonirrigated corn. However, in the case of irrigated corn, where the analysis primarily reflects the impact of temperature increases, the two scenarios show more agreement. When CO_2 fertilization was not considered, drops of 13 to 20% were estimated

Table 16-7. Impacts of Doubled CO_2 Climate Change on Soybean Yields for Selected Southeastern Sites for Climate Change Alone and for Climate Change and CO_2 Fertilization (percentage change in yield)[a]

Site	Climate change only		Climate change and CO_2 fertilization	
	GISS	GFDL	GISS	GFDL
Memphis, TN	-38	-88	-13	-70
Nashville, TN	-30	-52	+4	-81
Charlotte, NC	-7	-92	+32	-88
Raleigh, NC	-3	-87	+39	-76
Columbia, SC	-20	-78	+18	-62
Wilmington, NC	-11	-62	+25	-41
Atlanta, GA	-11	-78	+27	-67
Macon, GA	-25	-91	+11	-82
Tallahassee, FL	-20	-51	+15	-17
Birmingham, AL	-31	-54	0	-29
Mobile, AL	-34	-43	-8	error
Montgomery, AL	-39	-84	-10	-68
Meridian, MS	-37	-78	-9	-66
Lynchburg, VA	+1	-74	+49	-55

[a] The impacts of Cow fertilization cannot be quantified as accurately as climate change only. The climates shown here overstate the beneficial impact of CO_2 because Peart et al. assume that CO_2 has doubled. Because other gases contribute to the global warming, CO_2 will have increased by a smaller fraction.
[b] Peart et al. investigated the cumber of sites in states adjacent to the Southeast. Lynchburg is included to permit comparison of results for the Southeast with a colder site.
Source: Peart et al. (Volume C).

in the GISS scenario, and drops of 20 to 35% were calculated for the GFDL scenario. When CO_2 fertilization was included, the GISS scenario implied declines of less than 8% for all sites, and the GFDL model showed similar declines for two sites and respective declines of 17 and 27% for Charlotte, North Carolina, and Macon, Georgia.

Irrigation. The two scenarios show more agreement for agricultural fields that are already irrigated. Since the changes in water availability are irrelevant here, the impacts are dominated by the increased frequency of very hot days.

The results are mixed on whether currently dry land areas would be shifted to irrigation. Table 16-8 shows the percentage increases in yields that would result from adding irrigation for particular scenarios. All but four sites could increase yields today by 50 to 75% by irrigating. Under the wetter GISS scenario, irrigation would increase yields only 7 to 53% (compared with not irrigating under the GISS scenario). However, under the dry GFDL scenario, irrigation would increase yields by 50 to 493% -- that is, it would mean the difference between crop failure and a harvest slightly above today's levels in most years. Even without CO_2 fertilization, 75% of the nonirrigated southeastern sites could gain more from irrigation than they would lose from the change in climate resulting from the GFDL scenario.

A farmer's decision to irrigate, shift to other crops, or remove land from production would depend to a large degree on what happens to prices of both crops and water. Even though water is plentiful today, the capital costs of irrigation prevent most farmers in the

Table 16-8. Increases in Corn Yields from a Shift to Irrigation (percent, assuming no CO_2 fertilization)[a]

Site	Current climate	GISS	GFDL
Memphis, TN	70	50	270
Nashville, TN	65	49	205
Charlotte, NC	64	43	486
Raleigh, NC	51	28	444
Columbia, SC	58	47	386
Wilmington, NC	16	8	50
Atlanta, GA	15	7	79
Macon, GA	61	33	489
Birmingham, AL	6	9	61
Mobile, AL	36	41	91
Montgomery, AL	72	39	493
Meridian, MS	62	53	323
Lynchburg, VA	56	37	361

[a] Estimates represent change in yields, given particular scenario, from shifting to irrigation.
[b] Peart et al. investigated a number of sites in states adjacent to the Southeast. Lynchburg is included to permit comparison with Southeast results with those for a colder site.
Source: Column 1 from Peart et al. (Volume C); Columns 2 and 3 derived from Peart et al. and Column 1

Southeast from taking advantage of the potential 50% increases in yields. But if crop failures due to drought became as commonplace as Peart et al. project for the dry GFDL scenario, a major increase in irrigation probably would be necessary. Although groundwater is currently plentiful in the Southeast, no one has assessed whether there would still be enough water if the climate became drier and irrigation increased. Furthermore, climate change may increase the demand for water for nonagricultural uses.

Shifts in Production

Adams et al. (Volume C) examined the impacts of changes in crop yields on farm profitability and cultivated acreage in various regions of the United States. (The methods for this study are discussed in Chapter 6: Agriculture.) Their results suggest that the impact of climate change on southeastern agriculture would not be directly proportional to the impact on crop yields (Table 16-9).

Considering only the impact of climate change, Adams et al. found that the GISS and GFDL scenarios would reduce crop acreage by 10 and 16%, respectively. When CO_2 fertilization is considered, however, Adams et al. project respective declines in farm acreage of 57 and 33% for the GISS and GFDL scenarios. As yields increase, prices decline. Adams et al. estimate that most areas of the nation would lose farm acreage. However, they estimate that the Southeast would experience the worst losses: wlvle the Southeast has only 13% of the cultivated acreage, it would account for 60 to 70% of the nationwide decline in farm acreage. This result is driven by the increased yields that the rest of the nation would experience relative to the Southeast.

When the CO_2 fertilization effect is ignored, the reductions in acreage would be much smaller, although the Southeast would still account for 40 to 75% of the nationwide loss. The general decline in yields would boost prices, which could make it economical for many farmers to irrigate and thereby avoid the large losses associated with a warmer and possibly drier climate.

Agricultural Pests

The modeling and economic studies of agriculture do not consider the impact of pests on crop yields. However, Stinner et al. (Volume C) suggest that global warming would increase the range of several agricultural pests that plague southeastern agriculture. (For details on the methods of this nationwide study, see Chapter 6: Agriculture.) They point out that the northern ranges of potato leafhoppers, sunflower moths, black cutworms, and several other southeastern pests are limited by their inability to survive a cold winter. Thus, milder winters would enable them to move farther north, as illustrated in Figure 16-15. Stinner et al. also note that increased drought frequency could increase the frequency of pest infestations.

Implications of Agriculture Studies

Agriculture appears to be at least as vulnerable to a potential change in climate in the Southeast as in any other section of the country. Unlike many of the

Table 16-9. Impact of Climate Change on Cultivated Acreage in the Southeast' (figures in parentheses are percentage losses)

Region	Baseline	With Direct CO_2		Without Direct CO_2	
		GISS	GFDL	GISS	GFDL
Acreage (millions)					
SE coast	12.5	8.7(30)	7.8(38)	11.5(8)	11.2(10)
Appalachia	15.5	2.8(82)	7.4(52)	14.1(9)	12.9(17)
Delta	19.9	9.3(53)	16.7(16)	17.7(11)	16.2(19)
Total	47.9	20.8(57)	31.9(33)	43.3(10)	40.3(16)

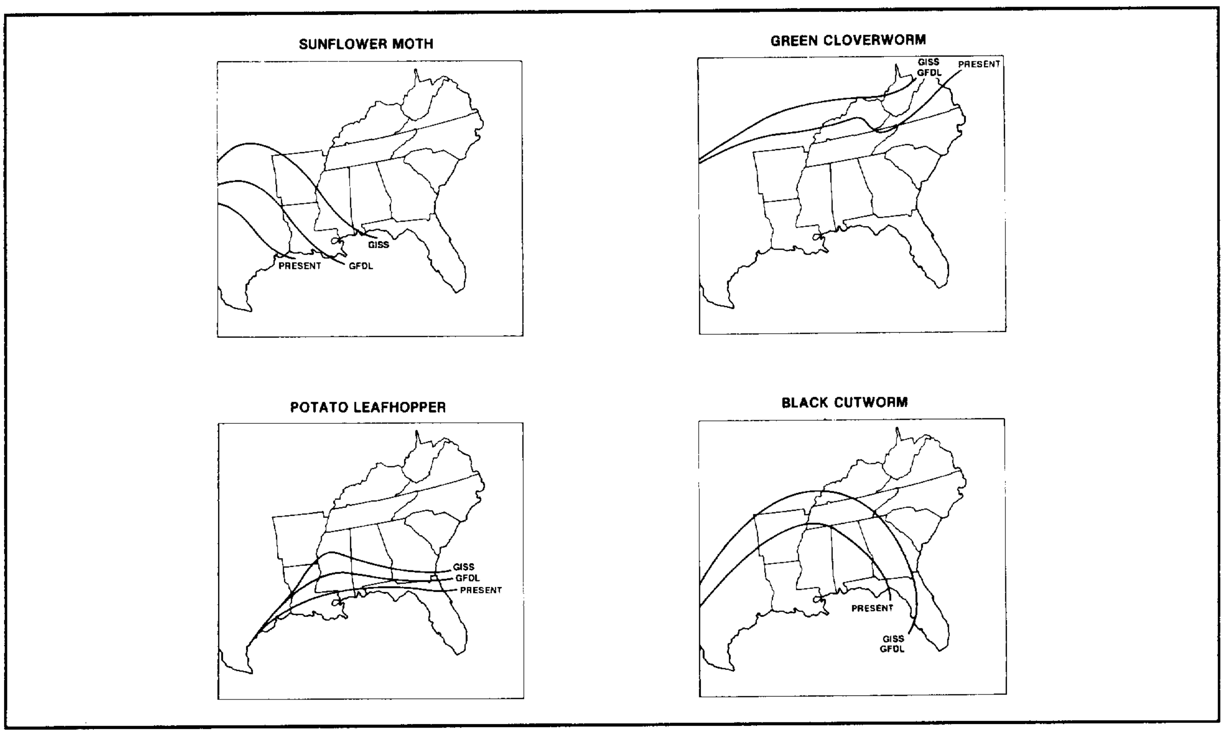


Figure 16-15. Present and predicted northern ranges of various agricultural pests (Stinner et al., Volume C).

colder regions, the benefits of a longer growing season would not appreciably offset the adverse impacts of warmer temperatures in the Southeast, where cold weather generally is not a major constraint to agricultural production.

Florida may present an important exception to the generally unfavorable implications of climate change for crop yields. Although Florida is the warmest state in the Southeast, its agriculture appears to be harmed by cold temperatures more than the agriculture of other states in the region. In recent years, hard freezes have destroyed a large fraction of the citrus harvest several times. As a result, the industry is moving south into areas near the Everglades, and sugarcane, which also thrives in warm temperatures, is expanding into the Everglades themselves. Global warming could enable the citrus and sugarcane areas to include most of the state. Warmer temperatures also would help coffee and other tropical crops that are beginning to gain a foothold in the state. This study, however, did not examine how the frequency of extreme events, such as the number of days below freezing in Florida, would change.

Although Florida's relative abundance of water may make it the exception, the current situation there highlights an important aspect of climate change: Within the context of current prices and crop patterns, the impact of climate change appears to be unfavorable. However, warmer temperatures may present farmers with opportunities to grow different crops whose prices would justify irrigation or whose seasonal cycles would conform more closely to future rainfall patterns.

Forests

Potential Range Shifts

Study Design

Overpeck and Bartlein (Volume D) used two independent methods to study the potential shifts in ranges of forest types over eastern North America. These analyses suggest where trees are likely to grow in equilibrium doubled CO_2 climate conditions after allowing for migration of tree species to fully catch up with climate change. The study only indicates the approximate abundance of different species within a range, not what the transitional effects of climate on forests might be, or how fast trees will be able to migrate to the new ranges. (For a discussion of the study's methodology and limitations, see Chapter 5: Forests.)

Results

Three GCM scenarios and two vegetation models yielded similar results. The abundance of deciduous hardwood populations (e.g., oak), which currently occupy the entire modeled eastern region from the Great Lakes region to the gulf coast, would shift northward away from the gulf coast and almost entirely out of the study region. Because the stand simulation model did not include subtropical species, it was unable to simulate any vegetation along the gulf coast under the very warm doubled CO_2 climate. The results for southern pine were less conclusive but generally show the upper border of the species range moving northward while the southern border remains stable. Growing conditions along the gulf coastal region, however, would also be favorable to subtropical species in a doubled CO_2 environment, but since the models used in the study had no data on such species, it is unclear how southern pine might fare under competition with subtropical varieties.

Transitional Effects

Study Design

Urban and Shugart (Volume D) applied a forest simulation model to a bottomland hardwood forest along the Chattahoochee River in Georgia and to upland sites near Knoxville, Tennessee, Macon, Georgia, Florence, South Carolina, and Vicksburg, Mississippi. Their study considered the OSU, GFDL, and GISS scenarios for doubled CO_2, as well as the GISS transient A scenario through the year 2060.

The model these researchers used was derived from FORET, the "gap" model originally developed by Shugart and West (1977). The model simulates forest dynamics by modeling the growth of each tree in a representative plot of forest land. It keeps track of forest dynamics by assigning each of 45 tree species optimal growth rates, seeding rates, and survival probabilities, and by subsequently adjusting these measures downward to account for less than optimal light availability, temperature, soil moisture, and soil fertility. In the case of the bottomland hardwood site, the model also considers changes in river flooding, based on the flows in the lower Chattahoochee calculated in the Lake Lanier study. The researchers applied the model to both mature forests and the formation of a new forest from bare ground.

Limitations

The results should not be taken literally owing to a number of simplifying assumptions that Urban and Shugart had to make. First, they assumed that certain major species, such as loblolly pine, could not tolerate more than 6,000 (cooling) degree-days per year. These species are not currently found in warmer areas, but the southern limits of their range are also limited by factors other than temperature, such as the Gulf of Mexico and the dry climate of Texas and Mexico. Although the 6,000 degree-day line coincides with these species' southern boundary across Florida, the peculiar environmental conditions of that state make it impossible to confidently attribute an estimate of thermal tolerance to that observation alone. This caveat does not apply to most of the oaks, hickories, and other species found in the cooler areas of the Southeast.

Another important caveat is that the model does not consider the potentially beneficial impact of CO_2 fertilization on photosynthesis, changes in water-use efficiency, or leaf area. Nor did the analysis consider introduction of new species into the region. Thus, there is more confidence about the fate of species currently in the region than about what may replace those species.

Results

The simulations by Urban and Shugart call into question the ability of southeastern forests to be generated from bare ground, particularly if the climate becomes drier as well as warmer. For the Knoxville site, the dry GFDL scenario implies that a forest could not be started from bare ground, while the GISS and OSU doubled CO_2 scenarios estimate reductions in biomass of 10 to 25%. For the South Carolina site, only the GISS climate would support a forest, albeit at less than 50% of today's productivity. The Georgia and Mississippi sites could not generate a forest from bare ground for any of the scenarios. Thus, even with increased rainfall, some sites would have difficulty supporting regeneration.

The transient analyses suggest that mature forests could also be lost -- not merely converted to a different type -- if climate changes. Figure 16-16 shows that none of the forests would decline significantly within 50 years; however, all would decline substantially before the end of the transient run in 80 years. The Mississippi forest would mostly die within 60 years, and the South Carolina and Georgia forests within 80 years. Only the relatively cool Tennessee site would remain somewhat healthy, although biomass would decline 35%.

Although the simulation results suggest that southeastern forests are unlikely to benefit from the global warming, the impact on forests may not be as bad as the model suggests, if new species move in or if loblolly pine can tolerate more than 6,000 degree days per year. Nevertheless, major shifts in forest types are almost certain to occur from the warmer temperatures alone.

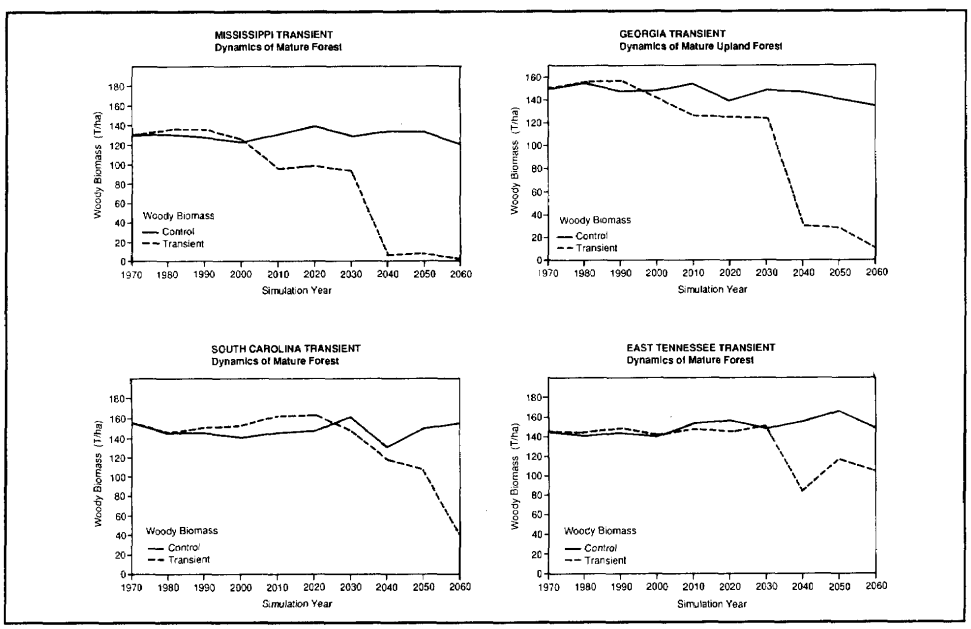


Figure 16-16. Response of southeastern forests to GISS transient scenarios of climate change (Urban and Shugart, Volume D).

Electric Utilities

Linder and Inglis (Volume H) examined the impact of global warming on the demand for electricity throughout the Southeast for the two GISS transient scenarios. (For additional details on the methods and limitations of this study, see Chapter 10: Electricity Demand.) Because their study was limited to electricity, it did not consider the reduced consumption of oil and gas for space heating that would result from warmer temperatures.

Table 16-10 shows the percentage changes in electric power requirements for various areas in the Southeast. Along the gulf coast, annual power requirements could increase 3 to 4% by 2010 and 10 to 14% by 2055; elsewhere, the increases could be somewhat less. Because peak demand for electricity generally occurs during extremely hot weather, peak demand would rise more than annual demand. (This result is also sensitive to changes in variability.)

Linder and Inglis compared increases in electric capacity required by climate change with those necessitated by economic growth. They estimated that through 2010, climate change could increase the expected capital costs of $137 billion by 6 to 9%; through 2055, it could increase expected requirements of $350 to $500 billion by as much as 20%.

COASTAL LOUISIANA

The sediment washing down the Mississippi River has formed the nation's largest delta at the river's mouth, almost all of which is in Louisiana. Composed mostly of marsh, cypress swamps, and small "distributary” channels that carry water, sediment, and nutrients from the river to these marshes and swamps, Louisiana's wetlands support half of the nation's shellfish, one-fourth of its fishing industry, and a large trapping industry. They also provide flood protection for metropolitan New Orleans and critical habitats for bald eagles and other migratory birds.

Water management and other human activities of the last 50 years are now causing this delta to disintegrate at a rate of about 100 square kilometers per year. Sediment that used to replenish the delta now largely washes into the deep waters of the gulf because flood-control and navigation guide levees confine the flow of the river. Thus, the delta is gradually being submerged, and cypress swamps are converting to open-water lakes as saltwater penetrates inland. If current trends continue, almost all the wetlands will be lost in the next century.

Table 16-10. Percentage Increases in Peak and Annual Demand for Electricity by 2010 and 2055 as a Result of Climate Change

Area	GISS A (2010)		GISS B (2010)		GISS A (2055)	
	Annual	Peak	Annual	Peak	Annual	Peak
North Carolina, South Carolina, Georgia	1.6	7.3	1.3	2.4	5.9	24.4
Florida	2.7	4.9	2.7	3.6	9.3	20.0
Eastern Tennessee	1.6	3.7	1.3	1.2	5.9	12.2
Alabama, Western Tennessee	1.9	3.8	2.2	5.7	6.8	13.5
Mississippi	3.8	7.6	4.4	11.4	13.6	6.9
Louisiana	2.9	7.6	2.7	6.6	10.2	23.4
East Texas	3.1	7.9	2.8	6.6	11.3	25.3

Source: Linder and Inglis (Volume H).

A rise in sea level would further accelerate the rate of land loss in coastal Louisiana. As shown in Figure 16- 17, even a 50-centimeter rise in sea level (in combination with land subsidence) would inundate almost all of the delta and would leave New Orleans, most of which is below sea level and only protected with earthen levees, vulnerable to a hurricane.

Strictly speaking, the entire loss of coastal Louisiana's estuaries should not be attributed to global warming because the ecosystem is already being lost. However, major efforts are being initiated by the U.S. Army Corps of Engineers, the U.S. Fish and Wildlife Service, the Louisiana Geological Survey, several local governments, and other federal and state agencies to curtail the loss, generally by erecting structures to provide freshwater and sediment to the wetlands. Technical staff responsible for developing these solutions generally fear, however, that a 1-meter rise in sea level could overwhelm current efforts, and that if such a rise is ultimately going to take place, they already should be planning and implementing a much broader effort (Louisiana Wetland Protection Panel, 1987).

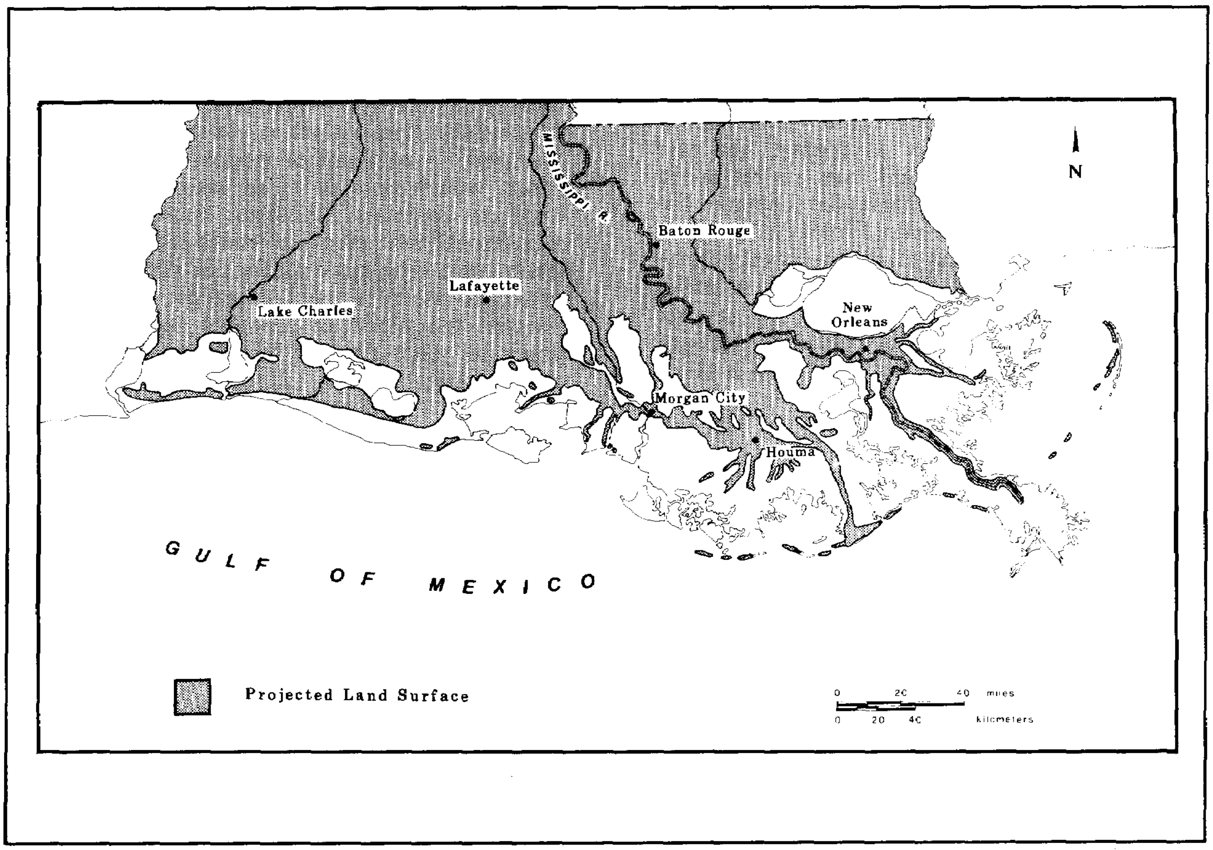


Figure 16-17. Projected future coastline of Louisiana for the year 2033, given a rise in sea level of 55 cm as predicted in the high scenario (Louisiana Wetland Protection Panel, 1987).

POLICY IMPLICATIONS

Agriculture and Forests

Climate change could have a major impact on land use in the Southeast. The estimated abandonment of 10 to 50% of the farmland in the Southeast and large declines in forests raise the an important question: How will this land be used?

In the past, forests have been cleared for agriculture, and when abandoned, they have been converted to forest again. But the forest models suggest that the impact of climate change on the generation of new forests from bare ground would be even more adverse than the impact on existing forests. If the forest simulations are correct, the abandoned fields would become grasslands or would become overgrown with weeds, and the Southeast could gradually come to resemble the scenery found today in the Great Plains.

However, no one has systematically investigated the extent to which human infrastructure might stabilize these changes. Changes in crops might enable more farms to stay in business than Adams et al. project, and new varieties of trees may find the region more hospitable. Because the commercial forests in the Southeast generally have short rotation cycles, it may be easier to respond to climate change there than in other regions. To a large degree, the ability of human intervention to maintain the present landscape would depend on international prices of agricultural and forest products, estimation of which is outside the scope of this report.

Water Resources

The water resource problems faced by the Southeast are not likely to be as severe as the problems faced by other regions of the country. Rainfall and runoff were estimated to increase in the GISS scenario. Although most other assessments suggest that runoff would decline, the magnitude of the decline does not appear to threaten the availability of water for municipal, industrial, or residential use. However, the nonconsumptive uses for hydropower, navigation, environmental quality, and recreation could be threatened. Although sufficient time exists to develop rational strategies to implement the necessary tradeoffs, current federal statutes constrain the ability of water managers to do so.

<u>Impacts of Wetter Climate</u>

Although most water resource problems have been associated with too little water, it does not necessarily follow that a wetter climate would be generally beneficial. The designs of water management infrastructure and the location of development along lakes and rivers have been based on current climate. Hence, shifts in either direction would create problems.

The chief problem from a wetter climate would be more flooding, particularly in southern Florida and coastal Louisiana, where water often lingers for days and even weeks after severe rainstorms and river surges. Inland communities, such as Chattanooga, also might face flooding if wetter periods exceed the ability of dams to prevent flooding.

<u>Impacts of Drier Climate</u>

A drier climate, on the other hand, would exacerbate current conflicts over water use during dry periods. Hydropower would decline, increasing the need to use fossil or nuclear power, both of which would require more water for cooling. Conflicts between municipal water users and recreational interests also would intensify. Lake levels could drop more during the summer, even if municipal use of water did not grow. However, warmer temperatures probably would increase municipal water demand for cooling buildings and watering lawns.

These conflicts could be further exacerbated if farmers increase the use of irrigation. Groundwater is available in reasonably shallow aquifers that drain into rivers. Any consumptive use of water from these aquifers would reduce, and in some cases reverse, the base flow of water from aquifers into these rivers. Water also could be drawn directly from rivers for irrigation in some areas.

A decline in riverflows could be important for both navigation and environmental quality. For the Tennessee, as well as the Chattahoochee and other small rivers, adequate reservoir capacity exists to maintain flows for navigation, if this use continues to take precedence over water supply and recreation. However, the 1988 drought has graphically demonstrated that there are not enough dams to guarantee navigation in the Mississippi. If this situation became more commonplace, the economic impact on New Orleans could be severe. On the other hand, traffic on the Tennessee and Ohio Rivers might use the Tennessee-Tombigbee Canal as an alternative, which would benefit the Port of Mobile.

Lower flows also would reduce the dilution of municipal and industrial effluents discharged into rivers and would decrease the level of dissolved oxygen. This would directly harm fish populations and would cause indirect harm by reducing the abilities of streams to assimilate wastes. Reduced flows also would threaten bottomland hardwood and estuarine ecosystems. To prevent these problems, factories and powerplants might have to erect cooling towers or curtail their operations more frequently.

Is Current Legislation Adequate?

The same issues that face the TVA and Lake Lanier would likely face decisionmakers in other areas. Federal laws discourage water managers in the Southeast from rigorously evaluating the tradeoffs between the various uses of water. Most dams are more than sufficient to meet the statutory requirements for navigation and flood safety and to continue generating substantial hydropower on demand. Consequently, there has been little need to analyze the tradeoffs between these factors. For example, a literal application of the law would not allow the U.S. Army Corps of Engineers to cut hydropower production or navigation releases to ensure a supply of water for Atlanta. Therefore, agencies have not analyzed the allocation of water that best serves the public for various levels of water availability (although the TVA is beginning to do so).

At a practical level, federal water managers have shown flexibility, as in the case of cutting navigation along the Chattahoochee instead of further cutting Atlanta's water supply. If climate changes and more than a modest level of flexibility is necessary, water resource laws could be changed; the physical infrastructure is largely in place to address water problems of the Southeast. But until the laws are changed, the federal agencies in the Southeast often would be forced to allocate water inefficiently. Moreover, people making decisions concerning siting of recreational and industrial development, long-term water supply sources, powerplant construction, and other activities sensitive to the availability of water would risk basing their decisions on incorrect assumptions regarding the future allocation of water.

Estuaries

Coastal plants and animals across the Southeast may have difficulty surviving warmer temperatures. For example, along the northern coast of the Gulf of Mexico, several types of fish spend at least part of their lifetimes in estuaries that are already as hot as they can tolerate. If climate became warmer, however, migrating north would not be feasible. While these species could escape the summer heat by fleeing to the cooler waters of the gulf, such a flight would make them vulnerable to larger fish.

In addition to the direct effect of climate change on estuaries, human responses to climate change and sea level rise also could hurt coastal estuaries. Besides the impacts of flood control, increased reservoir construction would decrease the amount of sediment flowing down the river and nourishing the wetlands. If the climate becomes drier, irrigation could further reduce freshwater flow into estuaries.

To a large extent, the policy implications for wetland loss in the Southeast are similar to those facing the rest of the U.S. coastal zone. Previous studies have identified several measures to reduce the loss of coastal wetlands in response to sea level rise (e.g., Titus, 1988). These measures include the following:

- increase the ability of wetlands to keep pace with sea level;
- remove impediments to landward creation of new wetlands; and
- dike the wetlands and artificially maintain water levels.

All these measures are being employed or actively considered.

Congress has authorized a number of freshwater and sediment diversion structures to assist the ability of Louisiana's wetlands to keep up with relative sea level rise. These structures are engineered breaches in river levees that act as spillways into the wetlands when water levels in the river are high.

Although decisions on where to build diversion structures are being based on current climate and sea level, consideration of global warming would substantially change the assumptions on which current analyses are being based and the relative merits of alternative options. More frequent or higher surges in the Mississippi River would increase the amount of water delivered to the wetlands. And if climate change resulted in more soil erosion, more sediment might also reach the wetlands; lower flows could have the opposite effect. Sea level rise might shorten the useful lifetimes of these projects, but because the flood-protection benefits of protecting coastal wetlands would be greater with a higher sea level (Louisiana Wetland Protection Panel, 1987).

Artificially managing water levels also has been proposed for Louisiana, particularly by Terrebonne Parish, whose eastern wetlands are far removed from a potential source of sediment. Such an approach also might be possible for parts of Florida, where wetlands already are confined by a system of dikes and canals, and water levels already are managed. Although no one has yet devised a practical means by which shrimp and other fish could migrate between ocean and estuary, other species spend their entire lifetimes within the estuary, and freshwater species could remain in artificially maintained freshwater wetlands.

A final response would be to accept the loss of existing wetlands, but to take measures to prevent development from blocking the landward creation of new wetlands. This approach has been enacted by the State of Maine (1987) and would be consistent with the proposals to discourage bulkheads that have been widely discussed by coastal zone managers and enacted by the State of South Carolina. Titus and Greene estimate that 1,800 square miles of wetlands in the Southeast could be created if developed areas were not protected. Although this area represents a small fraction of the potential loss, it would increase the remaining areas of wetlands by 30 to 90%, and it would maintain and perhaps increase the proportion of shorelines on which at least some wetlands could be found.

Beach Erosion

The implications of sea level rise for recreational beaches in the Southeast are similar to the implications for the mid-Atlantic and the Northeast. If shore-protection measures are not taken, the majority of resorts will have no beach at high tide by 2025 under the midrange scenario of future sea level rise. The cost of undertaking the necessary measures through 2025 probably would be economically justified for most resorts (see Chapter 7: Sea Level Rise). However, the cost of protecting all recreational beaches through 2100 would be $100 to $150 billion, which would probably lead some of the more vulnerable areas to accept a landward migration much as areas on North Carolina's Outer Banks are facing today, particularly if warmer temperatures also lead to more hurricanes.

The potential responses to global warming should be viewed within the context of current responses to erosion flooding. Florida has a trust fund to nourish its beaches and has received federal assistance for pumping sand onto the shores of Miami Beach. Mississippi has nourished the beaches of Biloxi, Gulfport, and other resort communities that lie on the mainland along the protected waters behind the barriers. Louisiana is rebuilding its undeveloped barrier islands because they protect the mainland from storms. Most states are moving toward "soft engineering" solutions, such as beach nourishment, because of doubts about the effectiveness of hard structures in universal erosion and their interference with recreational uses of the beach.

Land-use measures also have been employed to adapt to erosion. Because of unusually high erosion rates on the Outer Banks, houses along the coast are regularly moved landward. North Carolina requires houses, hotels, and condominiums to be set back from the shore by the distance of a 100-year storm plus 30 years' worth of erosion on the assumption that after 30 years, the house could be moved back. Texas requires that any house left standing in front of the vegetation line after the shore erodes must be torn down.

If a global warming increases the frequency of hurricanes, a number of southeastern communities will be devastated. However, the overall impact of increased hurricane frequency would be small compared with the impact of sea level rise. While a doubling of hurricanes would convert 100-year floodplains to 50-year floodplains throughout much of the Southeast, a 1-meter rise would convert them to 15-year floodplains.

Because the open-coast areas most vulnerable to sea level rise are generally recreational beach resorts, the costs of erosion and flooding should be viewed within the larger context of why people go to the beach. People from the north visit southeastern beaches to escape winter, and residents of the region go to escape the summer heat. As temperatures become warmer, Georgia and the Carolinas may be able to compete with Florida for northerners. Hotter temperatures also may increase the desire of the region's residents to visit the beach.

Thus, it is possible that the cooler communities will reap benefits from a longer and stronger tourist season that are greater than the increased costs for erosion control. Areas that already have a year-round season are less likely to benefit, and in a few areas like Miami Beach, the off-season may be extended.

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