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# An Ecological Characterization of the Florida Panhandle

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U.S. Department of the Interior
Fish and Wildlife Service and
Minerals Management Service

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# An Ecological Characterization of the Florida Panhandle

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# PREFACE

This report is one in a series that provides an ecological description of Florida's gulf coasts. The watersheds described herein, with their myriad subtropical communities, produce many benefits to people. The maintenance of this productivity through enlightened resource management is a major goal of this series. This report will be useful to the many people who have to make decisions regarding the use of the natural resources of the area.

Any questions or comments about or requests for this publication should be directed to the following:

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Slidell, Louisiana 70458

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New Orleans, Louisiana 70123-2394

# CONVERSION FACTORS

## Metric to U.S. Customary

| Multiply | by | To Obtain |
|---|---|---|
| millimeters (mm) | 0.03937 | inches |
| centimeters (cm) | 0.3937 | inches |
| meters (m) | 3.281 | feet |
| kilometers (km) | 0.6214 | miles |
| square meters ($m^2$) | 10.76 | square feet |
| square kilometers ($km^2$) | 0.3861 | square miles |
| hectares (ha) | 2.471 | acres |
| liters (l) | 0.2642 | gallons |
| cubic meters ($m^3$) | 35.31 | cubic feet |
| cubic meters ($m^3$) | 0.0008110 | acre-feet |
| milligrams (mg) | 0.00003527 | ounces |
| grams (g) | 0.03527 | ounces |
| kilograms (kg) | 2.205 | pounds |
| metric tons (mt) | 2205.0 | pounds |
| metric tons (mt) | 1.102 | short tons |
| kilocalories (kcal) | 3.968 | BTU |
| Celsius degrees | 1.8(°C) + 32 | Fahrenheit degrees |

## U.S. Customary to Metric

| Multiply | by | To Obtain |
|---|---|---|
| inches | 25.40 | millimeters |
| inches | 2.54 | centimeters |
| feet (ft) | 0.3048 | meters |
| fathoms | 1.829 | meters |
| miles (mi) | 1.609 | kilometers |
| nautical miles (nmi) | 1.852 | kilometers |
| square feet ($ft^2$) | 0.0929 | square meters |
| acres | 0.4047 | hectares |
| square miles ($mi^2$) | 2.590 | square kilometers |
| gallons (gal) | 3.785 | liters |
| cubic feet ($ft^3$) | 0.02831 | cubic meters |
| acre-feet | 1233.0 | cubic meters |
| ounces (oz) | 28.35 | grams |
| pounds (lb) | 0.4536 | kilograms |
| short tons (ton) | 0.9072 | metric tons |
| BTU | 0.2520 | kilocalories |
| Fahrenheit degrees | 0.5556(°F −32) | Celsius degrees |

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# ACRONYMS

## State and Federal agencies and programs

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|---|---|
| A–C–F | Apalachicola–Chipola–Flint Rivers |
| ANF | Apalachicola National Forest |
| FDA | U.S. Food and Drug Administration |
| FDER | Florida Department of Environmental Regulation |
| FDNR | Florida Department of Natural Resources |
| FNAI | Florida Natural Areas Inventory |
| FREAC | Florida Resources and Environmental Analysis Center |
| HRS | Florida Department of Health and Rehabilitative Services |
| IFAS | Institute for Food and Agricultural Service, University of Florida |
| NMFS | National Marine Fisheries Service |
| NOAA | National Oceanic and Atmospheric Administration |
| NPDES | National Pollution Discharge Elimination System |
| NWFWMD | Northwest Florida Water Management District |
| OCS | Outer Continental Shelf |
| OFW | Outstanding Florida Water |
| SR | State Route |
| USACE | United States Army Corps of Engineers |
| USFWS | United States Fish and Wildlife Service |
| USGS | United States Geological Survey |

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# Chapter 1. INTRODUCTION

## 1.1 Purpose and Organization

The Florida Panhandle is one of the most rapidly developing regions in the entire State. Coastal cities such as Panama City, Destin, and Pensacola, with their attractive white-sand beaches and clear waters, are the centers of this growth. Concomitant with such growth are rapid alterations in surrounding terrestrial and aquatic habitats caused by increased urbanization, industrialization, sewage and effluent discharge, river flow alteration, stormwater runoff, and dredge and fill activities.

Many Panhandle commercial interests, especially fishing and tourism, are highly dependent upon the maintenance of relatively unaltered habitats. The residents of many small Panhandle coastal communities such as Apalachicola and Carabelle derive practically all their incomes from the seafood industry. If unregulated growth occurs without regard to environmental impacts, the failure of this economy and the end of a unique way of life may follow. In addition, the destruction of the natural coastal setting would seriously curtail tourism.

Critical decisions on the preservation or economic development of particular areas are often made without knowledge of the composition, dynamics, and sensitivity of the local habitats and the associated flora and fauna to perturbations. Additionally, higher level interactions between systems and habitats are often overlooked. This report is an extensive review and synthesis of available literature on the local physical setting and ecology and a discussion of important impacts on the habitats within the Panhandle region. We have attempted to project possible future impacts and to point out areas that need further research before they are permanently altered.

The report is divided into two main sections. Chapters 2, 3, and 4 cover the geology and physiography, the climate, and the many aspects of the surface- and ground-water systems. These chapters provide the physical and chemical background information necessary to understand many of the environmental pressures affecting the biological habitats. These habitats—terrestrial, freshwater, estuarine, and marine—and their inhabitants are described in Chapters 5, 6, and 7. Chapter 8 is a summary of the Panhandle systems and a discussion of their unique aspects as well as of areas that are in need of further investigation.

## 1.2 The Florida Panhandle: Overview

The Florida Panhandle discussed in this report (Figure 1) extends from the Ochlockonee River basin west to the Florida-Alabama border (not including Perdido River basin and Bay) and north to the Georgia and Alabama borders. Major rivers in the region include the Ochlockonee, Apalachicola, Chipola, Choctawhatchee, Yellow, Blackwater, and Escambia. Major bays and estuarine systems include: Ochlockonee Bay, Apalachicola Bay, St. Joseph Bay, St. Andrew Bay, Choctawhatchee Bay, and Pensacola Bay. Also discussed are the nearshore Gulf of Mexico waters and the adjacent Continental Shelf region.

The Panhandle contains a wide variety of surface waters and physiographic regions. This lends it an ecological diversity found in few other areas in the United States. The Panhandle also boasts several of the largest and most productive estuaries in the State. Local fisheries and the fisheries of much of the coastal area depend on the water quality of these estuaries for spawning and nursery grounds. Their protection must be of high priority. Many inland

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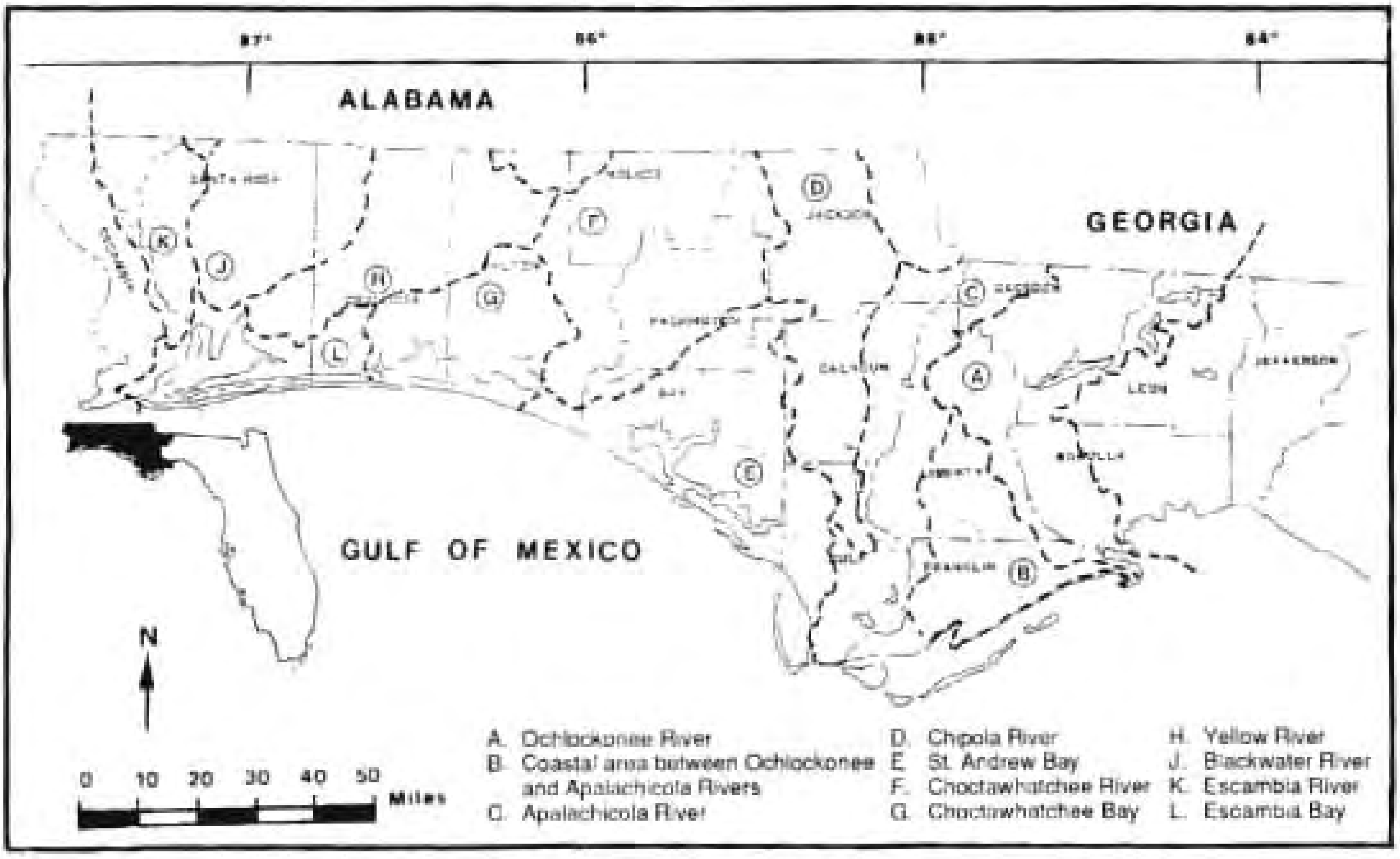

Figure 1. Florida Panhandle drainage basins and features.

areas are undeveloped and probably will remain so in the near future. Other areas, most notably the western coasts, are undergoing explosive growth very similar to that occurring in the southern part of the State. Unfortunately, this growth is often taking place with no more regard given to habitat destruction and environmental impact than is given in the south. We hope this document will help produce wise decisions concerning the direction and methods of Panhandle growth.

# Chapter 2. GEOLOGY AND PHYSIOGRAPHY

## 2.1 Introduction

The animals and plants of any region are greatly affected by its geology. Plants are rooted in soils derived from the inorganic rocks or sediments of the earth's surface and are further affected by the slope, moisture-bearing content, chemistry, and physical nature of the sediments. Animals, in turn, are affected by plants as food and shelter. Animals may also respond directly to the geology of a region because they live on the soil surface or burrow in it. The slope, friability, moisture-bearing capacity, and other properties of soils often have as much influence on animals as on plants.

The surface geology of Panhandle Florida is entirely sedimentary, comprised of three different types of sediment: limestones, organics, and clastics (silt, clay, sand, gravel). The northern half of the Panhandle is dominated by sandy clays or clayey sands deposited by the alluvial action of rivers and streams. The southern half of the Panhandle, especially in the west, is dominated by sands deposited along ancient shorelines. The surface of the ground in the eastern half of the Panhandle and in the vicinity of Marianna, Jackson County, is influenced by the presence of limestones near the surface which have caused the top of the ground to be modified topographically by various types of subterranean solution activity. In low lying areas (stream courses or natural depressions of varying kinds), especially south of Cody Scarp and east of the Choctawhatchee River, peat, muck, and other types of decomposing plant litter are very common.

Panhandle Florida has been slowly emerging from the sea since at least some time in the Miocene. The age of surface sediments, therefore, is older near the Alabama and Georgia borders and becomes progressively younger towards present sea level. The floor of each stand of the sea was a relatively flat, gently seaward-sloping terrace when first exposed by the receding shoreline. Terraces are separated from each other by step-like escarpments or by subtle changes in relief (Figure 2). Since their emergence, terraces have been eroded and dissected by streams and rivers. Entire strata have been removed in some areas, and materials from other strata have been deposited on top of lower terraces, and rearranged by the erosive power of water.

Fifty-two percent of the open gulf beaches from Mexico Beach to a point due south of Tallahassee have been eroding during historical times (Tanner 1975). In the same time period, 35% have been stable, and only 14% have been growing. An astounding 11.2 m per year of beach front has eroded from Cape San Blas between the years 1875 and 1942. Dog Island has been eroding at about 1 m per year, and St. George Island has been lengthening its eastern tip at a rate of about 20 m per year, but the beach face has been eroding at about 1.3 m per year between 1934 and 1970. Given the consensus of scientific researchers that sea level has been rising over the past century and that a greenhouse effect is now measurable due to increased $C0_2$ levels from fossil fuel combustion and other human activities, it seems certain that sea level will continue to rise over the next century. Some geologists have calculated that if all the ice in polar regions and montane glaciers were to melt, the ocean surface would rise at least 100 ft. This is close to the top of the Wicomico terrace, presumably the shoreline at the end of the Pliocene and at the onset of the Pleistocene. The land submerged under the Wicomico sea (Figure 2) indicates that about one-half of the surface of the Panhandle would be inundated in this scenario.

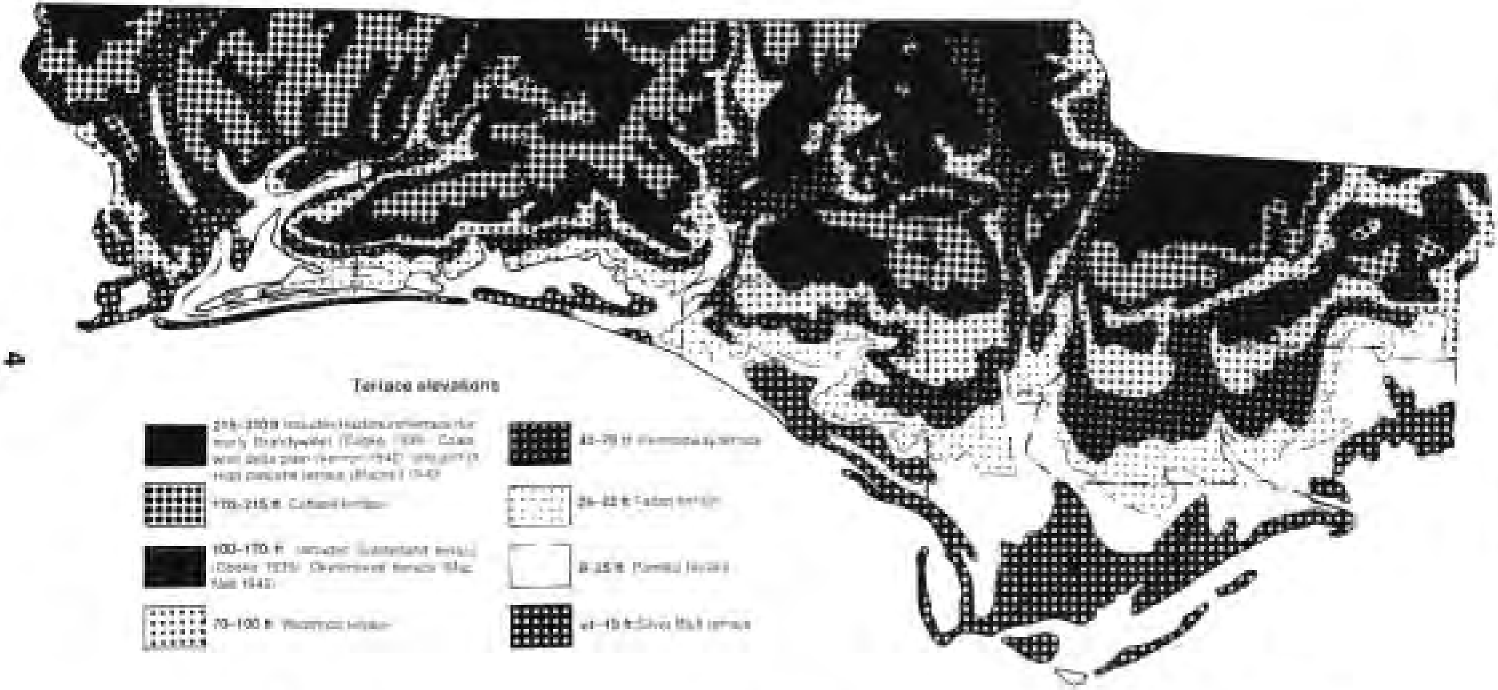

Figure 2. Terraces in the Florida Panhandle formed by previous sea-level stands (after Healy 1975a).

## 2.2 Structure and Geologic Setting

Three structural features dominate the geology of Panhandle Florida. These are the Gulf of Mexico Sedimentary Basin, Chattahoochee Anticline, and the Apalachicola Embayment. The Panhandle from about Okaloosa County westward is the eastern edge of the Gulf of Mexico sedimentary basin, a negative structural feature (i.e., a depression that receives sediments) whose sediments thicken westward toward the Mississippi River. A positive structural feature (a rise, from which sediments erode) called the Chattahoochee Anticline lies at the eastern end of the negative area, separating it from a smaller negative feature called the Apalachicola Embayment (Figure 3).

The Chattahoochee Anticline is aligned southwest to northeast across the northeastern portion of Panhandle Florida (Figure 3), and is very important to the ecology of the region because it brings Oligocene and Eocene carbonate rocks to the ground surface where the physical and chemical properties of the soil and water are greatly affected by the presence of the carbonates.

The Apalachicola Embayment and its probable northeastward extension, the Gulf Trough, is a negative structural feature that represents a downfallen block of land, called a graben (Schmidt 1984). This negative feature is important to the biology of the Panhandle because it is strongly affected by the predominantly clastic sediments. Clastics differ greatly from carbonates in their chemistry, physical properties, and weathering.

The Apalachicola Embayment (Figure 3) is a relatively shallow basin between the Ocala and Chattahoochee uplifts, narrowest on the northeast and opening up to the south and southwest. The magnitude of the basin increases with depth, indicating that it is a long-developing feature. Near the ground surface the Quaternary and Neogene rocks are gently downwarped, but the deeper Paleogene and Mesozoic rocks are downwarped even more, resulting in older strata that are thicker (Murray 1961). Southward along its axis, the upper sedimentary rocks (Triassic to Recent) of the Apalachicola Embayment plunge to a depth of nearly 15,000 ft before metamorphic Paleozoic rocks are encountered (Applegate et al. 1978). At the eastern limits of

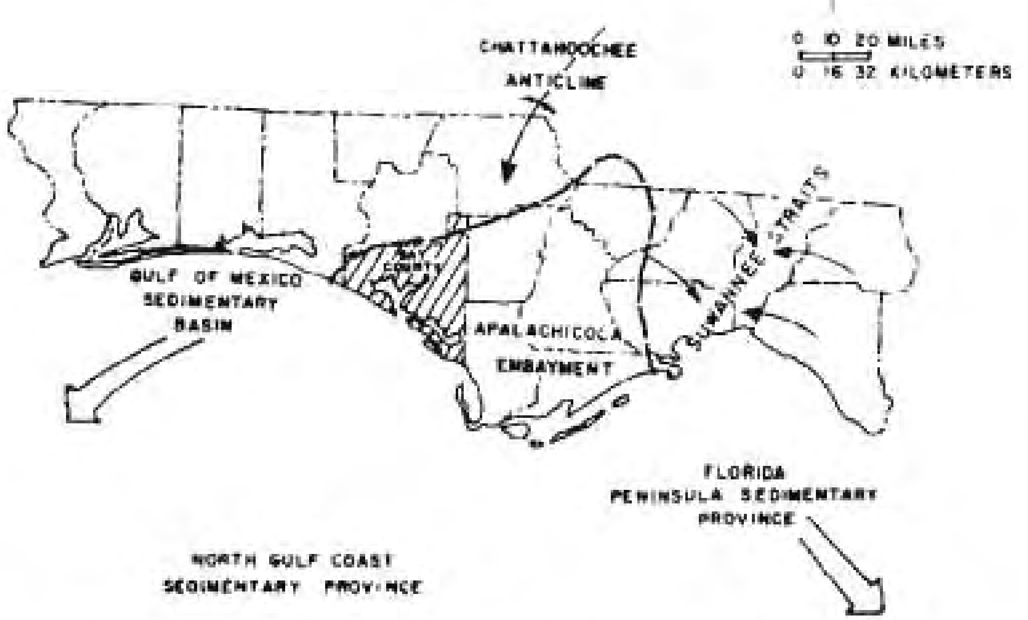

**Figure 3. Major structural features of the Florida Panhandle (from Schmidt 1984).**

of nitrogen may reinforce this inhibition. The oldest peat occurs at the bottom of a deposit, and new peat forms at the surface as dead plant materials accumulate. Other, nonfibrous peat is generally called muck. Most peats contain some sand, silt, or clay that was transported by water or wind from other areas. Well preserved wood commonly occurs in peat. Florida peat deposits and associated vegetation were surveyed by Harper (1910) and Davis (1946).

## 2.3 Stratigraphy

The rocks that underlie the Panhandle range in age from late Precambrian to Recent. The oldest rock exposed in the Panhandle is Eocene limestone of the Crystal River Formation. It is found near the surface of the ground in northern Holmes and northern Jackson Counties, and is exposed along the upper Chipola River and upper Holmes and Wrights creeks. The rocks of different age that are outcropped in Panhandle Florida are shown in Figure 4.

### 2.3.1 Igneous and Paleozoic Rocks

The igneous rocks of Florida include metabasalts in Volusia County, granites in Lake and Orange Counties, granite and diorite in St. Lucie County, and metabasalt in Hillsborough County (Grasty and Wilson 1967, Bass, 1969, Milton and Grasty 1969, Milton 1972, Barnett 1975). Panhandle deep wells have intercepted granite at 12,191 ft in Bay County, dacite porphyry and granodiorite in Gulf County at 13,000 ft, and granite at 14,480 ft below the surface in southern Walton County (Barnett 1975).

The Paleozoic sediments from deep wells in Florida have been described and correlated by Applin (1951), Bridge and Berdan (1952), Cramer (1971), and Barnett (1975). Strata range in age from late Precambrian to Early Devonian based on fossil evidence.

### 2.3.2 Mesozoic Era

Descriptions of the Mesozoic rocks in the Panhandle have been reported by Arden (1974) and Applegate et al. (1978). Overlying the Paleozoic igneous rocks is the Eagle Mills Formation of the Triassic Age. This formation contains dikes and sills of basic igneous rocks. Its overall lithology has been described by Applegate et al. (1978) as well-indurated, highly micaceous sandstones; argillaceous siltstones; and well-indurated shales.

In the eastern part of Bay County, the Eagle Mills Formation is probably absent, thinning from about 200 ft in western Bay County. The Norphlet, Smackover and Haynesville Formations are found here, overlying the basal granite. These formations are all Upper Jurassic in age. The Norphlet is 267 ft thick and consists of red sandstones, siltstones, and shales. The Smackover Formation is 163 ft thick and is composed of limestone and dolomitic limestones. The Smackover Formation was found to have oil locked in a dense impermeable section of limestone and conglomeritic calcareous sandstone. The next younger formation, the Haynesville, is just over 300 ft thick and is composed of red to gray, very well indurated calcareous shales, a few well sorted fine-grained sandstones, and a few thin-bedded micrites.

All three formations apparently thin westward because only a thin Haynesville section is present in a deep well drilled in western Bay County. West of Bay County these units thicken as they plunge into the Mississippi Embayment. In Bay County, the Eagle Mills Formation is overlain by 2,600 ft of the Cotton Valley Group sediments. This group also overlies the Haynesville section in eastern Bay County (Schmidt and Clark 1980). The Cotton Valley Group is Upper Jurassic in age and is a varicolored mudstone and coarse sandstone.

Above the Cotton Valley sediments are differentiated Lower Cretaceous sands and shales, varying from 5,000 to 6,000 ft in thickness. Above these lie the white sands of the Lower Tuscaloosa Formation, which is Upper Cretaceous in age.

The Tuscaloosa Formation consists of nonmarine, gray to green, fine to coarse, poorly sorted sand and variegated shales underlying a marine member consisting of a gray laminated micaceous glauconitic hard shale with shell fragments and carbonaceous seams and flecks. On top of this, the Tuscaloosa Formation consists of a gray to cream fine calcareous micaceous clayey silty sandstone with beds of calcareous shale. The thickness of the Tuscaloosa Formation varies but has been reported to be over 700 ft thick (Puri and Vernon 1964).

Overlying the Tuscaloosa Formation in Panhandle Florida is the Eutaw Formation: gray to cream calcareous fine sandstone that changed downdip into a soft pasty sandy chalk with limestone seams. It ranges between 150 and 300 ft in thickness.

Above the Eutaw are sediments of the Austin Age. These beds are equivalent to the Mooreville Chalk in Alabama. In northwest Florida, these sediments are gray soft glauconitic micaceous fine-to-coarse quartz sand interbedded with gray-green soft calcareous thinbedded clay, averaging 350 to 450 ft thick. Generally less than 500 ft in thickness, beds of the Taylor Age overlie the Austin Age beds. The uppermost Cretaceous sediments are beds of the Navarro Age. The presence of these sediments is questionable in northwest Florida, but a thin gray pasty marl occurs at the top of the Taylor beds in the western Panhandle.

The Mesozoic sediments total approximately 10,000 ft in combined thickness in the vicinity of Bay County. The first occurrence is generally deeper than 3,000 ft below sea level, and the sequence continues downward to about 13,000 ft below sea level.

### 2.3.3 Cenozoic Era

In the Florida Panhandle, an unconformity separates the basal Paleocene sediments from the Upper Cretaceous rocks (Applin and Applin 1944, Rainwater 1960). Applin and Applin (1944) have stated that in the Tallahassee area, Paleocene strata lie unconformably on beds of the Taylor Age, with the Navarro equivalent and upper beds of Taylor Age being present.

**a. Paleocene Series.** The Paleocene Series in Northwest Florida consists of clastic beds of the Midway Age. The Midway Stage has been divided into three units in Alabama: the Clayton, Porters Creek, and Naheola Formations. In the Florida Panhandle, these formations are undifferentiated, which led Chen (1965) to treat the entire stage as the Midway Formation. Lithologically, the formation consists of dark green-gray micaceous and slightly glauconitic laminated calcareous shales, with minor amounts of thinbedded argillaceous and fossiliferous limestones and glauconitic and calcareous sandstones. The thickness of these sediments varies from 250 to 750 ft throughout the central Panhandle.

The Midway Formation underlies the entire Florida Panhandle and extends widely throughout the southeastern Coastal Plain. Regionally, the vertical and lateral changes of lithologic character and the thickness of the unit are rather great, as demonstrated by Chen (1965). His isopach-lithofacies indicate that the clastic sediments, such as glauconitic and arenaceous shale and sandstones, are more dominant around the Chattahoochee Arch than elsewhere in the Panhandle. In addition, calcareous shale is a major lithologic component that occurs over most of the Panhandle region except in the southeastern area (Wakulla and southern Leon Counties), where limestone is predominant.

**b. Eocene Series.** The Eocene Series in the southeastern Gulf Coastal Plain has been divided into three stages. These stages are the Wilcox Stage, which is Lower Eocene; the Claiborne Stage, which is Middle Eocene; and the Jackson Stage, which is Upper Eocene.

The Wilcox Stage has been divided into three formations in southern Alabama, where it crops out. The stratigraphic equivalent of these three sections (the Nanafalia, Tuscahoma, and Hatchetigbee Formations) has been recognized in the Florida Panhandle as undifferentiated Wilcox. Chen (1965) treats the Wilcox Stage in northwest Florida as a formation.

In the outcrop belt in Alabama to the north of the study area, the Wilcox Stage has been demonstrated to be unconformable with both overlying and underlying rocks. In Florida, however, no distinctive geologic evidence of unconformable relationships is recognized. The Wilcox Formation includes marine and deltaic clastic sediments. These consist of glauconitic and calcareous sandstone and green-gray micaceous calcareous glauconitic and silty shale.

Using regional lithofacies maps, Chen (1965) shows that the amounts of clastic sediments decrease southeastward away from the Panhandle toward peninsular Florida. His maps also show the

Wilcox Formation to vary in thickness from less than 200 ft in the eastern Panhandle to nearly 1,000 ft southeastward.

The exposed strata of the Claiborne Stage in southern Alabama have been divided into three formations which are, in ascending order, the Tallahatta Formation, the Lisbon Formation, and the Gosport Sand. In the subsurface of northwest Florida, the sediments become more calcareous and less readily differentiated into distinct formations (Toulmin 1955). As a result, the Claiborne is divided into only two formations in the western part of Panhandle Florida, the Lisbon Formation at the top and the Tallahatta Formation below. These formations are correlative in time of deposition with the Avon Park Limestone and the Lake City Limestone, respectively, in peninsular Florida.

The Tallahatta Formation in northwest Florida consists of glauconitic and calcareous sandstone, green-gray glauconitic arenaceous and calcareous shale, and glauconitic argillaceous limestone. The Lisbon Formation is commonly a glauconitic arenaceous and fossiliferous limestone with some beds of calcareous shale. The combined thickness of the Claiborne near Bay County approaches 800 ft.

The literature pertaining to the Ocala Group is extensive. Summaries are contained in Vernon (1942, 1951), Cooke (1945), Puri (1957), and Puri and Vernon (1964). The Upper Eocene strata in Florida have been separated by Puri (1957) on the basis of a detailed biostratigraphic study into three formations of the Ocala Group, the Inglis, the Williston, and the Crystal River, in ascending order. In Panhandle Florida, the Ocala crops out in Jackson and Holmes Counties, which are located along the Alabama State line north of Bay County.

In his study on Holmes and Washington Counties, Vernon (1942) was able to divide the Ocala into two lithologic facies. The lower facies is typically developed in southern Alabama; it bears a lower Jackson fauna, and consists of greenish-gray glauconitic sandy limestone. The upper and more typical facies is exposed in Holmes County, and is described by Vernon as a limestone that is light yellow to white, massive, porous, and often silicified.

The Ocala was described in Jackson County by Moore (1955). He describes its lithology as a white to cream colored generally soft granular permeable fossiliferous pure limestone. Overlying the Ocala, Moore identifies the Bumpnose Limestone member of the Crystal River Formation (the youngest and uppermost formation of the Ocala Group). The Bumpnose is characterized by soft, white limestones with *Lepidocyclina chaperi* (a large flat foraminifera).

The top of the Ocala Group dips between 10 and 15 ft/mi as it approaches Bay County from the north (Vernon 1942, Schmidt and Coe 1978). In Bay County, the Ocala is entirely a subsurface unit (Schmidt and Clark 1980). The three formations into which Puri (1957) divided the Ocala are not recognizable in Bay County. As a result, the system devised by Vernon (1942), an upper and lower facies, is applied in Bay County. The lower facies consists of a light orange to white limestone with high porosity, both micrite and sparry calcite cement, crystal and skeletal grain types, small amounts of glauconite and sand, and abundant fossils. Dominant fossils include foraminifera, mollusks, echinoids, bryozoans, and corals. The large foraminifera are dominated by species of *Lepidocyclina, Operculinoides* and *Asterocyclina*. The upper facies is similar, except that glauconite is rare and chert is more common.

In the northern part of Bay County, thicknesses are less than 200 ft, the Ocala being over 300 ft below sea level. In the southern part of Bay County, the top of the Ocala dips to approximately 800 ft below sea level and attains a thickness of over 400 ft. The dip and thickness, therefore, increases in a nearly due-south direction.

**c. Oligocene Series.** The Oligocene series consists of two formations, the Marianna Limestone and the Suwannee Limestone. Originally named by Matson and Clapp (1909), the Marianna Limestone was described as a soft, porous, light-gray to white limestone at Marianna, Jackson County, Florida. Marianna Limestone is exposed at the surface of the ground along a narrow, nearly east-west band through Marianna, Florida. In Holmes County, the outcrop belt turns to the north and the strike changes to northwest-southeast as it crosses the Alabama state line.

From the outcrop area in Holmes and Jackson Counties, Marianna Limestone dips gently toward the gulf coast (Vernon 1942; Moore 1955; Schmidt and Coe 1978) at approximately 11 to 13 ft/mi. Its dip into southern Bay County is estimated to increase slightly to perhaps 15 or 16 ft/mi. The thickness is generally uniform in Jackson, Holmes and Washington Counties, and probably increases slightly in Bay County.

The name Suwannee Limestone was first used by Cooke and Mansfield (1936) to describe exposures of a hard crystalline yellowish limestone visible on the Suwannee River between Ellaville (Suwannee County) and White Springs (Hamilton County). Later, Vernon (1942), Cooke (1945), Moore (1955), and Reves (1961) established the formation's presence in the Florida Panhandle. The outcrop belt in the north-central Panhandle parallels that of the Marianna Limestone. In general, it can be described as a tan to buff-colored dolomitic and sometimes clayey limestone. In some areas, the Suwannee is predominately dolomitic.

**d. Miocene and Pliocene Series.** These series have been divided into at least 4 stages and 15 formations, ranging from the Early Miocene Tampa Stage to the Late Pliocene Miccosukee and Citronelle Formations.

Puri and Vernon (1964) defined the Tampa Stage (Lower Miocene) as comprising the Chattahoochee Formation and the St. Marks Formation. They included type-locality descriptions for both formations, but did not attempt to map their areal extent. Since 1964, several publications have reported on the geology of various areas throughout the Florida Panhandle, and all have used Puri and Vernon's nomenclature. Their description describes the St. Marks facies downdip as calcareous, and the Chattahoochee facies updip as silty.

From well cuttings in Bay County, the Tampa Stage limestones can be described as a white to light gray limestone with biogenic, micritic, and crystal grain types, moderately indurated with a micrite cement; minor amounts of quartz sand and a trace of pyrite. It often has a chalky appearance and contains fossil remains of foraminifera, coral, and mollusks (Schmidt and Clark 1980).

The thickness of the Tampa Stage in Bay County is variable. Along the northern part of the county it ranges between 50 and 100 ft thick. The top of the Tampa Stage dips from approximately sea level in the northern part of Bay County to nearly 500 ft below sea level at the extreme southeastern corner of the county. The Tampa stage is entirely subsurface in Bay County. Banks and Hunter (1973) reported on post-Tampa, pre-Chipola sediments in the eastern Florida Panhandle. They called the clays, sands, and shell beds found in Liberty, Gadsden, Leon, and Wakulla Counties the Torreya Formation. The stratigraphic position of the Torreya was determined by the presence of *Miogypsinida* (a foraminiferan genus).

Gardner (1926) named the Alum Bluff Group to include Chipola, Oak Grove, and Shoal River beds. Cooke (1945) then divided the Alum Bluff Group into three formations: the Hawthorn (east of the Apalachicola River), the Chipola, and the Shoal River (both west of the Apalachicola River). Puri (1953), added the Oak Grove of Gardner (1926) to Cooke's three formations and called them all facies of the Alum Bluff Stage (Middle Miocene). Later, Puri and Vernon (1964) included in the Alum Bluff Stage the Shoal River, Oak Grove, Chipola, and Hawthorn Formations and added the Pensacola Clay, Course Clastics, and Fort Preston Formations.

Huddleston (1976) redefined the marine deposits of the central Florida Panhandle. He included in the Alum Bluff Group five formations: the Chipola Formation, the Oak Grove Sand, the Shoal River Formation, the Choctawhatchee Formation, and the Jackson Bluff Formation. The main mass of the Alum Bluff Group was considered by Huddleston to be restricted to the eastern margin of the Gulf Coast Basin and to the vicinity of the Chattahoochee Arch. Planktonic foraminifera were used by Huddleston to establish the time of deposition of the deposits. He reported the Chipola Formation to be Early Miocene, the Oak Grove Sand and part of the Shoal River Formation to be Middle Miocene, the Choctawhatchee Formation of Late Miocene Age, and the Jackson Bluff Formation to be Pliocene in age.

The Chipola Formation was described by Puri and Vernon (1964) in the area of its type-locality as a blue-gray to yellowish-brown highly fossiliferous marl studded with molluscan shells. This marly facies only exists in the vicinity of the Chipola and Apalachicola Rivers. Further west, Cooke (1945) described two other facies: a sandy limestone which he said is mostly subsurface, and a light-colored coarse sandy facies that contains clay.

The lithology of the Chipola varies slightly throughout its extent in Bay County; however, it can be summarized as a very light orange sandy limestone, with crystal, micrite and pellet grain types, fine to coarse grain size, a sparry calcite and micrite cement, with foraminifera, mollusks, coral and bryozoans. Its induration, porosity, sand content, and occasionally the presence of argillaceous material, are the common lithologic variables.

The Chipola is distinguishable from the underlying Tampa sediments in that the Tampa is generally a pure white limestone with relatively few fossils. The Chipola is distinguished from the Bruce Creek again by the latter being a purer limestone. This distinction is a subtle one and often difficult to identify.

The Tampa and Chipola sediments become indistinguishable from the Bruce Creek Limestone downdip. The Chipola Formation along the Washington County line appears to strike almost east-west and maintains a thickness of about 50 ft. The top of the formation dips along the strike from near sea level east of the Econfina Creek to about 150 ft below sea level near East River, a dip of about 5 ft/mile. Gardner (1926) reported on a comprehensive study of the molluscan fauna of the Alum Bluff Group from a number of outcrops in the Florida Panhandle. In 1965 Vokes suggested, as indicated by the Muricinae (Mollusca: Gastropoda), that the formation might be equivalent to the Helvetian of Europe (lower Middle Miocene). The benthic foraminifera of the Chipola Formation were described by Cushman (1920), Cushman and Ponton (1932), and Puri (1953). Puri's report also included a list of identified ostracod species. Planktonic foraminifera were described by Gibson (1967), Akers (1972), and Huddleston (1976). In addition to foraminifera, Akers (1972) discovered the presence of some calcareous nannofossils in the Chipola material. Coral species from the Chipola were reported by Vaughan (1919) and Weisbord (1971). Finally, Bender (1971) dated corals from the Chipola using the He/U radiometric age. He placed a concordant age of 14–18 million years on ten of the samples. This would put the Chipola in the early Middle Miocene or late Lower Miocene.

The Bruce Creek Limestone was named by Huddleston in 1976. He included it in a group of three formations he mapped in coastal Walton County. The three formations, in ascending order, are the Bruce Creek Limestone, the St. Joe Limestone, and the Intracoastal Limestone. Huddleston placed these three formations in the Coastal Group, which he explained was a new name for Alum Buff equivalent carbonate units that underlie the coastal area of Walton County and vicinity.

The Coastal Group is recognized by Huddleston as far west as Niceville in Okaloosa County, and as far east as Carrabelle in Franklin County. He further states that it is not present in southern Washington County, or at Alum Bluff in Liberty County.

This formation has been identified previously as a limestone facies of the Chipola Formation (Gardner 1926, Cooke and Mossom 1929). Limestones of similar description were reported by Cooke and Mossom (1929) in southwestern Washington County in the vicinity of the Choctawhatchee River. Samples from the type outcrop on Bruce Creek in Walton County can be correlated lithologically with cuttings and cores from areas in Bay County. Only two lithologic types within the group can be recognized. The two types consist of well-consolidated white to light gray limestone, overlain by a poorly consolidated argillaceous abundantly microfossiliferous limestone.

In Bay County, the Bruce Creek Limestone is a white to light yellow-gray moderately indurated granular to calcarenitic limestone. It may contain up to 20% quartz sand, with common minor accessories being phosphorite, glauconite, and pyrite. In some locations, sparry calcite or dolomite is present. It is commonly cemented by micrite and becomes less indurated toward the east. The Bruce Creek Limestone is dominated by macrofossils, but microfossils including planktonic and benthic foraminifera, ostracods, bryozoans, and calcareous nannofossils are also present.

The Bruce Creek Limestone is overlain in Bay County by the Intracoastal Formation or the Jackson Bluff Formation. It is distinguished from the Intracoastal unit by containing less sand, clay, and phosphate. It is also much more indurated and crystalline. The Bruce Creek Limestone also contrasts in color with a white to light yellow-gray being easily distinguished from the olive to gray green color of the Intracoastal Formation. Lastly, the Bruce Creek Limestone is less fossiliferous than the Intracoastal Formation with its abundant fossils. In northern Bay County, the Bruce Creek Limestone is sometimes overlain by the Jackson Bluff Formation, which is much less indurated and contains larger quantities of sand and clay. The Jackson Bluff Formation essentially is an olive-green shell marl, which is easily distinguished from the white, crystalline to micritic Bruce Creek Limestone.

The Bruce Creek Limestone extends westward across southern Walton County and is thought to lose its identity somewhere in Okaloosa County. To the east, it has been identified in a core on St. Joe Spit in Gulf County and in a core near Dead Lake in Calhoun County. The Bruce Creek Limestone is a very low-angle, wedge-shaped deposit reaching a maximum thickness along the gulf coast of about 300 ft. Planktonic foraminifera place the Bruce Creek Formation in the Middle Miocene (Huddleston 1976).

Sediments of the Choctawhatchee Stage in the Florida Panhandle are exposed in a narrow band extending from 20 mi west of Tallahassee, Leon County, northwest to DeFuniak Springs, Walton County, a distance of about 80 mi. The exposed sediments are tan, orange-brown, or gray-green sandy clays, clayey sands, and shell marls. The outcrops generally are poorly exposed and small. True stratigraphic relationships are poorly understood (Puri and Vernon 1964, Rainwater 1964, Waller 1969, Akers 1972, Huddleston 1976).

The Intracoastal Formation describes the body of sediments which was called the Intracoastal Limestone and St. Joe Limestone in Walton, Bay, Okaloosa, Calhoun, Gulf, and Franklin Counties (Huddleston 1976). The Intracoastal Formation in Bay County is a low-angle, wedge-shaped deposit up to 240 ft thick and occurring principally along the coast. It thins and rises to the north, and extends westward into southern Okaloosa County. The upper part of the Intracoastal Formation, although predominantly a quartz sand, can easily be distinguished from the Pliocene to Recent sand because it contains phosphorite, poorly consolidated limestone, and foraminifera.

The Hawthorne Formation exhibits a wide range of lithotypes in the Panhandle, including shallow marine carbonates, restricted lagoonal clays, and possible prodelta clastics. Thought to be middle Miocene in age, it underlies most of the surface outcropping sediments of the Tallahassee Red Hills in the Panhandle. Its influence on plants and animals is confined, therefore, to the lower slopes of ravines where it has been exposed by gully erosion. It is most common in central Florida where it was described.

The Jackson Bluff Formation is found through most of the central and southern parts of the Panhandle. Its outcrop pattern is a narrow belt extending from southern Washington County eastward to the Jackson Bluff area of Leon County. From there the outcrop belt apparently turns southwest where exposures occur in the vicinity of Crawfordville in Wakulla County (Banks and Hunter 1973, Huddleston 1976).

The Jackson Bluff Formation along the lower Ochlockonee River consists of three clayey, sandy shell beds, differentiated on the basis of lithology and mollusks. In Bay County the Jackson Bluff Formation is a calcareous sandy clay to clayey sand containing large quantities of mollusk shells. Along the coast in the vicinity of Bay County the Jackson Bluff Formation is underlain by the Intracoastal Formation. The limestone portions of the Jackson Bluff Formation has more mollusks and is better indurated than the Intracoastal Formation. In color, the Jackson Bluff limestones are light grays in contrast to the olive-green to buff color of the Intracoastal Formation (Schmidt and Clark 1980). Overlying the Jackson Bluff Formation is the Pliocene to Recent Sand Unit, which is readily distinguished from the Jackson Bluff Formation by having no limestones, very little clay, and almost no fossils. Studies of the planktonic foraminifera of the Jackson Bluff Formation place its age as Late Pliocene (Akers 1972, Huddleston 1976).

The Miccosukee Formation is a series of silts, sands, clays, and gravels that were deposited as deltaic and fluvial sediments. It outcrops in the Tallahassee Red Hills beginning about the Ochlockonee River (eastern margin of the Panhandle as we have defined it), and is common eastward through the Northern Highlands and Central Highlands of peninsular Florida at the highest elevations. Thought to be Late Pliocene in age, it may be contemporaneous with the Citronelle Formation of the Panhandle. Most of its physical and chemical properties that affect plants and animals are the same as those of the Citronelle Formation.

The Citronelle Formation is composed of prodeltaic, deltaic, and fluvial deposits of sands, clays, and gravels. These clastics appear to have been deposited contemporaneously with the Miccosukee Formation, but are geographically separated from it. The Citronelle deposits outcrop across the Northern Highlands from Gadsden County and Liberty County on the east to Escambia County on the west. They range in thickness from a few tens of ft in the western Tallahassee Red Hills to hundreds of ft in the Western Highlands. In the Gulf Coastal Lowlands, the Citronelle Formation thins toward the coast, and is overlain by terrace sands and other Pleistocene and Recent deposits.

Clays and silts in the Citronelle Formation give soils derived from it their loamy character. The water retaining capacity of these soils make them better suited for a wide range of plants, such as the rich groundcover flora of grasses and forbs in the longleaf clayhill community. These soils are more nutrient rich from inorganic mineral leachates than the pure quartz sands of sandhills.

The high clay and silt content of the Citronelle Formation facilitates surface erosion by allowing excessive rainwater to runoff over the surface of the ground. Because of this and the generally higher elevations reached in the Panhandle by the Northern Highlands, landforms underlain by the Citronelle at the surface are highly gullied. The topographic relief of the Northern Highlands is due, primarily, to this erosion. The ravine valleys provide many of the lower valley slopes that are naturally protected from fire, allowing mesic hardwoods communities to develop on them. Many animals and plants are maintained in the fire-protected ravines, and accommodated by the higher humidity of ravines.

**e. Pleistocene to Recent.** The relatively short period of the Pleistocene (2.0 million years) witnessed several drastic fluctuations in sea level. These were brought on by climate changes that caused water in the oceans of the world to accumulate in continental ice sheets and extensive montane glaciers. As the glaciers grew, ocean levels dropped to as much as 300–400 ft lower than the present sea level. During warm interglacial periods ocean waters rose, but probably did not exceed present sea level until the past 10,000 years (end of the Pleistocene). Evidence from the two lower terraces, the Silver Bluff (1–10 ft) and the Pamlico (8–25 ft), indicate that two stands of the sea slightly higher than present may have lasted for short periods of time before the present sea level was established only about 6,000 years ago.

As a result of these post-Pleistocene fluctuations, coastal regions of the Panhandle less than about 25–35 ft above sea level have experienced a complicated history of erosion, deposition, and reworking of sediments from the action of rainfall, wind, and waves. Dunes, bars, spits, beach ridges, and other coastal features were stranded inland as sea level receded. Some of these are delineated on the physiographic map of the Panhandle (Figure 5).

The consequences of sea level fluctuations during the Pleistocene had little effect upon the present exposed land surfaces of the Panhandle above the two terraces just mentioned. This is because once the ocean withdrew from the higher terraces it never returned. The surface of the Panhandle above the Pamlico terrace was exposed to erosion and colonization by plants and animals just as this area is today. Pleistocene sea level fluctuations had their greatest effects, however, on the lands that today are submerged under the ocean. During lowered levels of the ocean surface much of the present sea floor was exposed to the air and to colonization by terrestrial plants and animals. During the Pleistocene the acreage of the Panhandle increased by a factor of 1 1/2 to 2 times by newly emerged Continental Shelf that was annexed to the present coastline.

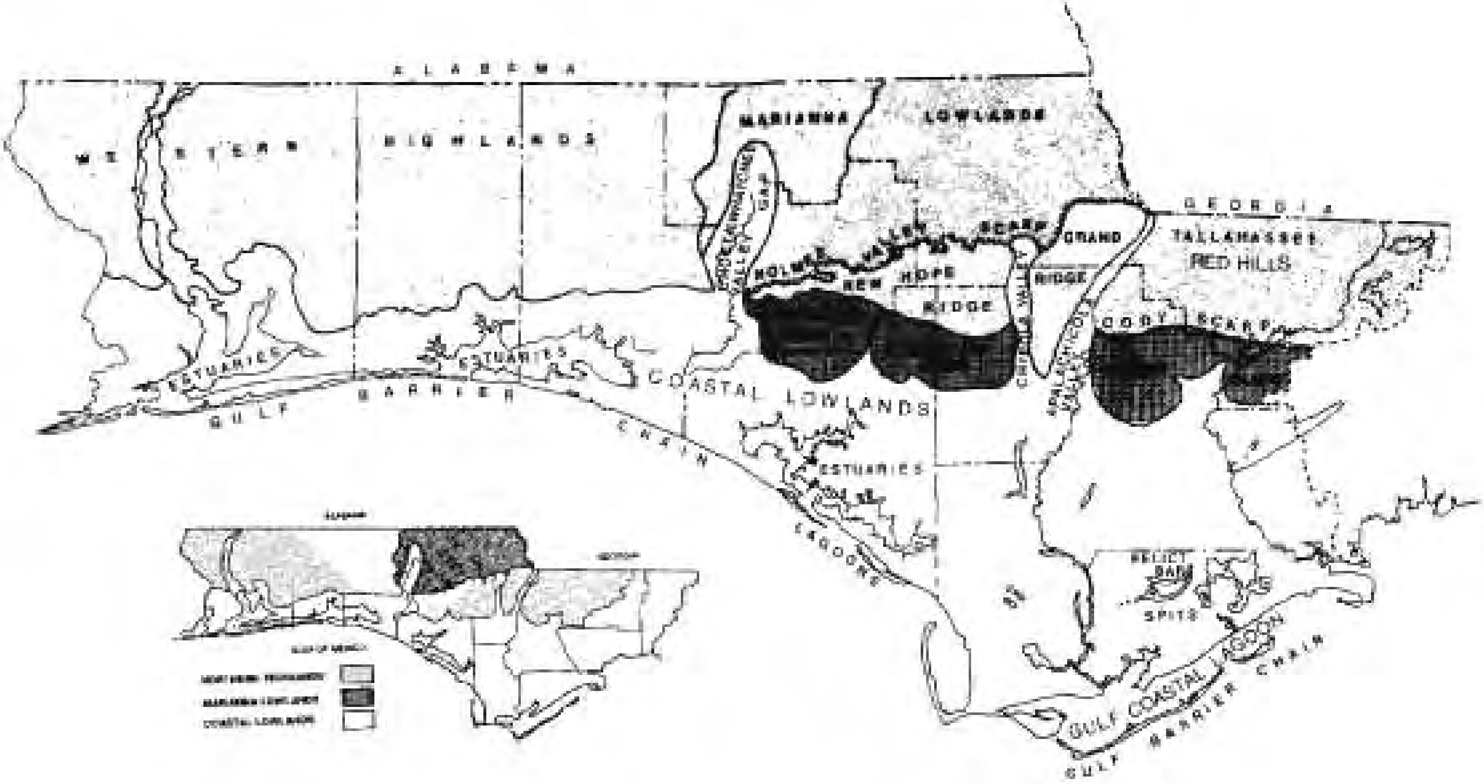

Figure 5. Physiography of the Florida Panhandle (after Puri and Vernon 1964, Brooks 1981b).

The land surface is well drained and has a well developed dendritic stream pattern. It is pocked by sinks interspersed with rolling hills and abrupt ridges. The ridges are bounded by stream channels or by sink rims. Broad, shallow basins are generally present, some filled by water. The Marianna Lowlands possess Florida's most extensive system of air-filled cavern passageways, and the only ones in the Panhandle. The calcium-rich soils that develop on top of the limestone are often moist and rich in nutrients.

### 2.4.3 The Gulf Coastal Lowlands

The Gulf Coastal Lowlands physiographic region extends inland to its contact with the Northern Highlands along Cody Scarp (Figure 5). It is continuous from southern Escambia County on the west to Wakulla and southern Leon Counties on the east. The Gulf Coastal Lowlands are generally low in elevation and poorly drained on the east, but rise to form a high, sandy, well-drained plateau whose southern margin is a wave-cut escarpment west of Walton County. Coastal terraces characterize many of the landforms of the Gulf Coastal Lowlands and their low scarps form the boundaries between them.

The Gulf Coastal Lowlands are at least as diverse physiographically and biologically from west to east as are the Northern Highlands. Puri and Vernon (1964) listed nine subdivisions and there may be more. Immediately adjacent to the coast, the Gulf Coastal Lowlands are composed of barrier islands, lagoons, estuaries, coastal ridges, sand dune ridges, and relict spits and bars, with intervening coast-parallel valleys. Inland, northern Bay, southern Washington, and western Calhoun Counties have well developed karst ponds and lakes.

Greenhead Slope is a massive sand deposit that is pocked by circular depressions and round lakes. Aside from the limestone-dominated Marianna Lowlands, Greenhead Slope is the only other land area of the Panhandle exhibiting extensive karst features. It possesses a few steepheads, some draining into Econfina Creek and others into karst depressions.

Beacon Slope east of the Apalachicola River has more steepheads developed in it than any other part of the Panhandle, although by sheer volume of flow some on Eglin Air Force Base are larger. Because Beacon Slope is immediately adjacent to and below the well developed Apalachicola ravines in the Tallahassee Red Hills, the steephead ravines of Beacon Slope support most of the same endemic and relict species that are found just north.

Beacon Slope, Fountain Slope, Greenhead Slope, and the massive sand deposit in southern Santa Rosa, Okaloosa, and Walton Counties may all be ancient coastal sand deposits formed contemporaneously during the Pliocene when the sea stood near Cody Scarp. Today they are stranded inland by lower sea level, but it is significant that each feature contains numerous steepheads and endemic plants and animals that may have evolved on each feature during the long period when each was part of a developing barrier island-lagoon set.

Relict bars and spits are common in Gulf, Liberty, and Franklin Counties. In fact, ancient bird's-foot deltas can be traced on the land surface on both sides of the lower Apalachicola River. Moreover, this part of the Gulf Coastal Lowlands is biologically so distinctive that it probably deserves its own physiographic rank. At least 15 races and species, and one genus of plants and animals have their distributions centered on the lower Apalachicola valley (Means 1977). Many unique, silt-bottomed savannas and cypress wetlands occur here, and the region beckons for further exploration.

## 2.5 Regional Marine Geology

Two regional geologic features control the coastal configuration of the Florida Panhandle: the Apalachicola or Southwest Georgia embayment and the Chattahoochee arch (Figure 3) (Schnable 1966). The Apalachicola embayment is a shallow basin (syncline) situated between the Ocala and Chattahoochee uplifts. It is located where the east-west strike of the coastal element changes to approximately north-south in southwestern Georgia and northern Florida (Murray 1961). The Apalachicola delta lies near the center of the embayment. The thickness of the Pleistocene and Miocene sediments in the eastern portion of the area reflect the influence of the Ocala uplift as a structural high (Schnable and Goodell 1968).

The thickness of the tertiary sediments in the northeastern Gulf of Mexico is substantially less than those of the northwestern and north central gulf (Vause 1959). This is probably a result of the Apalachicola delta region lying further from the main axis of the Gulf Coast Geosyncline than most coastal areas to the west and as a result being more stable and structurally less complex (Schnable 1966). Pleistocene to Recent sediment thicknesses along the present coast vary from less than 3 m in the easternmost portion of the Panhandle to 36 m in the westernmost part (Figure 6) (Schnable 1966).

Several investigators have examined the offshore sediments in the region (Lapinski 1957, Milton 1958, Chen 1978). West of Ochlockonee Bay, the Apalachicola and Ochlockonee Rivers supply alluvium downdrift for a system of barrier islands (Dog Island, St. George Island, and St. Vincent Island), beaches, spits, and bars. The Ochlockonee and Apalachicola are the eastern most rivers carrying appreciable amounts of detrital and mineral matter to the gulf. The region from the western end of St. George Island to the Ochlockonee Bay is classified as a low-energy area (Figure 7) (Tanner 1960b). The sediment from alluvial and shelf sources is mostly lost to coastal deposition west of St. Joseph Bay where the 25-m depth contour approaches the nearshore region and funnels material from the westward drift out into deeper water (Stout 1984). Further west, Santa Rosa Island receives sediment downdrift from Choctawhatchee Bay and sands from the Continental Shelf (Kwan 1969).

Most of the fine-grained sediment carried by the Apalachicola and Ochlockonee Rivers is contained within the estuaries (Kofoed and Gorsline 1963). Kofoed (1961) and Schnable and Goodell (1968) concluded that no significant quartz sand was being supplied to the littoral drift system outside the barrier-island chain. They contended that the "large volume of sand composing the barrier islands and offshore shoals can have been supplied only during lower sea-level stands." There has been extensive beach erosion on the spits and barrier islands in recent time in this area of supposed excess sediment (Warnke 1967). Clear evidence for erosion are tree stumps in the water on the beaches near East Point in the Apalachicola system and on St. George Island.

The littoral drift, or longshore sand transport, along the Panhandle coast has been described by Tanner (1964), Bruno (1971), and Walton (1976). Figure 8 gives a view of littoral drift along a portion of the Panhandle from Cape San Blas in Gulf County to the western border of Okaloosa County. From the western end of the Panhandle toward Bay County, the shoreline becomes concave. This natural concavity is broken by St. Joseph Bay. The area from Panama City west to East Pass is presently undergoing erosion. In recent geologic times this area may have been a source of sand for areas to the west (Walton 1976). In contrast, the shoreline from East Pass (St. Andrew Bay system, Bay County) to Perdido Pass may have been an area of accretion (Santa Rosa Island is evidence) in recent geologic times, though Santa Rosa Island is now in a state of equilibrium.

There are no true barrier islands present in the region west of St. Joseph Bay to Destin (Tanner 1960b). Moderate-energy waves form the gulf front beaches. From Panama City Beach to Destin the shoreline is a mainland beach (Gorsline 1966). For approximately 85 km the beach is unbroken, with only small streams interrupting the continuity. Associated with the larger streams are small brackish-water bays. A wide recent beach abuts a prominent bluff 6–10 m high. The present coast is relatively stable.

From Choctawhatchee Bay Pass westward to the Alabama border, a series of narrow barrier islands border the mainland. Santa Rosa Island is nearly 81 km long and is not more than 0.7 km wide. It represents the largest unbroken stretch of beach in the eastern Gulf (Brooks 1973). The beach is composed of pure white quartz sand (median diameter approximately 0.25 mm). During heavy storms there is local washover across the island. There is extensive dune development on the eastern fifth of the island.

Near the western end of the island salt marsh peat is exposed on the foreshore. The foreshore slope is relatively steep (approximately 9°–10°) so that the 15-m depth contour comes within 0.6–0.8 km of the shoreline. Because of this steep ramp, the area has recorded some of the highest waves in the northeast Gulf of Mexico (Gorsline 1966, Brooks 1973).

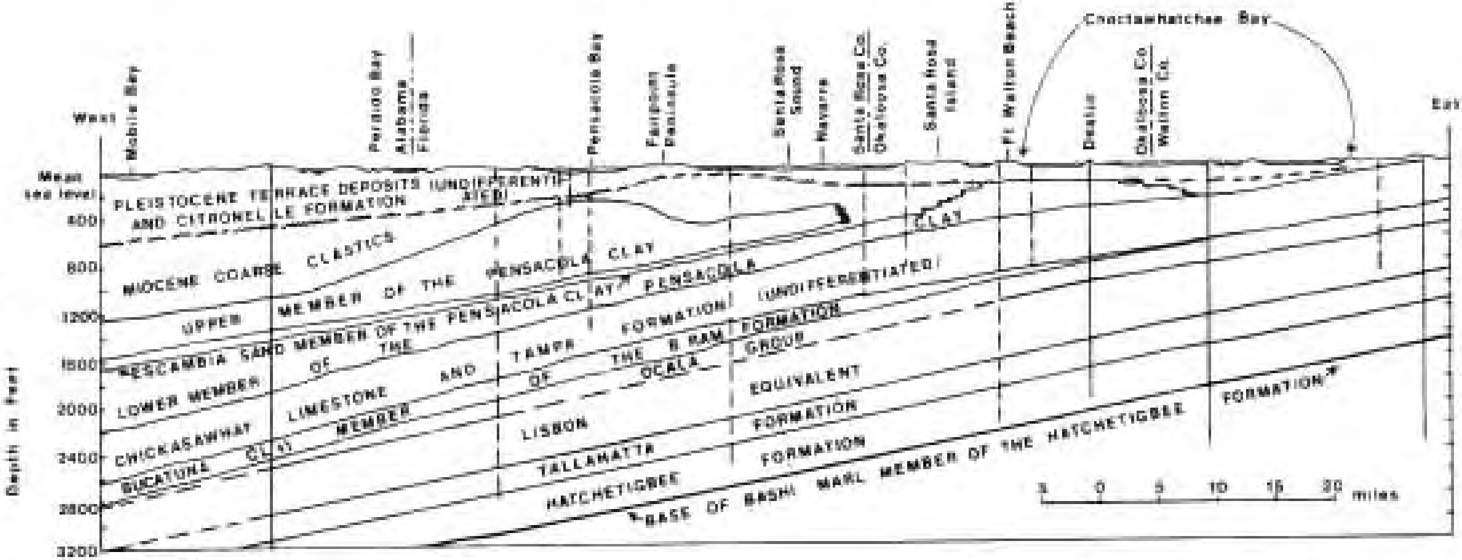

Figure 6. The thickness of Eocene to Recent sediments along the Panhandle coast from Choctawhatchee Bay to the Alabama-Florida border (after Marsh 1966).

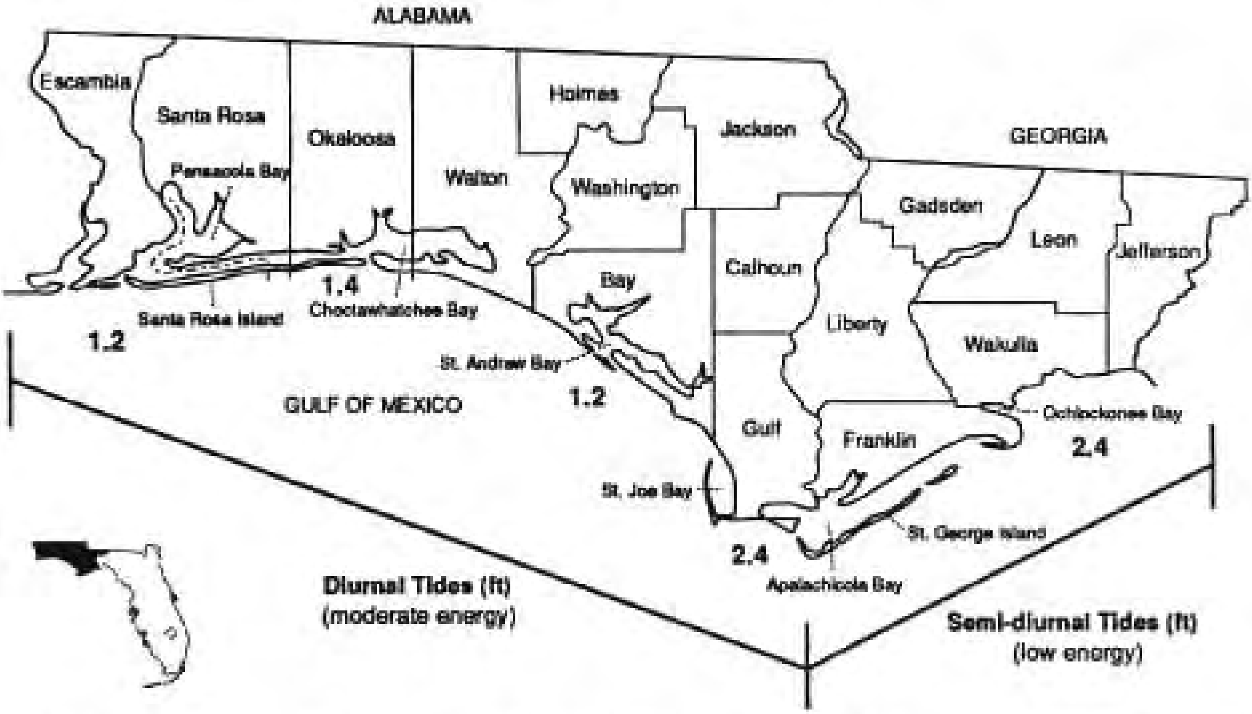

Figure 7. Coastal energy levels and tidal ranges for the northeastern Gulf of Mexico (after Stout 1984).

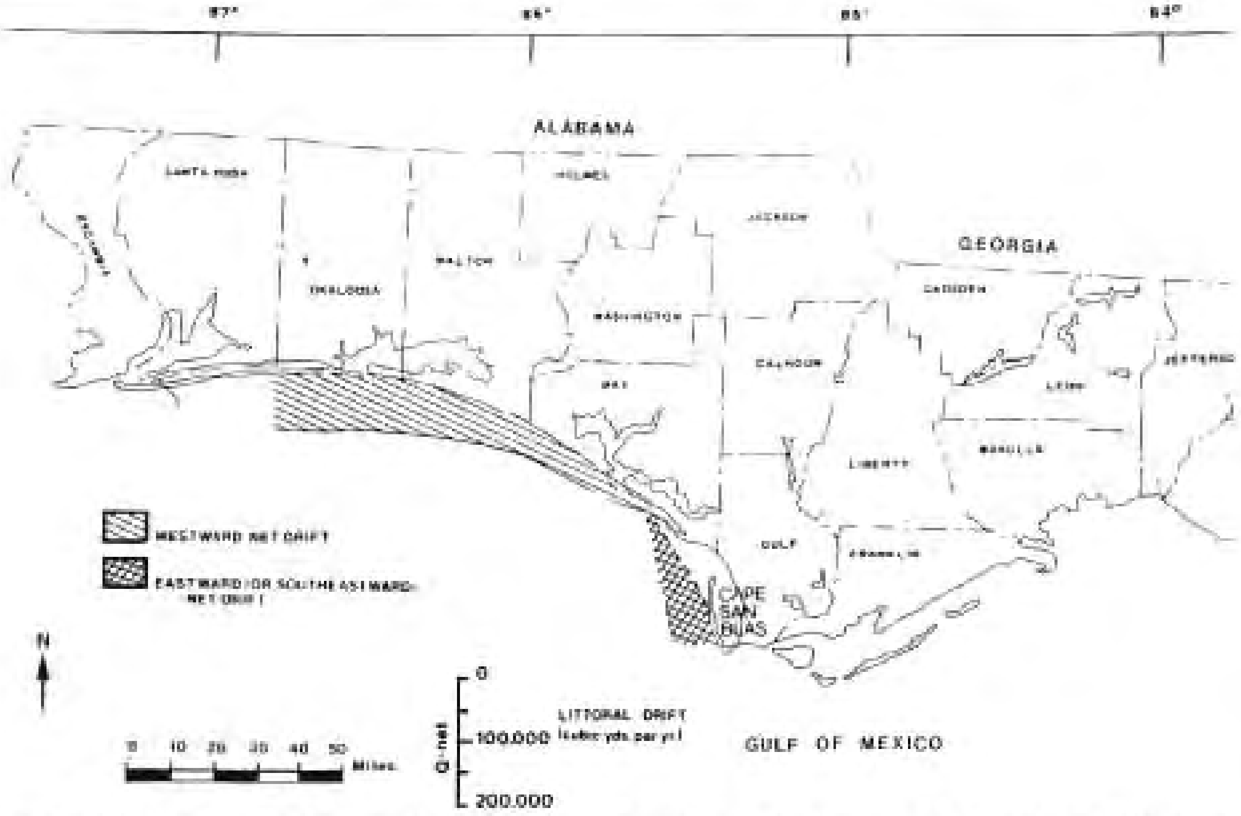

Figure 8. Schematic of net littoral drift along "idealized" Panhandle coast (after Walton 1976). $Q_{net}$ shows magnitude of littoral drift in cubic yds/yr.

The northeastern Gulf of Mexico is not as tectonically active as areas to the west. The Apalachicola delta region has been a relatively stable area since at least Pamlico (Sangamon — the last glacial recession) time (Schnable 1966).

There are two prominent offshore morphological features present in the eastern portion of the Panhandle region: the two large shoal areas off Cape San Blas/Cape St. George (Stauble 1971) and the submarine sand bodies in the nearshore gulf off Choctawhatchee Bay (Figure 9; Hyne and Goodell 1967). The two broad shoals extend nearly 16 km into the gulf and are characterized by a series of broad ridges and troughs. Mean grain size of the quartz sand increases seaward from the beach and therefore the sand in these shoals is coarser than the sand now being transported by the longshore drift system (Schnable 1966). The present energy levels along this coast are not sufficient to redistribute or remove sand from the shoal areas or sand bodies (Tanner 1961, 1964; Tanner et al. 1961). The outer shoals have remained relatively unchanged for over a century (Schnable 1966). The sands in these offshore areas are relict and were probably originally deposited at some early low stand of sea level.

Several mechanisms have been proposed to explain the origin of the shoals. One is a storm-surge

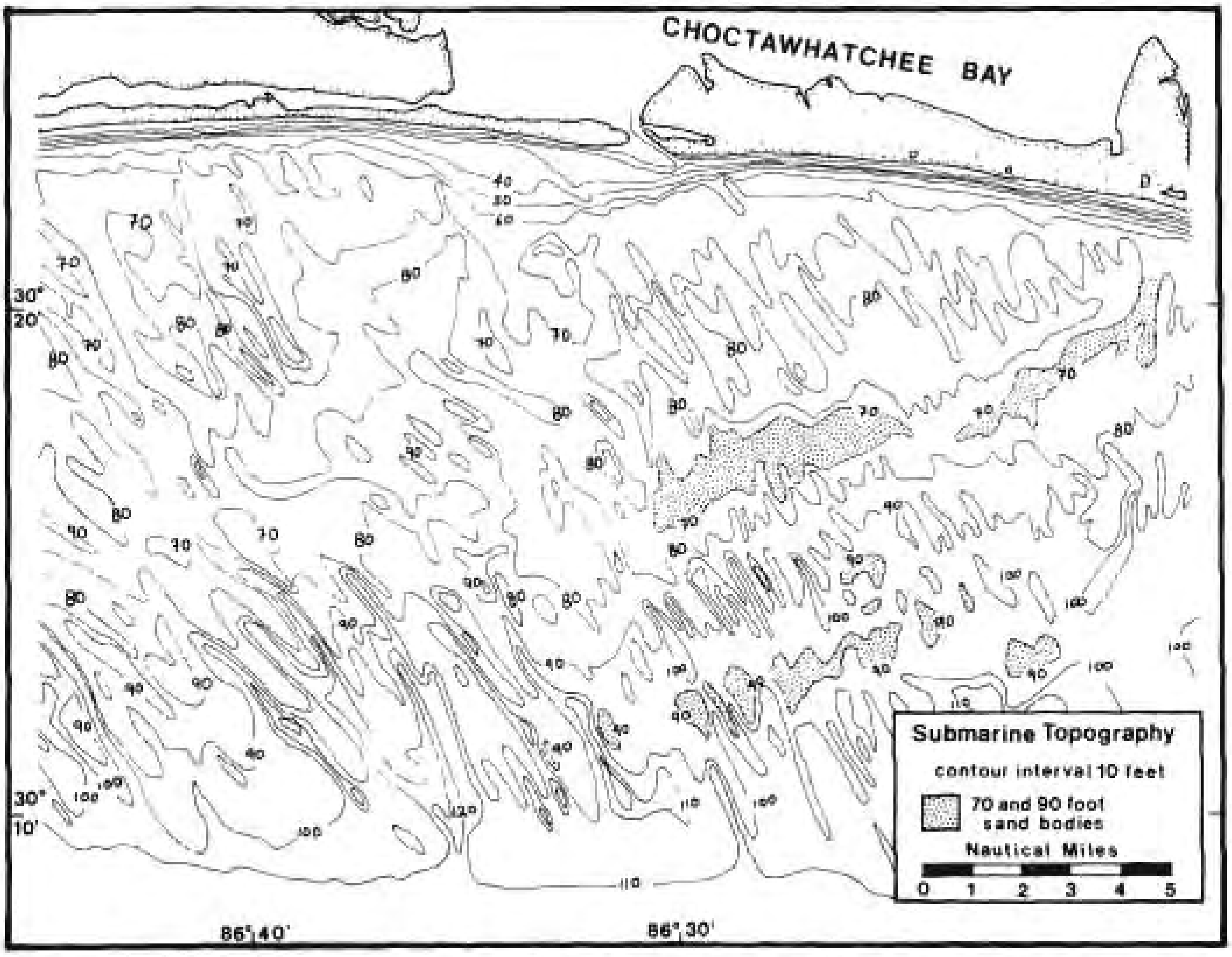

Figure 9. Nearshore bottom topography off Choctawhatchee Bay showing sand body features (after Hyne and Goodell 1967).

phenomenon that formed the ridge and trough configuration (Tanner 1960a). Others have proposed that the shoals are drowned barriers, although the sand has been extensively reworked. In addition, the ridges of the shoals contain concentrations of heavy minerals that may indicate a dune origin (Schnable 1966).

An interesting discovery has been made in the offshore waters south of Panama City Beach. Remnants of an ancient forest are present at a depth of approximately 18 m directly south of the beach and in 6 to 15 m of water nearer the St. Andrew Bay entrance (Lawrence 1974, Burgess 1977, Salsman and Ciesluk 1978). The latter site is located beneath sediments comprising the present-day barrier island complex. The wood dates from 27,00 to 36,500 years old and is believed to be part of a large forest that covered the area during a lower sea level stand. The forest extends many kilometers south of the present shoreline. The wood is mostly pine but contains small amounts of hardwoods such as oak, beech, hickory, and elm. This suggests the vegetation was very similar to present-day stands 32–48 km north of Panama City. The submerged forest further supports the contention that the present-day beaches and islands are recent geologic features.

## 2.6 Local Marine Geology

The following section is a discussion of the origin and geological aspects of the major bay systems included in the Panhandle region.

### 2.6.1 Ochlockonee Bay

The Ochlockonee Bay represents a drowned river valley that was cut during lower stands of sea level in the Pleistocene. Bottom topography at the mouth of the bay resembles a drowned delta with two linear shoals on each side of the channel that may represent an old river channel with natural levees on each side. The "old" Ochlockonee River probably had several routes to the gulf during the late Pleistocene (Schnable 1966).

The stratigraphy of the nearby region is unique in the Panhandle. The Miocene is very close to the surface at the present coastline in the vicinity of Turkey Point-St. Teresa (Figure 10). From there the

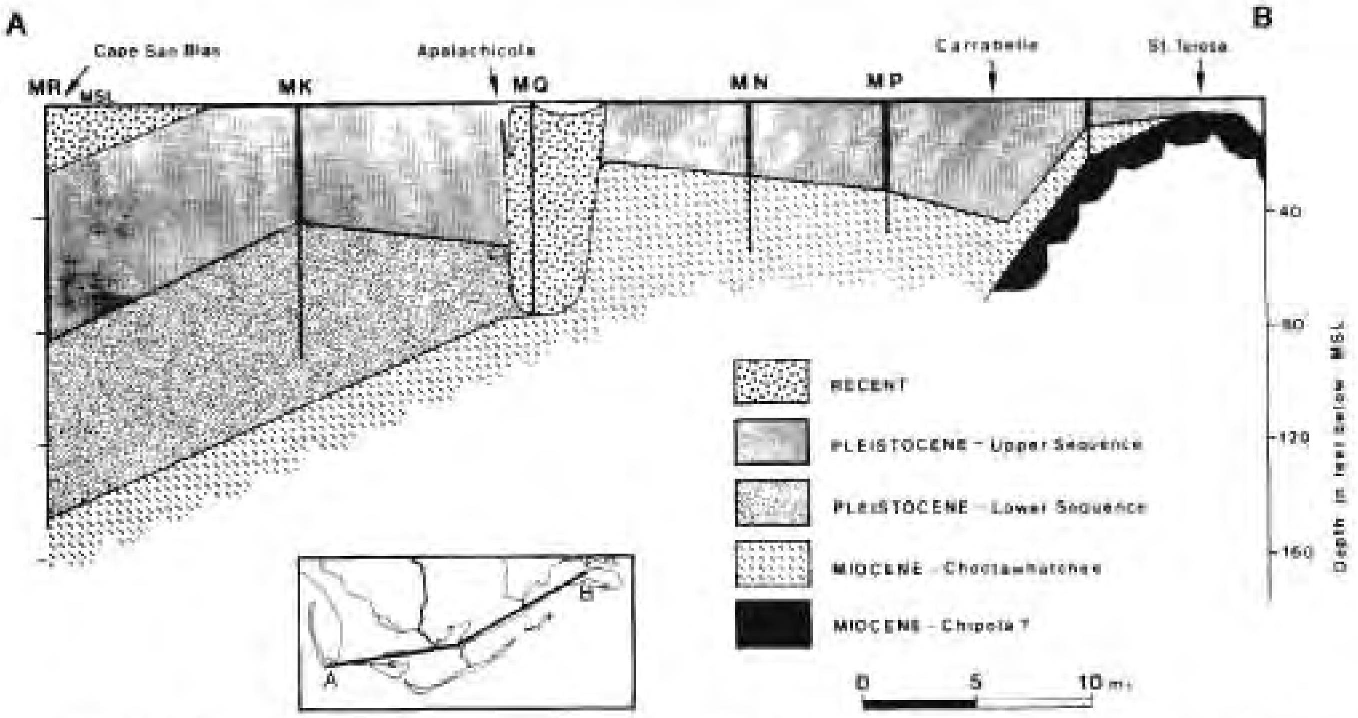

**Figure 10. Stratigraphy of coastal region from Cape San Blas to Ochlockonee Bay in the eastern Panhandle (after Schnable 1966).**

surface dips to the southwest and the Pleistocene-Miocene contact is approximately 45 m below the ocean floor off Cape San Blas.

### 2.6.2 Apalachicola Bay

During the Cretaceous period, the present Apalachicola River system was submerged under ancient seas (Tanner 1983). The origin of the present Apalachicola River probably occurred some time during the Miocene epoch (Livingston 1984). The present structure of the bay is nearly 10,000 years old (Tanner 1983). The present barrier island chain formation began approximately 5,000 years ago when sea level reached its modern position. It was at this time that the general configuration of the bay was determined, except for the southward migration of the delta flat (Tanner 1983).

### 2.6.3 St. Joseph Bay

Stewart and Gorsline (1962) described the following sequence of events leading to the formation of modern St. Joseph Bay:

(1) Following the last rise of sea level (approximately 5,000 years ago), a series of north-south trending beach ridges was formed and an open coast profile was established offshore. An even older set of ridges was submerged and subjected to marine degradation, resulting in the formation of a shoal trending south-southwest from the mainland through the Cape San Blas area.

(2) A large distributary of the Apalachicola River, its course controlled by beach ridge development, emerged about 8 km north of the present bay and deposited a wedge of fine-grained material over the terrace sediment. At approximately the same time, gyral currents established by the presence of the southern shoal initiated spit growth from the east.

(3) Rapid spit development segregated a large portion of the older surface and prevented substantial filling of the bypassed area. At this time, the detrital supply from the distributary had ceased and sand supplied by longshore drift and biologic carbonate formed the major contribution.

(4) Development of stronger tidal currents in recent times controlled spit growth and furnished a mechanism for the transport of sand into the basins. Sand has completely covered the fine-grained material to the north. Under the lower energy conditions of the past lagoon, sand encroachment has been slow and limited, and a large portion of the older surface remains relatively unobscured.

Present-day sedimentation in the bay comes from 2 dominant sources: the coastal transport of clean quartz sand from the east and biological activity within the area itself. In the absence of a substantial amount of silt-size quartz particles, carbonate tests and shell fragments increase in importance as the applied energy of the environment decreases southward in the lagoon. Residual gravels and sands dominate a sizeable portion of the southern slope of the bay that is removed from active deposition of detrital material (Figure 11).

Since the formation of the enclosing spit, a reduced rate of deposition has preserved the bottom contour in the central portion of the lagoon. The depth and gradient closely approximate that of the offshore slope (Stewart and Gorsline 1962). There is a far larger accumulation of clay in the central bay basin than can be accounted for by present minor sources. This has led to the conclusion that these fine sediments represent a relict surface produced by the discharge of an old distributary of the Apalachicola River.

The sediments of the area are typical of those from a Coastal Plain source. Small differences can be attributed to attrition and loss in transport. Less than 1% of the typical east gulf "kyanite-staurolite" suite of heavy minerals is present. Kaolinite, montmorillonite, and illinite are the clay minerals present, with kaolinite dominating.

### 2.6.4 St. Andrew Bay System

The St. Andrew Bay system is a typical tidal embayment. It appears that it was formed during the last major rise in sea level (the Holocene transgression) that took place approximately 5,000 years ago. As sea level rose and flooded the valley of a local river system, ocean waves and longshore currents built up a barrier bar across the mouth of the resulting bay.

Uniform sediment ridges on the bottom of St. Andrew Bay were documented by Salsman et al. (1966). The ridges, composed of a fine sand, were asymmetric, with steep slopes, 30 to 60 cm high,

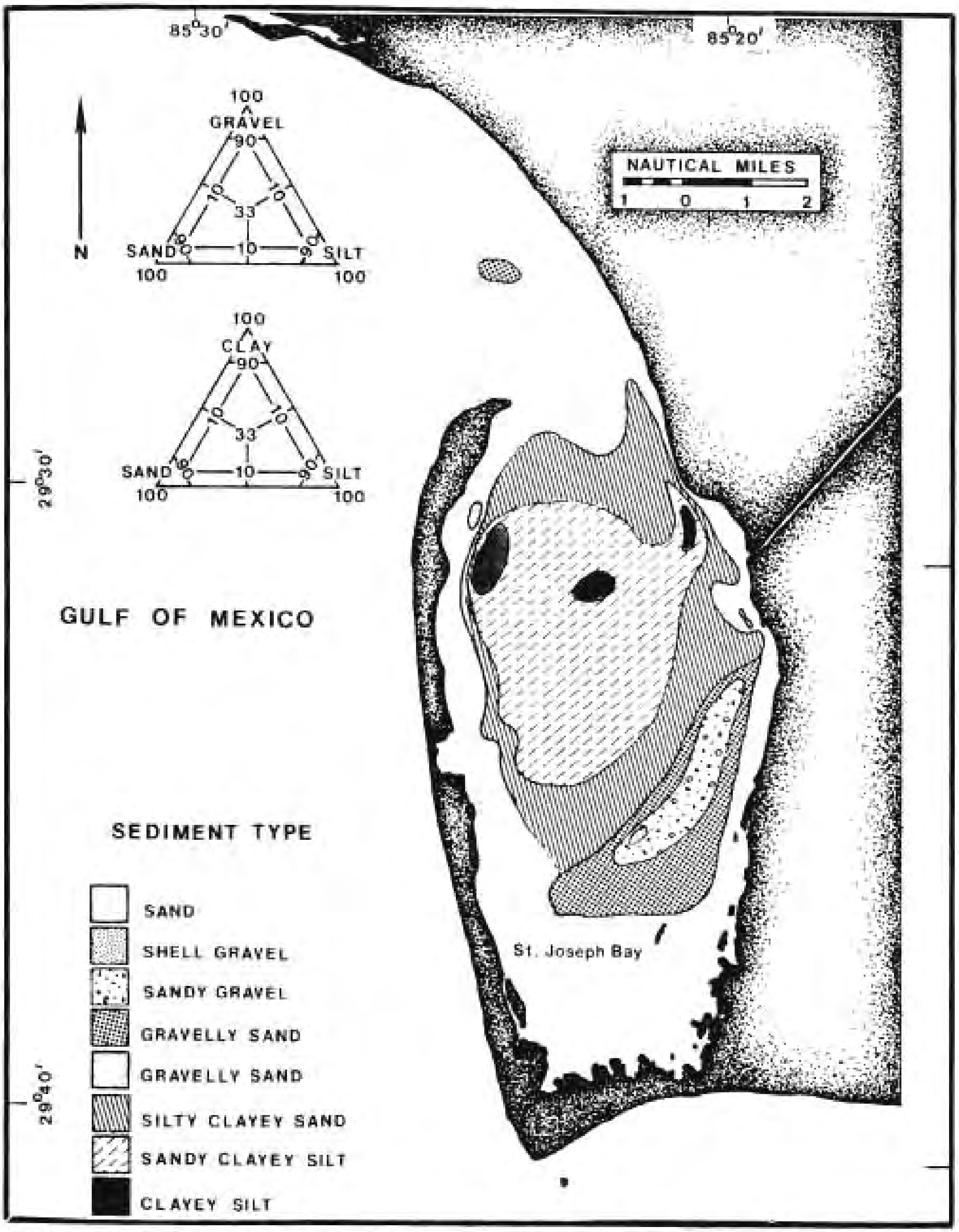

Figure 11. Surface sediment composition in St. Joseph Bay (after Stewart and Gorsline 1962).

facing down current, and had 13 to 20 m wavelengths. The predominant flood tide caused them to migrate northeastward at an average rate of 1.35 cm per day. The migration rate was very sensitive to changes in current speed. Near the leading edge of the ridge zone, where sand transport was primarily of bed-load mode, each ridge passing a point left behind an average 12 cm-thick sand layer.

Holmes and Goodell (1964) have reported on the sediments in St. Andrew Bay.

### 2.6.5 Choctawhatchee Bay System

The region presently covered by the Choctawhatchee Bay was as much as 92 m above sea level during the Pleistocene epoch (Puri and Vernon 1964) and became gradually inundated by oceanic waters in more recent times. As the Gulf of Mexico approached its present level, a persistent westerly drift of littoral sand created Moreno Point. This barrier eventually isolated the bay from the gulf, except for a narrow passage through the embayment now known as Old Lagoon Pass. At times before the formation and stabilization of East Pass, Choctawhatchee Bay became a freshwater lake when periodic shoaling closed the natural pass.

The land immediately adjacent to the bay is composed of unfossiliferous sand and clay deposits of Pleistocene and Tertiary age (Puri and Vernon 1964). Moreno Point is part of a massive sand ridge described by Tanner (1964). Sand cliffs from 2 to 4 m high make up the north shoreline of the bay. The narrow Garnier and Rocky bayous in the northwest corner of the bay have very steep shores, with sharp slopes extending down to depths of more than 10 m. This contrasts with the eastern end, which is marshy due to poor drainage, and the western end, which is composed of residual sand. Both of these ends are relatively shallow, with low gradient slopes. The bedrock limestone underlying Choctawhatchee Bay is found at a depth of approximately 45 m (Tanner 1964). The recent sediments of the bay are described by various authors (e.g., Postula 1967, Palacas et al. 1968, 1972).

Goldsmith (1966) reported a large contrast in condition between the present sedimentary environment and the one previously occupying the area. He reported the following sequence of events leading to the formation of Choctawhatchee Bay.

(1) A sharp rise in sea level (7,000 to 20,000 years ago) inundated the Pleistocene River valleys, from the coastal embayments that are presently the bayous on the north side of the bay. Between 3,000 and 7,000 years ago, when the rate of sea-level rise slowed, the westward longshore drift system began to form Moreno Point, the eventual barrier spit. It was not until sometime after 3,000 years ago that Moreno Point effectively closed off the bay.

(2) Isolation from the Gulf of Mexico had a profound effect upon the sedimentary environment within the bay, producing modifications in three factors that caused the sediments to undergo radical alteration. Biologically, the present environment lacks the prolific shell-producing organisms of the past. Physically, the entrapment of fine material brought by the Choctawhatchee River may have brought on the decline of the formerly abundant and diverse molluscan life of the bay. Finally, the changes in both biological and physical conditions caused modifications in the physiochemical environment, as reflected in the low alkalinity and highly reducing character of the surface sediments of the bay.

Minor fluctuations in sea level within historical times in Choctawhatchee Bay have been documented by the presence of submerged trees (approximately 0.5 m under water) next to emergent marsh remnants (1 m above water) (Goldsmith 1966). These features are located at about the middle of the south shoreline of the bay. This change in water level of the bay may be related in part to general coastal subsidence determined by Marmer (1952) from tidal observation.

Of historical note, farmers originally dug a ditch across Santa Rosa Island that eventually became the main Destin channel and resulted in major changes in the depositional and erosional patterns within the bay. The channel has since been maintained by the U.S. Army Corps of Engineers.

### 2.6.6 Pensacola Bay System

The recent sedimentology of the Pensacola Bay system is a result of watershed erosion since the Pleistocene epoch (Olinger et al. 1975). During the Pleistocene, Citronelle deposits were reworked and intermixed with marine terrace sediments (Marsh 1966). These deposits are presently eroding. Present-day sediments consist primarily of unconsolidated sand, silts, and clays of the Coast Plain Province that were deposited before the last sea-level rise. This layer is underlain by a veneer of Pleistocene terrace deposits that overlie tertiary beds of sand, silt, and limestone (Figure 12). The Citronelle Formation, the only formation with marine outcrops in the region is composed of layers of sand, gravel, iron-cemented sandstone, fossil woods, and kaolinite (Marsh 1966).

Horvath (1968) described the recent sedimentology of the Pensacola Bay system:

(1) Sediments enter into the system from two sources: stream discharge from the surrounding land, and wave and current action that bring them into the bay from the Gulf.

(2) The Escambia River discharges more coarse material into the bay than do the other rivers.

(3) Sediment distribution reflects the bay's circulation pattern, consisting of strong north-flowing currents along the eastern shores and south-flowing currents near the western coasts.

(4) Sand-size sediment predominates with silt-clay being the second most abundant.

(5) Grain size increases in every direction away from the bay center.

(6) The main mineral constituents are quartz, kaolinite, montmorillonite, and calcite.

(7) The Santa Rosa Sound is different from the three bays in the Pensacola Bay system, with a coarser mean grain size and lower average silt-clay content. Most of its sediments were probably derived from offshore sources and are not of fluvial origin.

## 2.7 Offshore (Outer Continental Shelf) Oil and Gas Reserves

Recently, the development of the Outer Continental Shelf (OCS) oil and gas resources has been a major concern of coastal Panhandle residents. At present, three offshore lease areas lie off the immediate Panhandle coast (Figure 13): (1) the Pensacola area; (2) the Destin Dome area, and; (3) the Desoto Canyon area.

Since the early 1970's, various oil companies have maintained exploratory interest in these lease areas. The Destin Anticline and the southwest corner of the Pensacola area are believed the most promising as hydrocarbon-producing areas (Figure 13). Eighteen exploratory wells have been drilled within the Destin Dome area in the Smackover geological formation, as of the summer of 1985. The depths to which the wells were drilled, 5185–5795 m, indicate natural gas may be a more likely yield than oil. Thus far, the natural gas discovered in the Smackover Formation in other regions has contained hydrogen sulfide (said to be "sour") that is corrosive and must be subjected to more costly processing than higher quality gas. Offshore oil activities have the potential for many harmful impacts to the nearshore coastal habitats. Some of these are discussed in the chapters dealing with the individual estuarine and marine habitats.

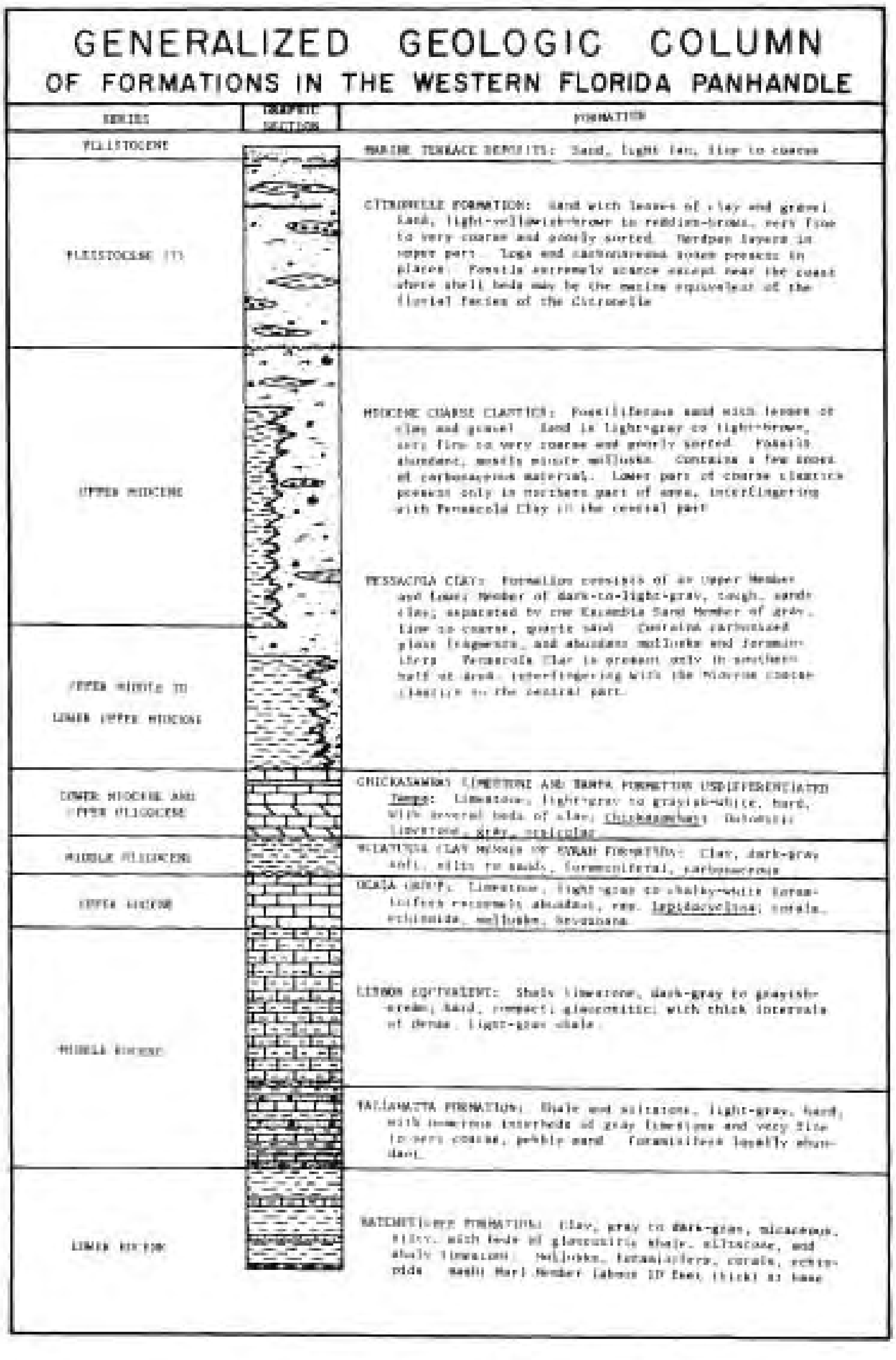

**Figure 12. Generalized geologic column of formations in the western portions of the Florida Panhandle (after Marsh 1966).**

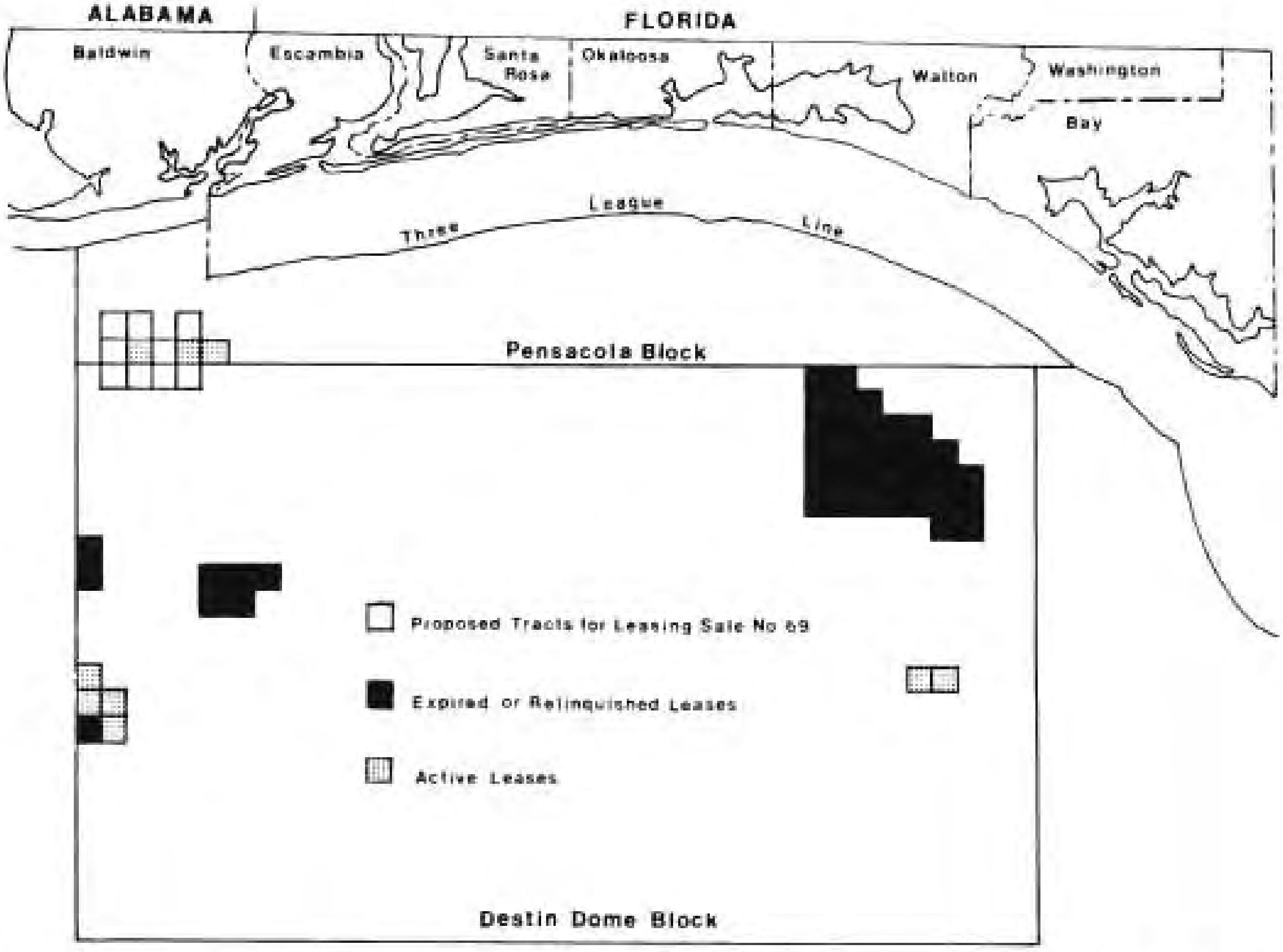

Figure 13. OCS leases in the Pensacola and Destin Dome Blocks offshore from west Florida (Lynch and Risotto 1985).

# Chapter 3. CLIMATE

## 3.1 Introduction

The Florida Panhandle experiences a mild, subtropical climate as a result of its latitude (30°– 31° N) and the stabilizing effect of the adjacent Gulf of Mexico (Bradley 1972). The waters of the gulf moderate winter cold fronts by acting as a heat source and minimize summer temperatures by producing cooling sea breezes. This gulf influence is strongest near the coast, weakening inland. Fairly detailed long-term climatological summaries are available for Apalachicola and Tallahassee. Though Tallahassee lies a few miles outside the eastern boundary of what we call the Panhandle, it is the location of much data collection and will be used to provide a more comprehensive report. More limited data are also available for Pensacola and certain other Panhandle locations (Jordan 1973). The locations of NOAA climatological stations are shown in Figure 14.

## 3.2 Climatological Features

### 3.2.1 Temperature

The annual average of the mean daily temperature is in the upper 60's Fahrenheit with mean summer temperatures in the low 80's and mean winter temperatures in the low 50's. Annual and seasonal temperatures vary greatly (Figures 15 and 16) with summer highs generally in the low to mid 90's with occurrences of 100 °F or higher infrequent. The summer heat is tempered by sea breezes along the coast and up to 50 km inland, as well as by the

**Figure 14. NOAA climatological station sites in the Florida Panhandle (after Wagner et al. 1984).**

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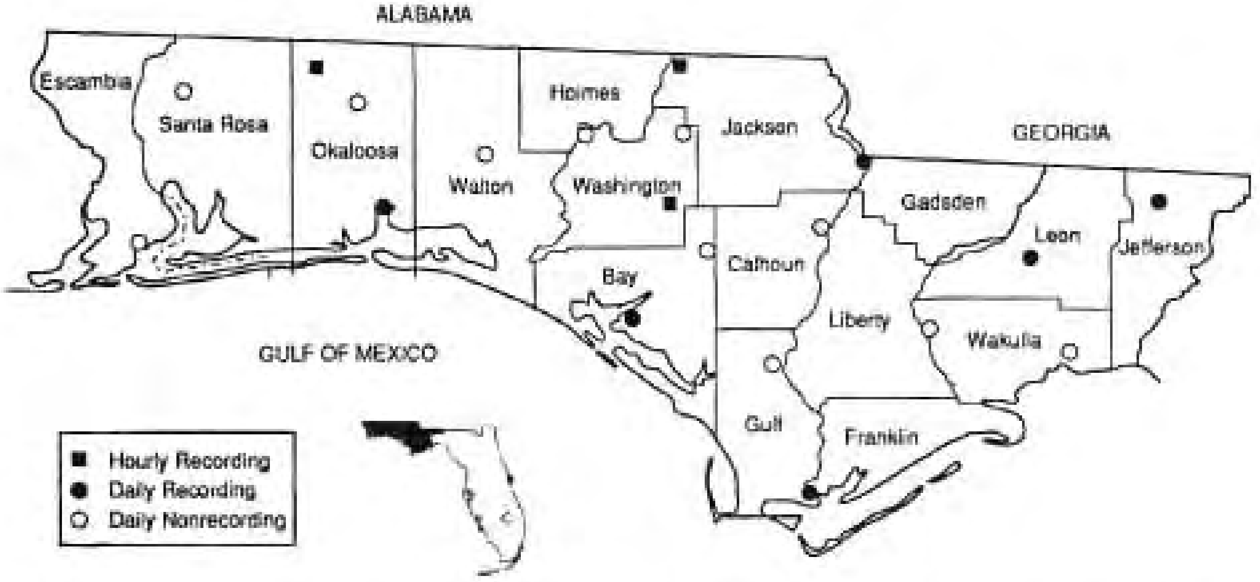
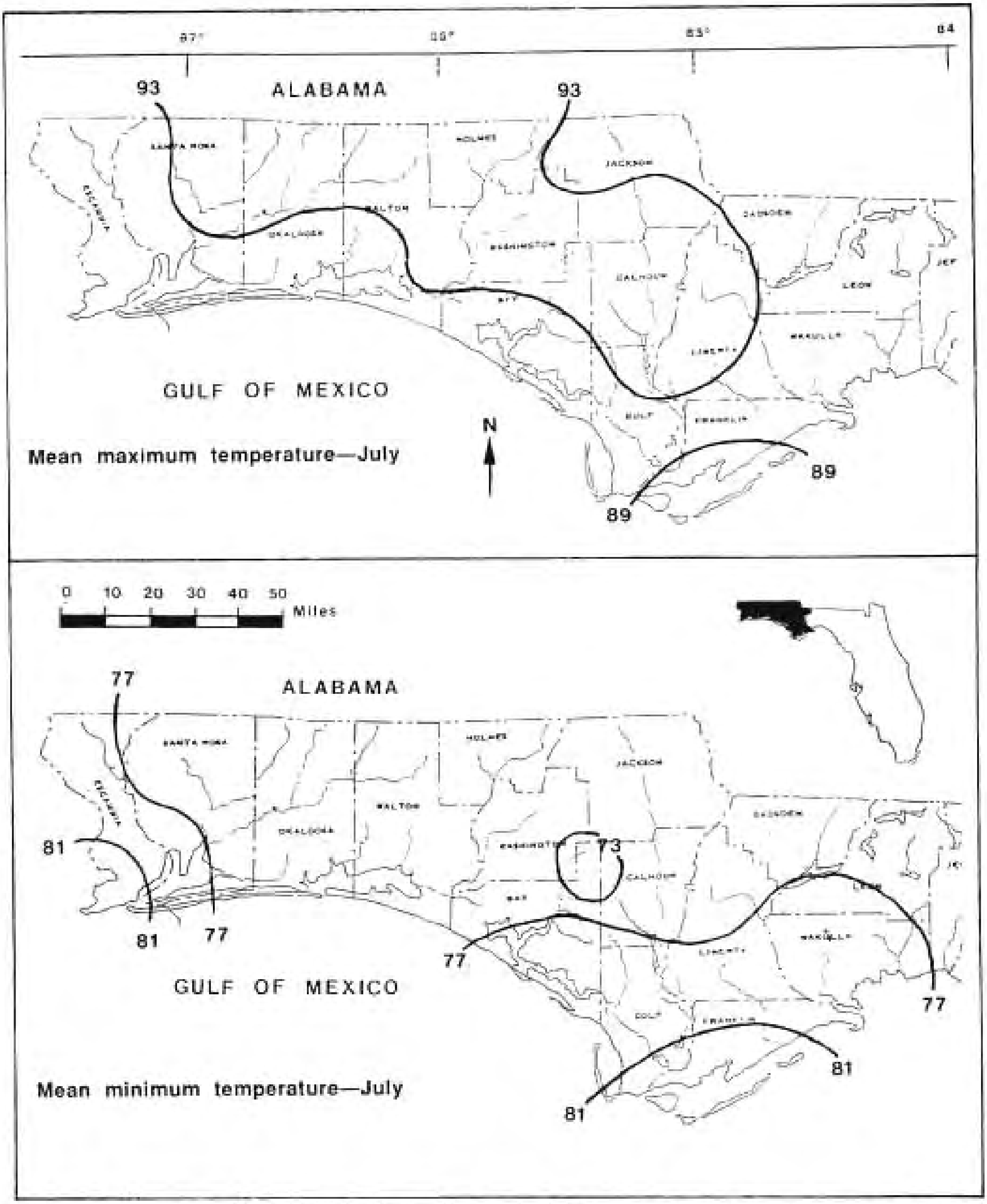


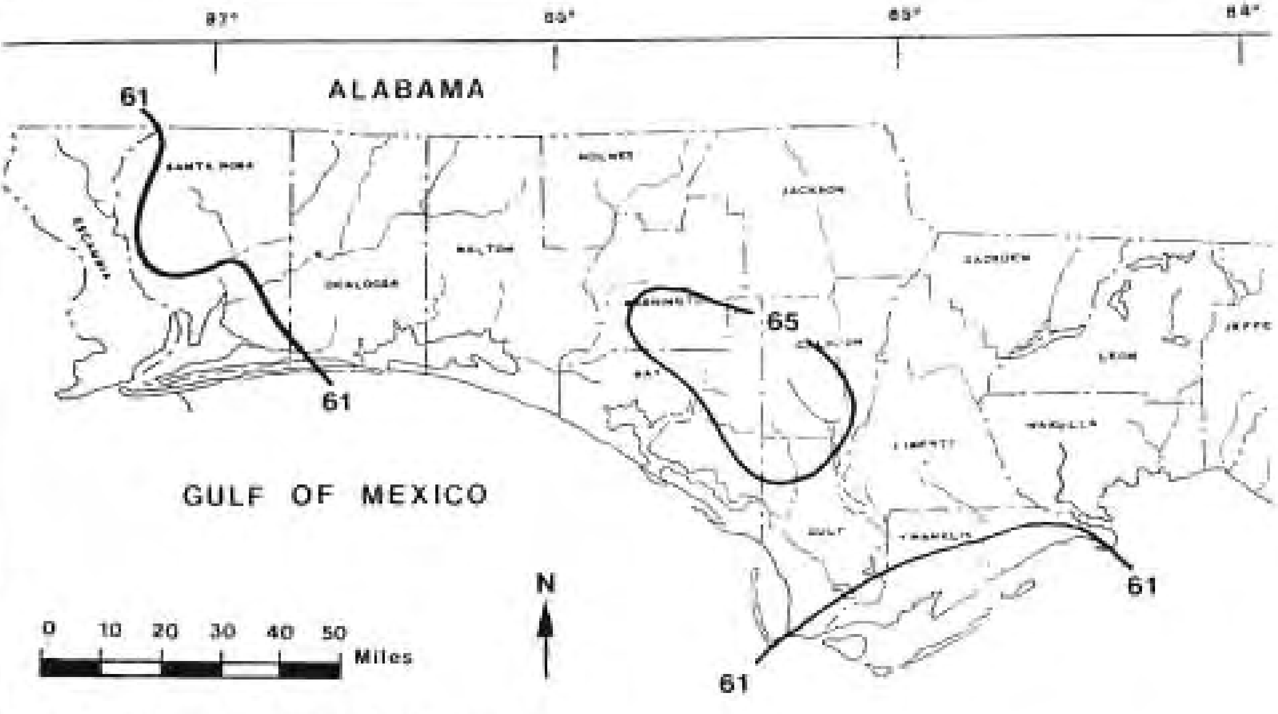
**Figure 14. NOAA climatological station sites in the Florida Panhandle (after Wagner et al. 1984).**



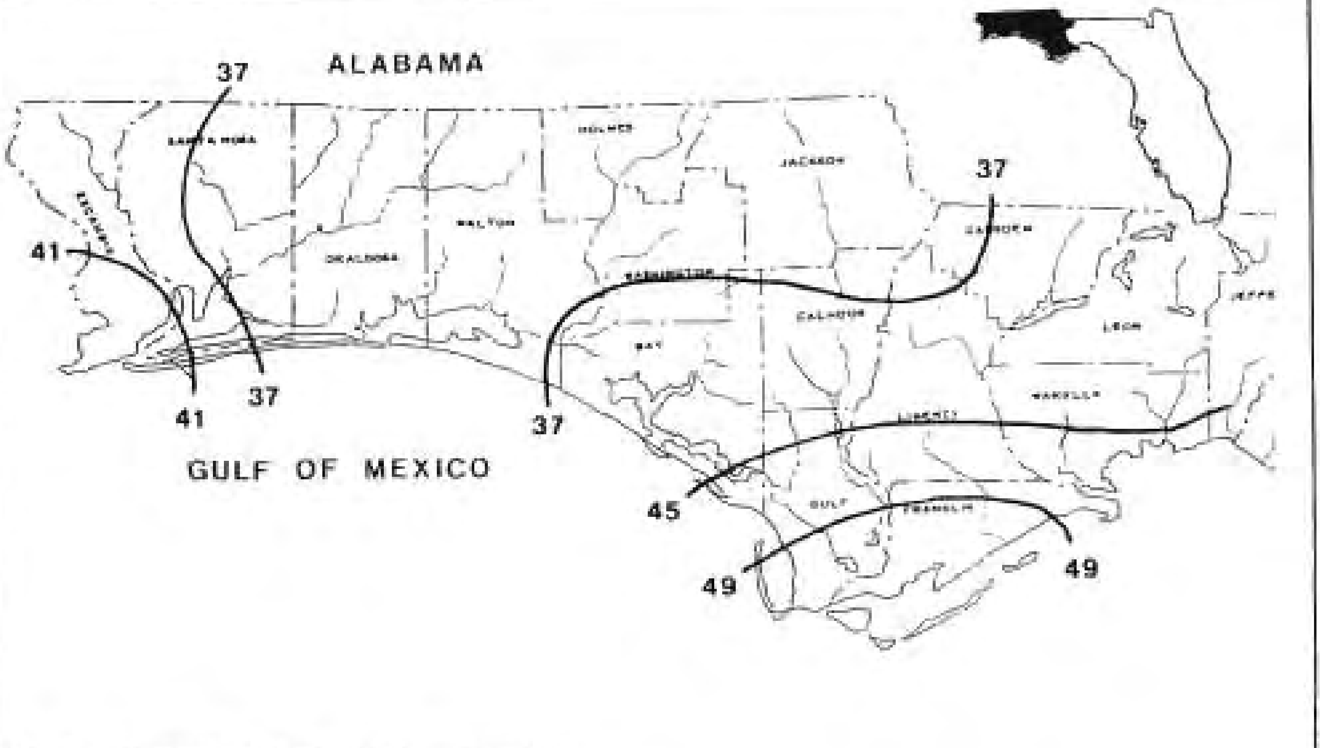
Mean maximum temperature—July

Mean minimum temperature—July

Figure 15. Isotherms for mean maximum and mean minimum July temperatures in the Florida Panhandle (after Fernald 1981).



Mean maximum temperature—January



Mean minimum temperature—January

Figure 16. Isotherms for mean maximum and mean minimum January temperatures in the Florida Panhandle (after Fernald 1981).

cooling effect of frequent afternoon thundershowers. Thundershowers occur on approximately half of the days during summer and frequently cause 10 to 20 degree drops in temperature (Bradley 1972).

Winter temperatures are quite variable due to the frequent passage of cold fronts. The colder of these fronts are of Arctic origin and may bring minimum temperatures ranging from 15 to 20 °F with single-digit lows some years. Temperatures rarely remain below freezing during the day and the cold fronts generally last only 2–3 days. Temperatures in the 60's °F and sometimes 70's °F often separate the cold fronts. This weather pattern results in average low temperatures in the mid 40's °F during the coldest months (mid-January through mid-March).

### 3.2.2 Rainfall

The Florida Panhandle has two peak rainfall periods: a primary one during summer (June–August) and a secondary one during late winter through early spring (February–April). Additionally, there are two periods of low rainfall: a pronounced one during October–November and a lesser one in April–May (Figure 17). Average annual rainfall across the Panhandle is near 152 cm, varying from approximately 163 cm at the west end to about 142 cm at the east end (Figure 18). The dearth of gauging stations in some Panhandle regions may affect the accuracy of the isopleth placements in these figures. The annual rainfall varies widely (Figure 19), and the maximum recorded amount has ranged from 73 cm at Pensacola in 1954 to 284 cm at Wewahitchka in 1966 (Wagner et al. 1984).

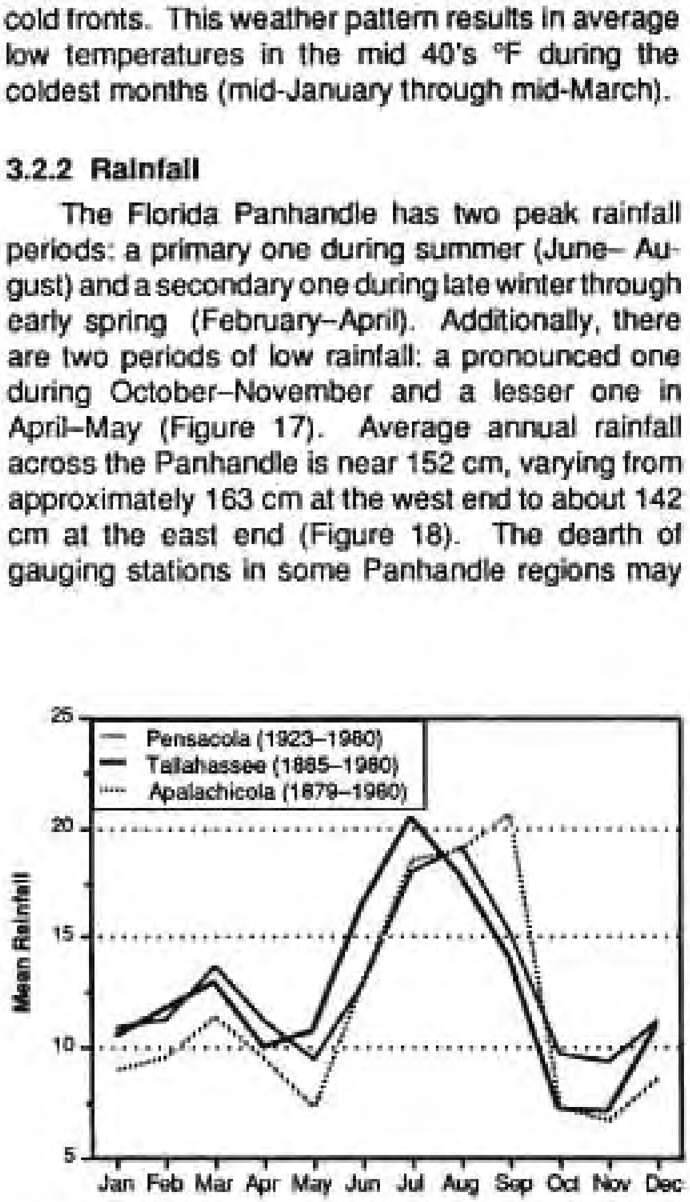


**Figure 17. Seasonal rainfall variation at selected sites in Florida Panhandle (data from U.S. Dept. Commerce 1980a,b,c).**

During rainy years the maximum rainfall tends to occur near the coast; however, during dry years the rainfall maximum occurs farther inland. Rainfall patterns tend to be more consistent approximately 25–95 km inland (Jordan 1984). Rainfall gradients are quite strong along some portions of the gulf coast; annual totals are as much as 12–25 cm less at stations very near the coastline than at those a few kilometers inland (Jordan 1973).

Studies of the distribution of summer rainfall, based on weather radar observations at Apalachicola and with the results supported by corresponding studies at Tampa, showed that showers within 160 km of the radar installation were nearly as frequent over the sea as over the land when averaged over a 24-hour period (Smith 1970). This and similar studies in south Florida (Frank et al. 1967) found high numbers of showers over land in the afternoon and low numbers in the early morning. They found a minimum number over the sea in the afternoon and a maximum during late night and early morning, especially within 50 km of the coast.

When interpreting the rainfall data, it is important to note that the start and end of the rainy seasons may vary by 6 or 7 weeks from year to year. As seen in Table 1, the majority of thunderstorm activity occurs during the summer.

Most of this summer rainfall occurs in the afternoon in the form of often heavy local showers and thunderstorms of short duration (1–2 hours) that are on rare occasions during the spring accompanied by hail. Summer rain which lasts for longer periods is often associated with occasional tropical disturbances. Winter rains are associated with frontal systems and are generally of longer duration than the summer rains, but are fewer in number and have a slower rate of rainfall accumulation. Hourly data taken at Tallahassee beginning in the 1940's through the 1970's demonstrate the different diurnal patterns of the summer and winter rains (Figure 20). Snowfall

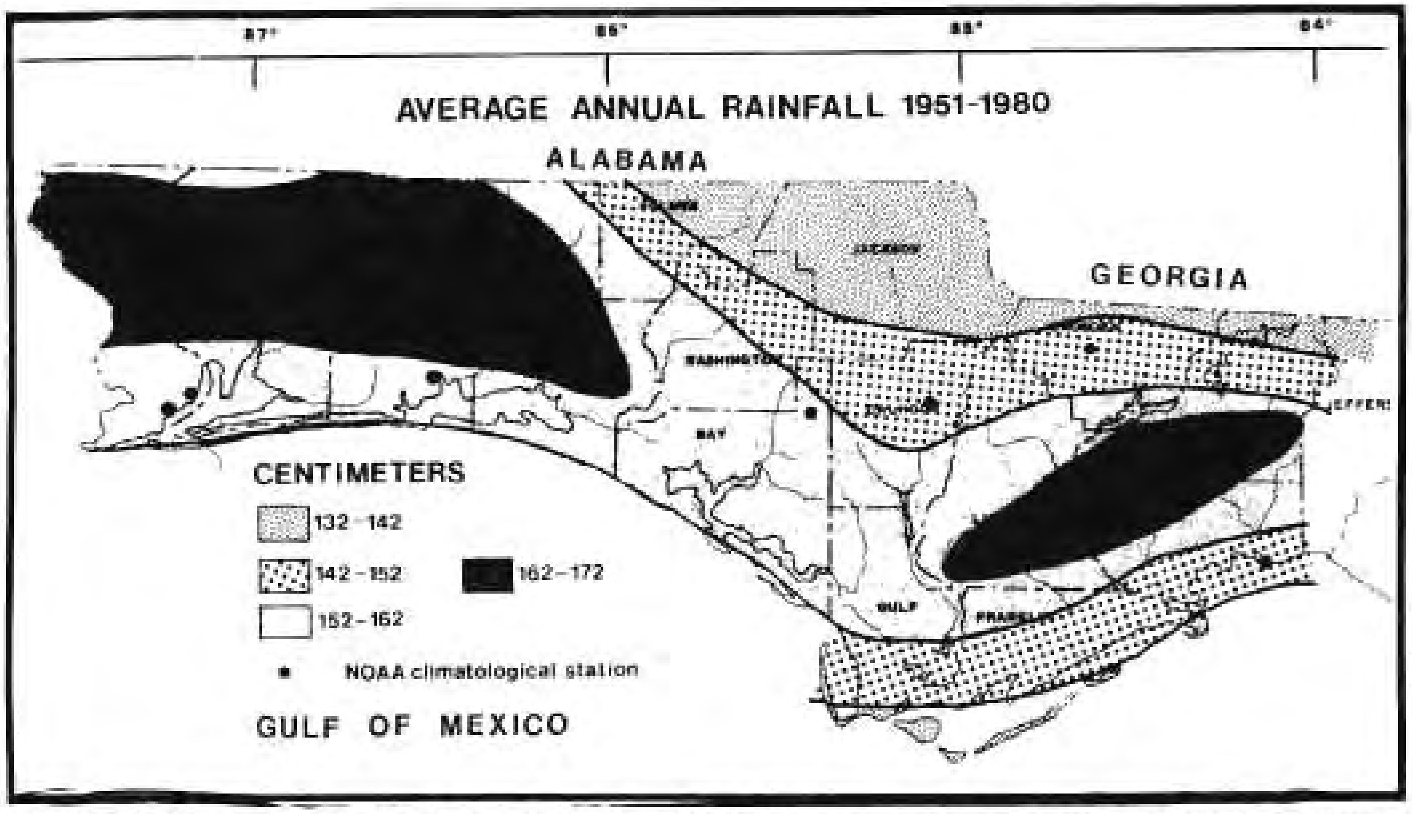


**Figure 18. Panhandle average annual rainfall and NOAA climatological station locations (after Jordan 1984).**

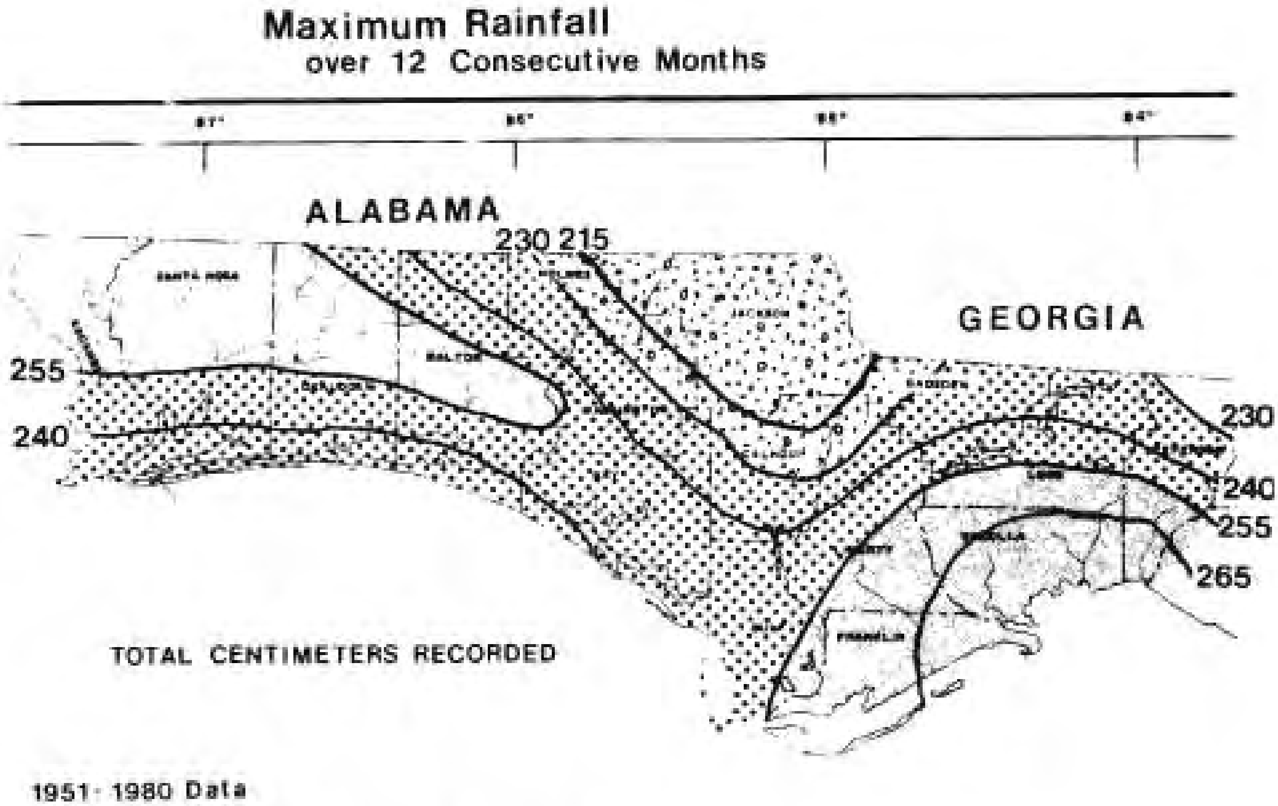
occurs at rare intervals across the Panhandle, approximately 1 year in 10 for measurable falls, and approximately 1 year in 3 for trace amounts (U.S. Dept. of Commerce 1980a, 1980b, 1980c).

Despite large average annual rainfalls, droughts occur (Figure 21). Even short periods of drought, when combined with the reduced area of lakes and wetlands and the low water table found during generally dry years, can cause extensive crop losses in the agricultural areas, as well as increase damage from forest fires. Fires during extended droughts can cause severe damage even in the longleaf pine areas adapted to seasonal fires and result in the burning of parched wetlands and other habitats normally protected from fire. These areas, not adapted to the normal periodic fires of the pine forest, may recover very slowly (Means and Moler 1979).

### 3.2.3 Winds

**a. Normal wind patterns.** From March through September, the Panhandle is under the western portion of the Bermuda high-pressure cell, which has a general clockwise (anticyclonic) circulation of the low-level winds (i.e., those measured at an altitude of 600–900 m) (Atkinson and Sadler 1970) (Figure 22). The latitude at which the wind shifts from out of the southeast to out of the southwest (the "ridgeline"—shown by the dashed lines in Figure 22) changes substantially during spring and summer. During October through February, a western anticyclonic cell separates from the Bermuda anticyclone and establishes itself in the Gulf of Mexico (Figure 22). The center of the cell migrates somewhat as indicated by the X's, but generally results in low-level winds from a westerly direction over the Panhandle.

These circulatory patterns indicate that the Panhandle is primarily influenced by tropical air masses in the spring and summer and by continental (cold) air masses during the fall and winter. The prevailing winds in the Florida Panhandle are from a southerly direction during the spring and summer (Figure 23). Locally, wind directions may be determined by



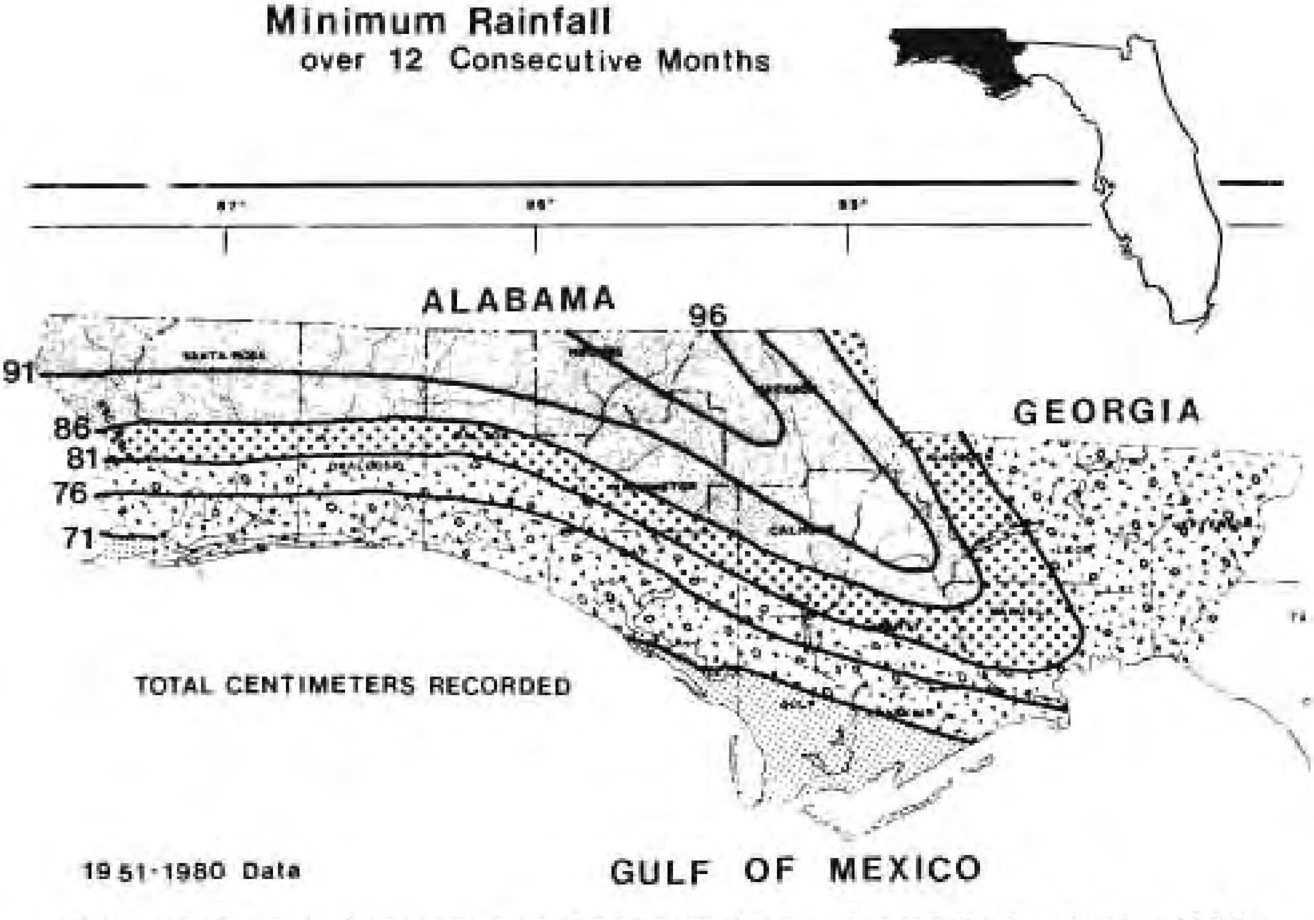


Figure 19. Panhandle maximum and minimum 12-month rainfall (after Jordan 1984).

**Table 1. Panhandle thunderstorm frequency statistics (Jordan 1973).**

| | Mean annual days with thunderstorms | Percent of thunderstorms during June–Sept | Percent of thunderstorms during Nov–Feb |
|---|---|---|---|
| Pensacola | 65 | 65 | 12 |
| Apalachicola | 73 | 73 | 7 |
| Tallahassee | 79 | 70 | 6 |

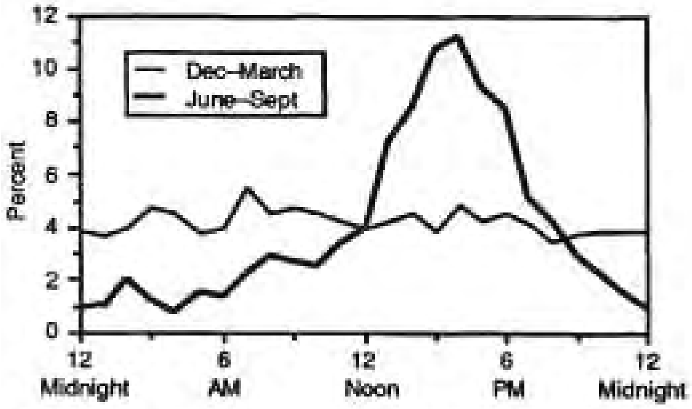


**Figure 20. Percent of total daily rainfall during individual hours of the day at Tallahassee (after Jordan 1984).**

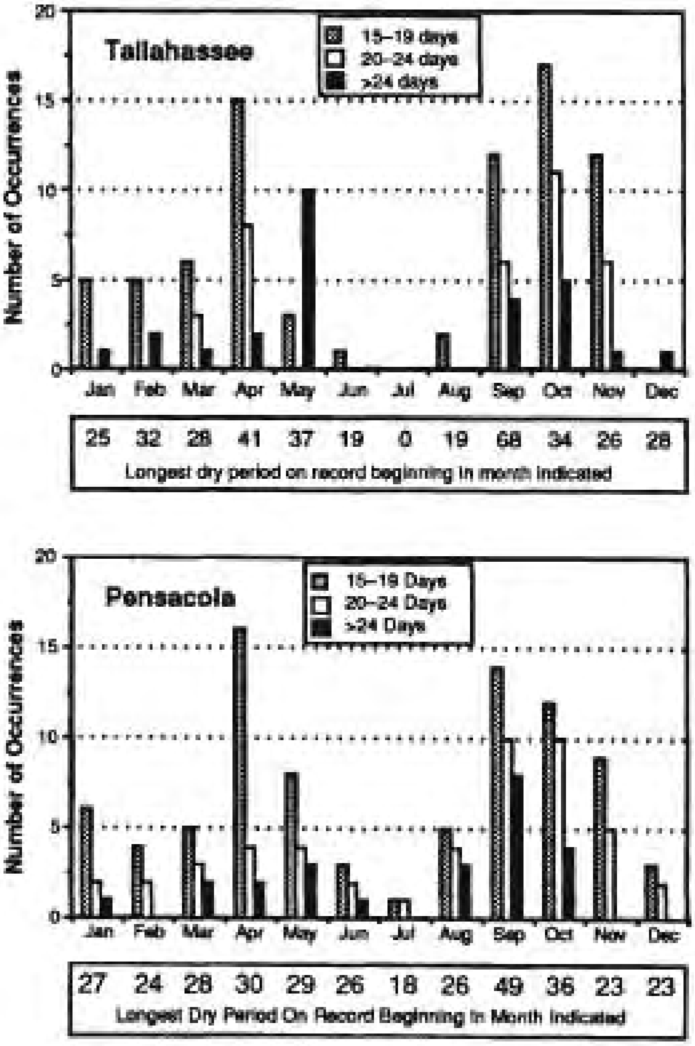
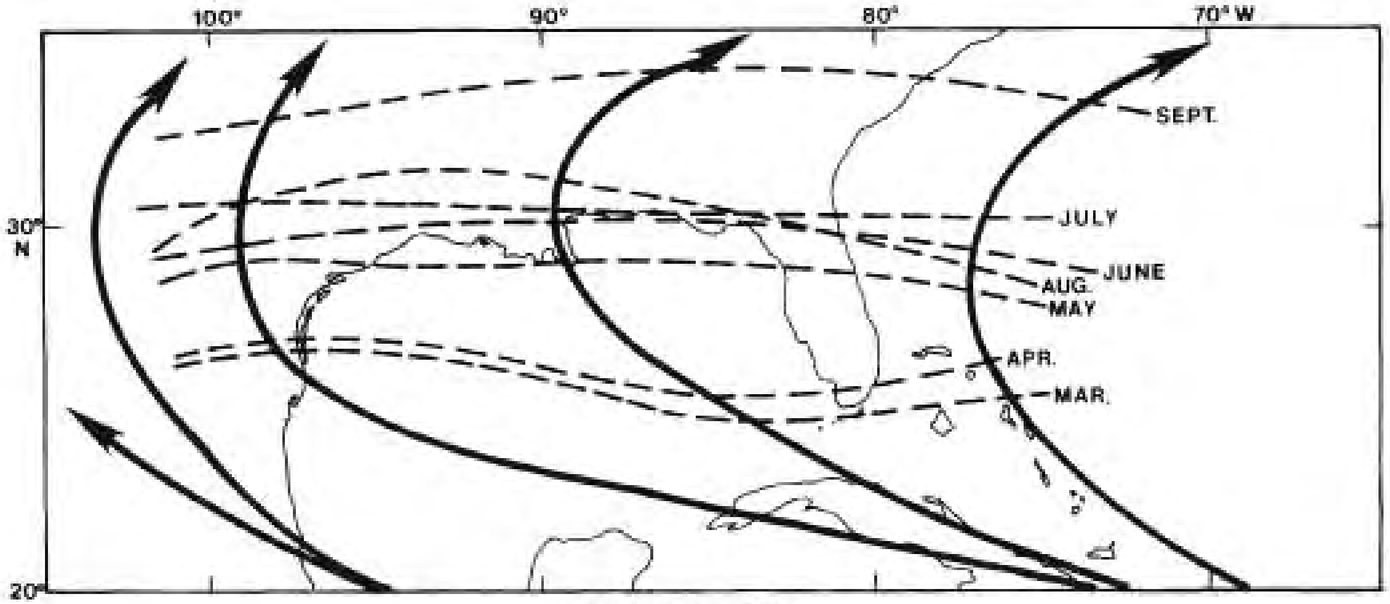


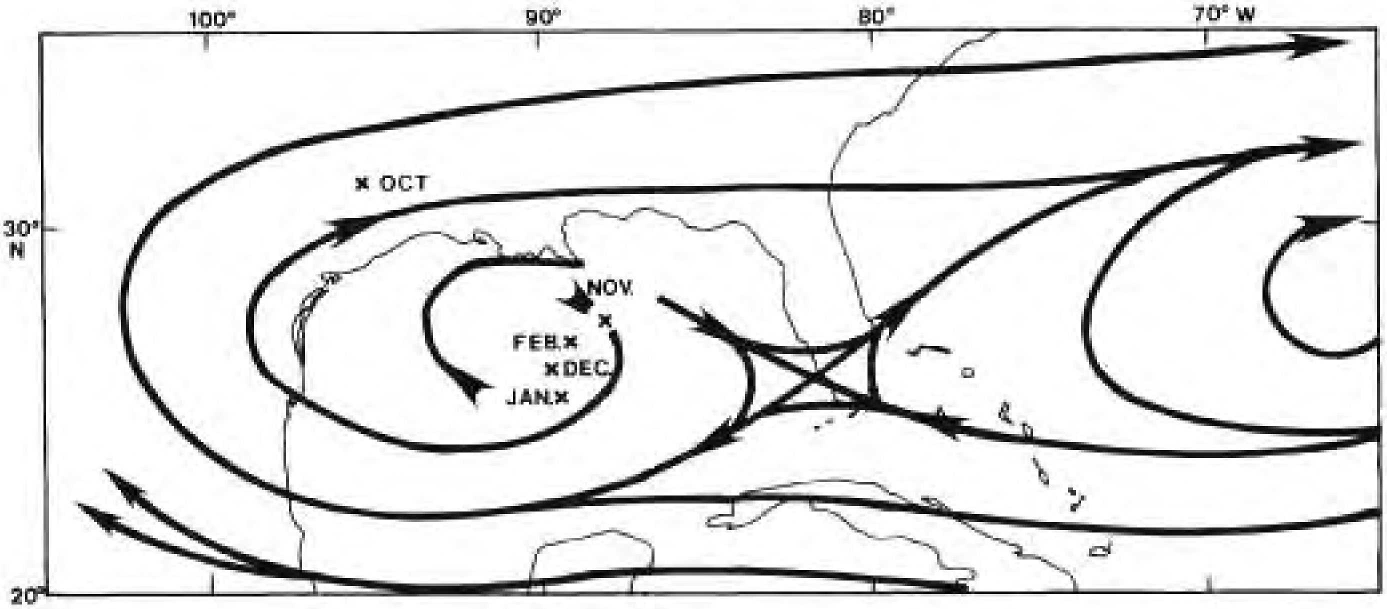
**Figure 21. Occurrence of extended dry periods at Tallahassee and Pensacola, 1950–80 [no day over 0.25 cm] (after Jordan 1984).**

thunderhead formation and thunderstorms. Wind direction changes with the passing of each cold front; most commonly these occur during the fall and winter (September through March). As the front passes through, the wind, which normally blows out of a southerly direction, rapidly changes direction with a clockwise progression ("clocks") through the west, then pauses out of the northwest quadrant for approximately 1–3 days, blowing toward the front receding to the south or southeast. After the front has passed a sufficient distance to allow the "normal" wind patterns to reassert themselves, the wind finishes clocking through the east and back to the south. The directional orientation of the front and the direction from which the wind blows immediately following its passage depends upon the origin of the front; the winds are from the north for fronts of Arctic and Canadian origin, from the west to northwest for those of Pacific origin.

This cycle is sometimes interrupted by the approach of a new cold front closely following the first. As a result, the most prevalent winds during September through February (the season of frontal passages) are out of the northern half of the compass



March–September



October–February

Figure 22. Low-level (600–900 m) winds (from Atkinson and Sadler 1970).

(following the fronts) with less frequent and weaker winds from the southern half of the compass (before the fronts) (Figure 24). The annual average resultant wind (i.e., the vector sum of the monthly wind speed and direction) in the Panhandle is from the north. This is due to the greater wind speeds that follow the winter fronts than blow during the rest of the year. All of these wind patterns are somewhat erratic due to convective forces inland and because of the resulting land- and sea-breeze mechanism near the coast.

The mean monthly wind strength is less in summer months than during the fall, winter, and spring (Figure 25). Since data for Pensacola were unavailable, those for Mobile are included in the figure. Inland stations exhibit somewhat lower

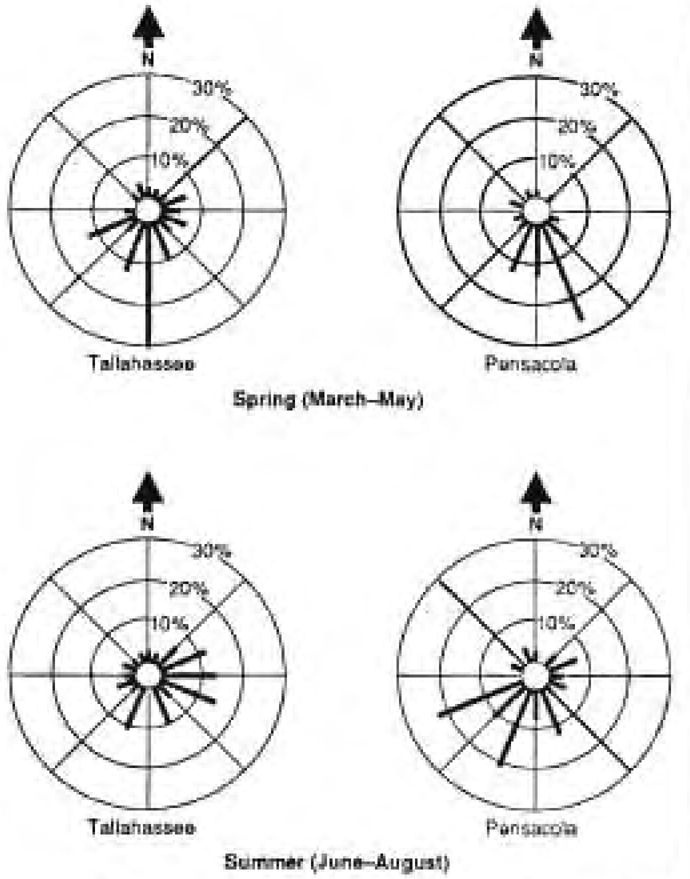


Figure 23. Percentage of time wind blew from different directions in Panhandle during spring and summer, 1959–79 average (after Fernald 1981).

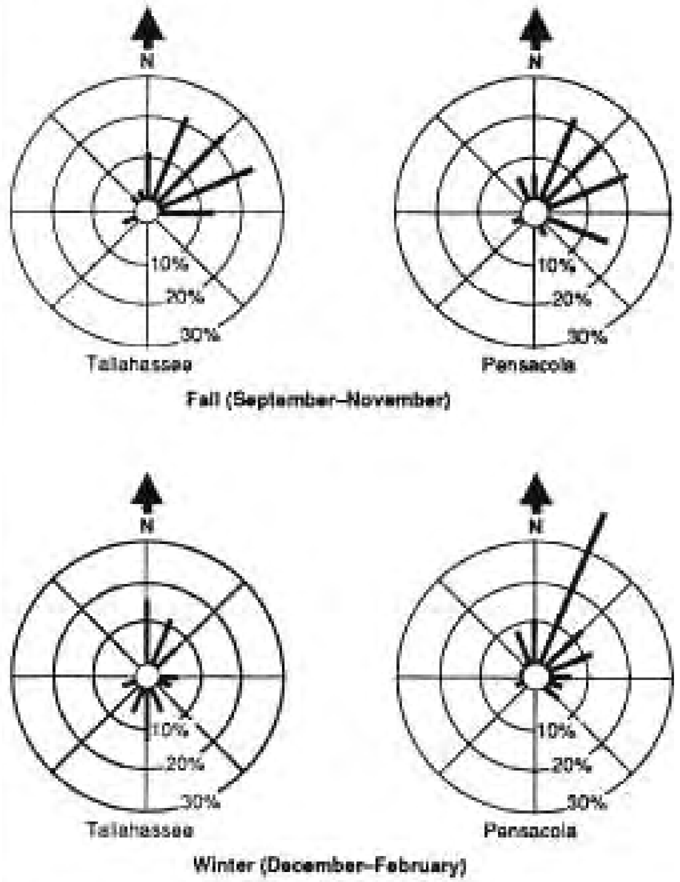


Figure 24. Percentage of time wind blew from different directions in Panhandle during fall and winter, 1959–79 average (after Fernald 1981).

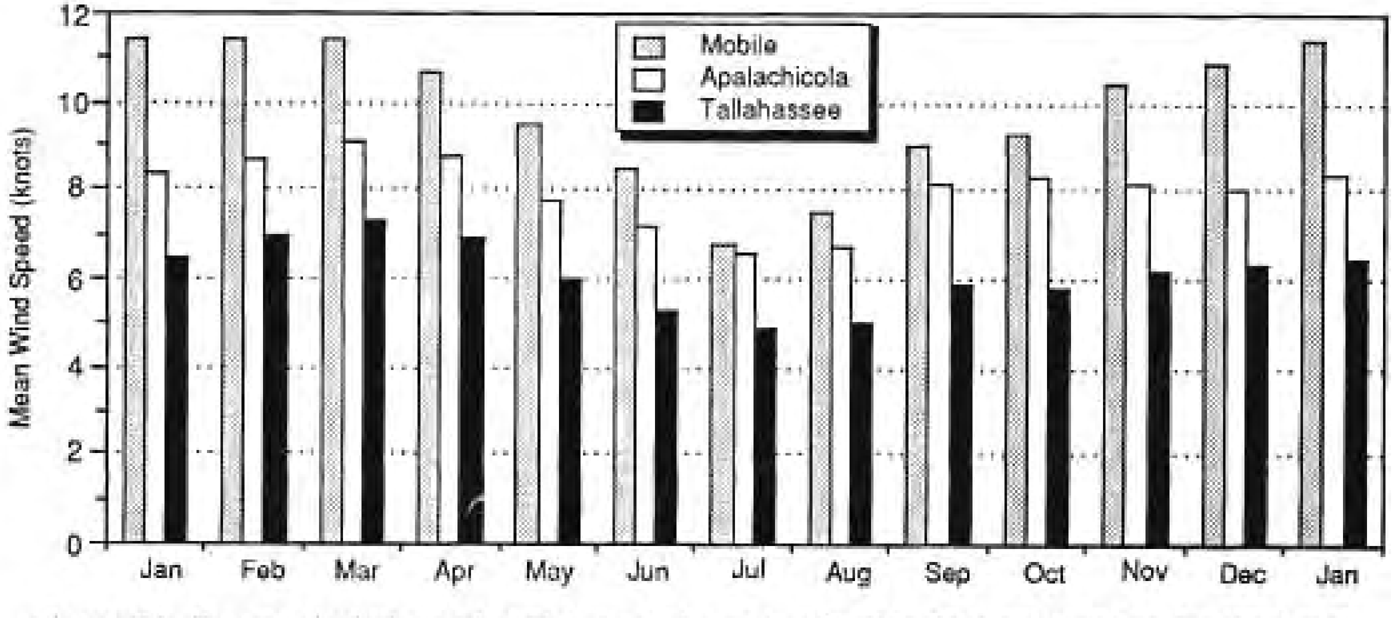


Figure 25. Seasonal windspeed at sites in and near the Florida Panhandle (after Jordan 1973).

average speeds than those along the coast (Jordan 1973). The highest 1-minute sustained wind speed is seldom over 50 km/h, though sustained non-hurricane-associated winds in the 85–95 km/h range have been recorded (Bradley 1972). These peak sustained wind speeds are generally higher at the eastern end of the Panhandle than at the western end (U.S. Dept. of Commerce 1980a, 1980b, 1980c; Fernald 1981).

**b. Hurricanes, tornadoes, and waterspouts.** Hurricanes pose a major threat to the Florida Panhandle. A hurricane is a cyclonic storm (i.e., the winds rotate counterclockwise in the northern hemisphere) with sustained wind speeds in excess of 120 km/h. Forty-eight hurricanes have come ashore in this region from 1885 to 1985. Figure 26 shows the tracks for hurricanes hitting the Florida Panhandle during this period while Table 2 gives their monthly distribution.

Much of hurricane damage is caused by the local rise in sea level known as storm surge. For hurricanes striking the Panhandle from the gulf, this rise occurs east of the "eye" (the storm's center) as the counterclockwise wind circulation about the eye pushes water ahead and traps it against the coastline. An embayment helps contain this water and can increase storm-surge magnitudes substantially when a hurricane strikes its western side. Tidal stage and phase, bottom topography, coastline configuration, and especially wind strength combine to

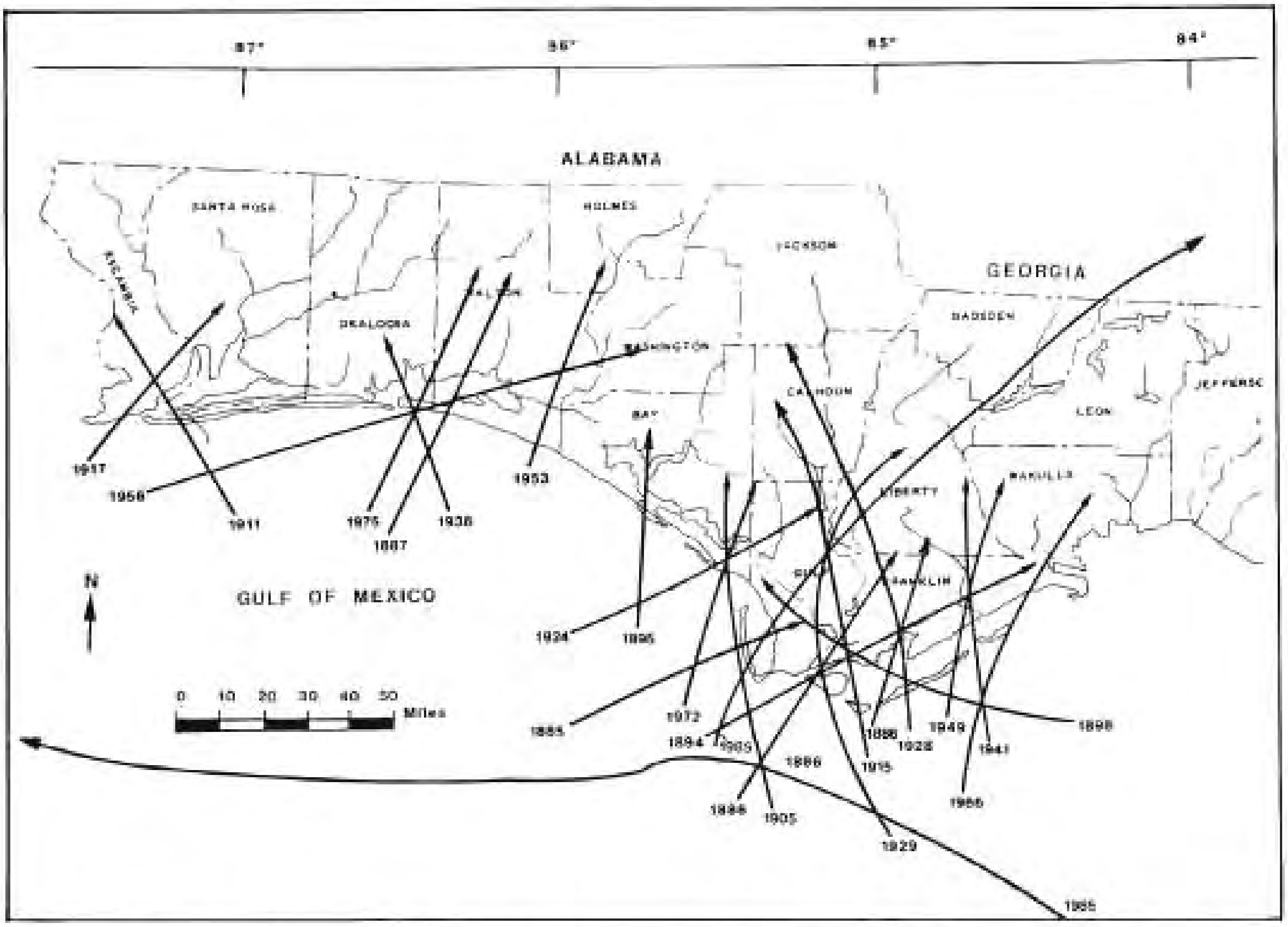


Figure 26. Paths of hurricanes striking the Panhandle coast, 1885–1985 (after Jordan 1984, Case 1985).

**Table 2. Total number of hurricanes and tropical storms striking or passing within 150 miles of the Florida Panhandle during 1885-1985 (Jordan 1984, Case 1986).**

| Jun | Jul | Aug | Sep | Oct | Nov–May | Total |
|---|---|---|---|---|---|---|
| 7 | 5 | 8 | 20 | 6 | 2 | 48 |

determine the storm-surge magnitude. The State of Florida addressed coastal safety, property protection, and beach erosion during hurricanes in Henningsen and Salmon (1981).

Tornadoes and waterspouts form infrequently. They occur most commonly in the spring, associated with frontal weather systems, and in connection with tropical storms and hurricanes. Tornado paths in Florida are usually short, and historically damage has not been extensive. Waterspouts occasionally come ashore but dissipate quickly after reaching land and, therefore, affect very small areas (Bradley 1972).

### 3.2.4 Insolation

The amount of sunlight, or insolation, reaching the Florida Panhandle directly affects temperature as well as photosynthesis. It indirectly affects processes in which these factors play a role, including weather patterns, rates of chemical reactions (e.g., metabolism), productivity, and evapotranspiration (evaporation and water transpired into the atmosphere by plant foliage). The amount of insolation is controlled by two factors: season and atmospheric screening.

**a. Seasonal changes.** Seasonal insolation is controlled by five factors: (1) the changing distance between the Sun and Earth as Earth follows its elliptical orbit; (2) the increasing thickness of the atmosphere through which the solar rays must travel to reach the Earth's surface at points north or south of the orbital plane (Figure 27); (3) the reduced density of rays striking an area on Earth's surface north or south of the orbital plane (Figure 28); (4) the changes in cloud cover associated with the progression of the seasons; and (5) seasonally induced changes in atmospheric clarity due to particulates. Factors 2 and 3 are caused by Earth's axial tilt relative to the orbital plane and the resultant change

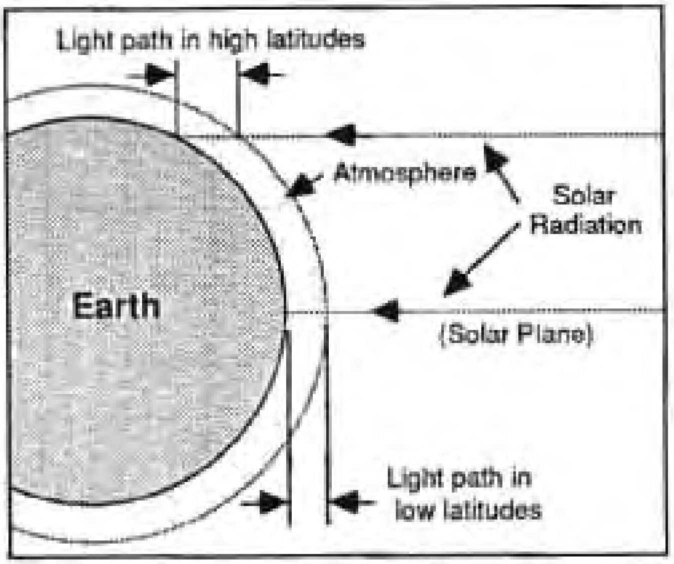


Figure 27. Change in length of atmospheric light path with change in distance above or below orbital plane.

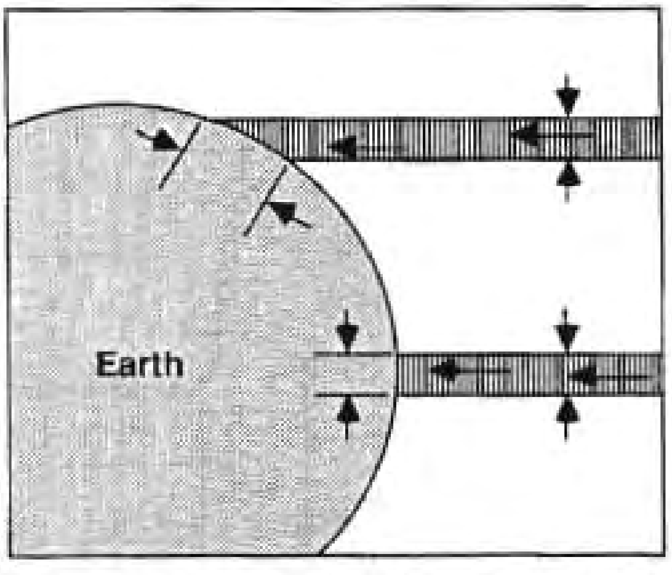


Figure 28. Change in light intensity at Earth's surface with change in distance above or below orbital plane.

in the angle at which solar rays strike a point on the globe during Earth's year-long trip around the sun. This change alters the distance through the atmosphere that the rays must travel and, therefore, changes the percentage of the rays reflected or absorbed by the atmosphere. Factors 4 and 5 are products of seasonal variations in insolation upon circulation of air masses, hence the effects from insolation affect the amount of it reaching the Earth's surface. The concentration of screening particulates in the atmosphere is further affected by seasonal variations in emissions resulting from human activities (e.g., smoke from heating during winter) and by the variations in the speed with which both natural and anthropogenic particulates are removed by rainfall or diluted by atmospheric circulation.

**b. Atmospheric screening.** Absorption or reflection by water vapor, clouds and atmospheric particulates such as dust and smoke effectively reduce the solar radiation penetrating to the Earth's surface. On a clear day approximately 80% of the solar radiation entering the atmosphere reaches the Earth's surface. About 6% is lost because of scattering and reflection and another 14% from absorption by atmospheric molecules and dust. During cloudy weather another 30%–60% may reflect off the upper surface of the clouds and 5%–20% may be removed by absorption within the clouds. This means that from 0% to 45% may reach Earth's surface (Strahler 1975). Thus it is clear that the single largest factor controlling short term insolation is cloud cover.

The percentage of cloud cover varies seasonally (Figure 29), as do the patterns of cloud cover. The seasonal patterns of cloudiness are controlled primarily by extratropical cyclones and fronts in the winter, and by localized convective weather patterns in the summer. Though the types of clouds and rainfall patterns are different under each of these systems, they result in similar amounts of cloudiness and rainfall in winter and summer in the Panhandle. Daily cloud cover variations are considerably greater in winter than in summer. That is, in summer many days have partial cloud cover while in winter the days tend to be entirely overcast or entirely clear. In south Florida, where winter cyclones and fronts are less frequent, the winter and summer amounts differ greatly.

The maximum insolation striking Earth's atmosphere at the latitude of Panhandle Florida is approximately 925 langleys/day (Strahler 1975). Figure 30 shows the seasonal variation of the daily insolation

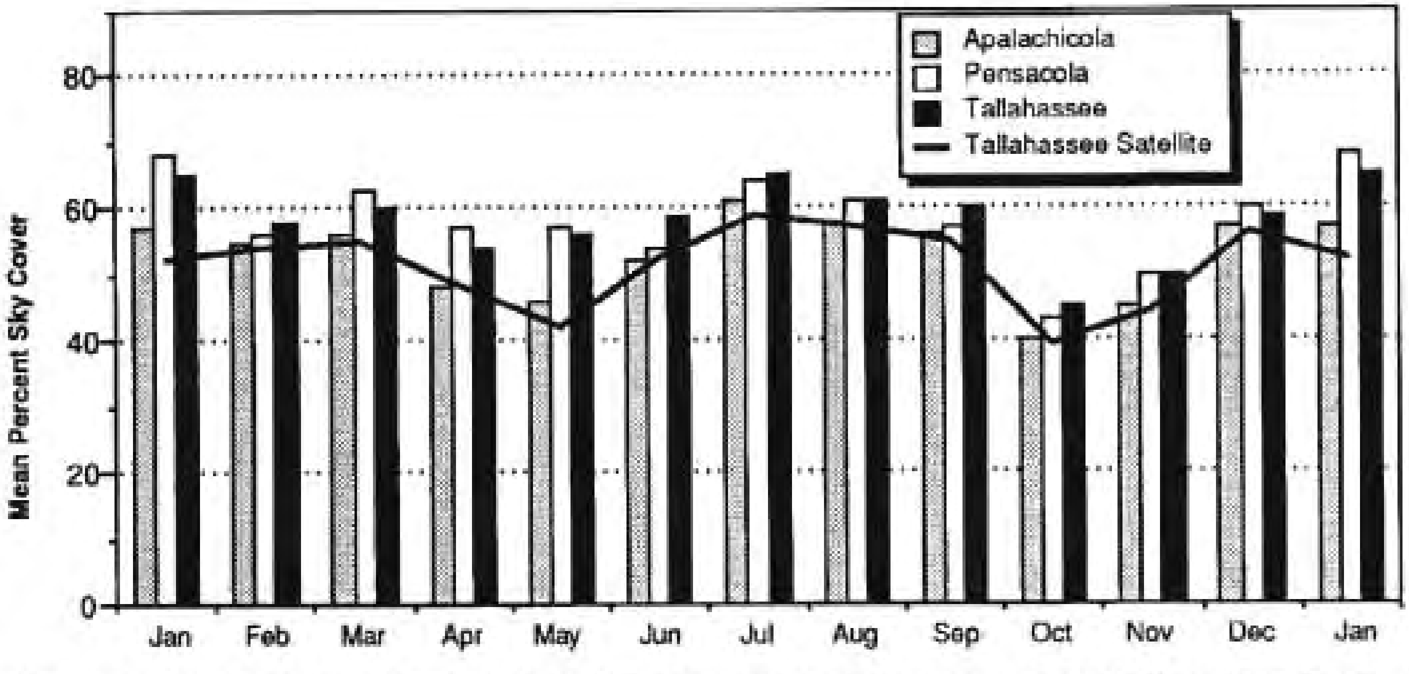


**Figure 29. Mean daytime sky cover (data from U.S. Dept. of Commerce 1980a,b,c) and Tallahassee cloud cover from 3 years of satellite data (after Atkinson and Sadler 1970).**

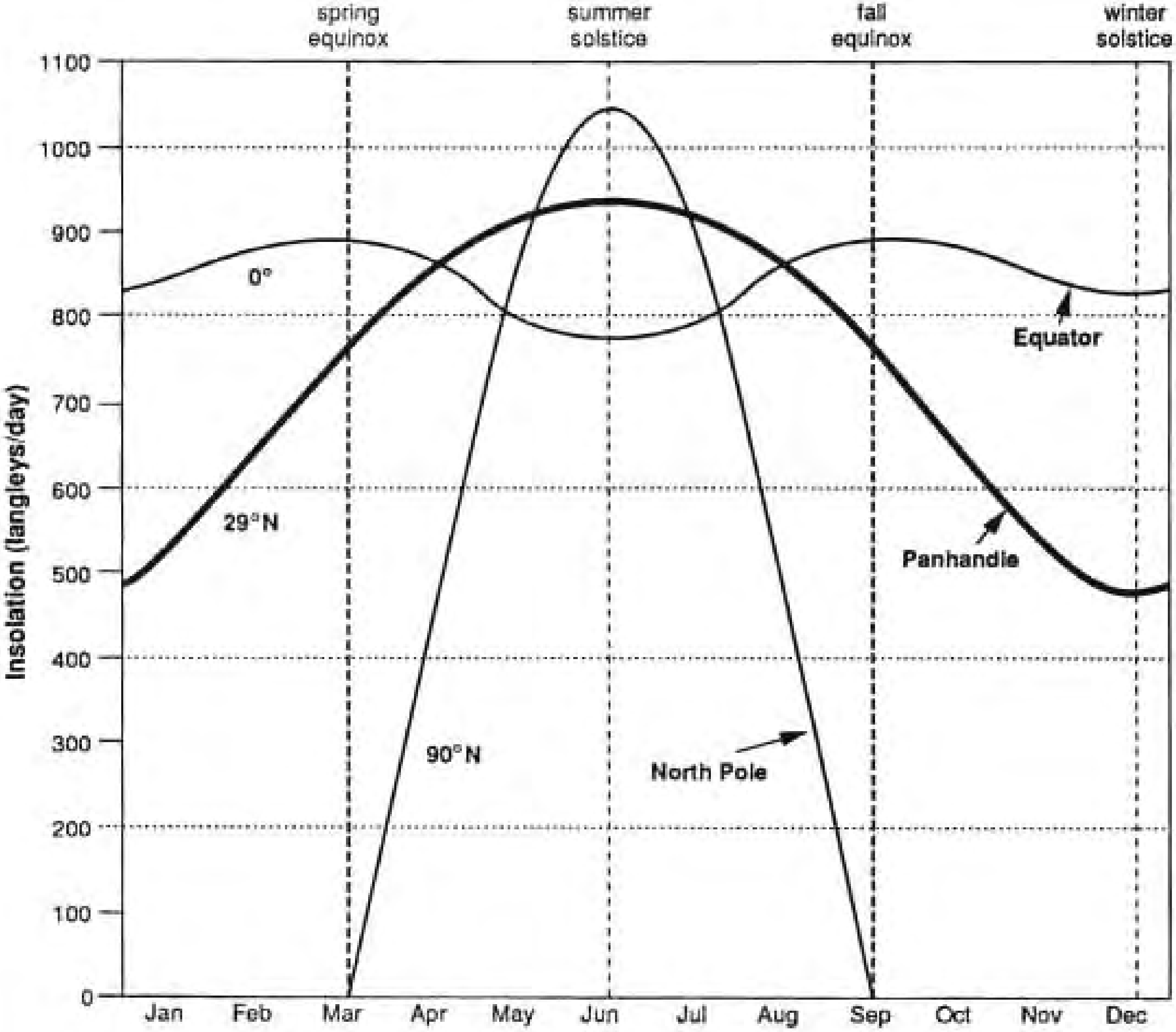


**Figure 30. Variations in insolation striking the atmosphere depending on latitude and season (after Strahler 1975).**

striking the atmosphere over the Panhandle region. The monthly average of the daily insolation amounts actually received at Tallahassee and Apalachicola are presented in Figure 31. In addition, the percent of possible sunshine measured at Tallahassee and Pensacola is presented in Figure 32.

Atmospheric clarity over the Panhandle is, with the exception of clouds, generally very good. Occasional atmospheric inversions during summer months may result in "haze" as natural and anthropogenic aerosols are trapped near the surface and concentrated, thereby reducing insolation.

### 3.2.5 Relative Humidity

The Florida Panhandle is an area of high relative humidity. Relative humidity is the amount of water vapor in the air, expressed as a percent of saturation at any given temperature. Air incapable of holding further water vapor (saturated) has a relative humidity of 100%. The amount of water necessary to saturate a volume of air depends upon temperature.

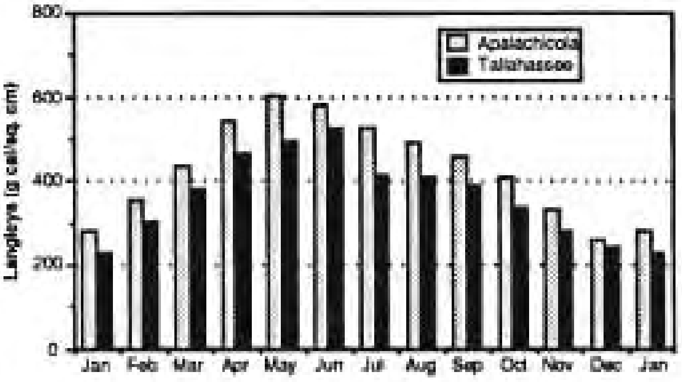


Figure 31. Monthly insolation at selected sites in Florida Panhandle (after Bradley 1972).

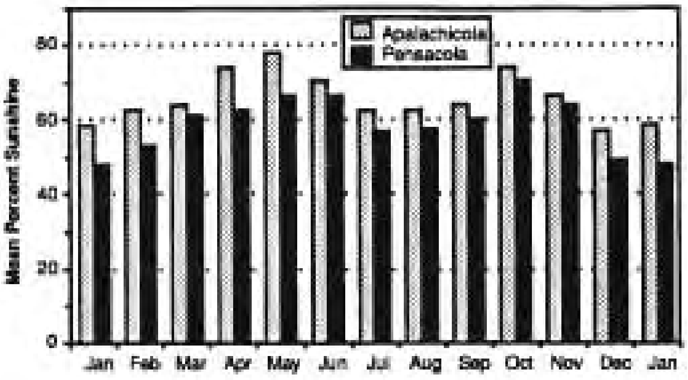


Figure 32. Percent of possible sunshine at selected sites in Panhandle (data from U.S. Dept. of Commerce 1980a,b,c).

Air at a higher temperature is capable of holding more water than that at a lower temperature; therefore, air near saturation will become oversaturated if cooled. This oversaturation can produce dew, precipitation, or, when very near saturation, clouds or fog. In the seasons when prevailing winds bring moist air from the Gulf of Mexico (i.e., spring, summer, fall), humidity is often 85%–95% during the night and early morning, and 50%–65% during the day (Bradley 1972).

High relative humidity can greatly accentuate the discomfort of high summer temperatures. There are several formulas commonly in use (e.g., Temperature Humidity Index, Humidity Stress Index, Humiture) that generate a "comfort" value based upon a combination of temperature and humidity. The afternoon Panhandle climate during June through September is usually well into the uncomfortable zone. These indices are based on the effect of humidity upon evaporation rates. The humid air flowing from the Gulf of Mexico has minimal capacity to hold further moisture. As a result, evaporative drying of wetlands and other water bodies in the Panhandle is minimized, thereby helping to maintain them between rains. Summer rains and slow evaporation also provide ideal conditions for many fungal and bacterial diseases, prominent problems in area farming (Shokes et al. 1982).

Fog is common at night and in the early morning hours as the ability of the cooling air to hold water decreases and the relative humidity rises over 100%. Heavy fogs (visibility ≤ 0.4 km) generally form in the late fall, winter, and early spring. On the average, they occur 35–40 days per year (Bradley 1972). Apalachicola experiences fog on an average of 14% of the days in November through March, and 2% of the days from April through October (Jordan 1973). Fogs usually dissipate soon after sunrise.

## 3.3 Effects of Climate on Ecosystems

Climate exerts control on the regional ecology through two major mechanisms. The normal climate of the Panhandle establishes the basic conditions under which all species must be able to live and compete if they are to find a niche in the ecosystem. The occasional abnormal or extreme climatic condition may prevent establishment of a species that would otherwise thrive by producing periodic local extinctions or near-extinctions. The rare severe or prolonged freeze, heat wave, drought, or flood may decimate a population so that years or decades are required for its reestablishment.

No clear separation exists between conditions constituting normal and extreme climatic conditions. Regular events which are beyond a species' ability to adapt may reduce what would otherwise be a dominant organism to a minor position in the ecosystem or prevent its establishment altogether. A Panhandle example is the mangrove. A dominant species on Florida's southwest coast, mangroves are represented in the Panhandle by one small colony of black mangrove on the bay side of the eastern end of Dog Island. In conditions otherwise conducive to mangrove growth, the occasional cold winters limit them to this marginal colony. In contrast, an otherwise minor organism may be dominant through its ability to survive the climatic extreme and thereby outcompete ecological rivals. Relatively small changes in the "normal" extremes of climate may produce effects on ecosystem composition as large as those produced by changes in the average climate. An example might be a situation where a slow-growing and reproducing shrub species and a fast-growing and reproducing shrub species compete for space in a forest clearing commonly visited by foraging wild pigs. All other factors being equal, the slow-growing species might dominate, even though it would be very slow to recolonize areas where it was dug up by the pigs, because it could better tolerate the annual dry summers. An increase in the normal summer rainfall (a change in the "average climate") might lead to dominance of the fast-growing species. The same effect might result, however, if the area began to experience previously unknown hard freezes during occasional winters (a change in the climatic extremes), and the slow-growing species was killed by freezes while the fast-growing species was freeze tolerant. Either change will have the greatest effect upon those organisms living near their limits of tolerance.

## 3.4 Major Influences on Climate

### 3.4.1 Natural Influences on Climate

**a. Long-term influences on climate.** Long-term changes (over thousands to millions of years) in worldwide climate are primarily a function of changes in the concentration of atmospheric carbon dioxide ($CO_2$) (Revelle 1982). Carbon dioxide traps incoming solar radiation (Hansen et al. 1981). This effect is commonly known as the "greenhouse effect." The resulting temperature increase allows the atmosphere to hold more water vapor, itself an effective greenhouse gas, which accentuates the warming. Other gases (e.g., methane, nitrous oxide, chlorofluorocarbons) act similarly, but their effects are generally subordinate to those of $CO_2$ because of their relatively low concentrations. The Sun "drives" Earth's climate since the wind and rain systems, as well as the temperature regime, are products of varying insolation.

**b. Short-term influences on climate.** Short-term (up to hundreds of years) natural fluctuations in climate are generally caused by changes in insolation screening. The concentration of natural atmospheric particles results from the balance between input from wind scouring (particularly of desert and other arid regions), volcanic dust output, smoke from forest fires and volcanoes, and removal by gravitational settling and atmospheric scrubbing during rainfall.

The Panhandle, along with the rest of the northern temperate lands, has experienced an approximately 0.1 °C reduction in average temperature over the last decade despite an increasing greenhouse effect worldwide. It is probable that this is the result of: (1) the screening of insolation at these latitudes by increased atmospheric smoke and dust from recent increased volcanic activity and/or dust from the expanding Sahara desert and drought areas in North Africa, and /or (2) variation in the Sun's output (Hoffman et al. 1983). These variations are historically common and Titus and Barth (1984) concluded that they were incapable of overwhelming the overall greenhouse effect.

Periodic changes in climate and weather affecting the Panhandle have recently been tied to the phenomenon known as El Niño. Though all the parameters of cause and effect are not yet understood, a major current off the coast of Peru, which drives the upwelling responsible for one of the world's largest fisheries, apparently moves well offshore and weakens because of changes in the wind patterns driving it. Changes in equatorial wind patterns which either cause the shift in water currents or are caused by the shift (which factors are cause and which are effect are not yet understood) affect worldwide climate by altering patterns of rain, temperature, and wind. The Panhandle may have just recovered from a period of weather in the early 1980's influenced by an exceptionally strong El Niño. The hotter and drier summers and warmer winters followed by a rebound period of spring flooding, heavy summer rainfall, and colder winters that have been experienced in the Panhandle and other unusual weather patterns worldwide have been tentatively identified as indirect effects of El Niño.

Another mechanism controlling short-term climate changes as well as being involved in long-term variations is albedo, or the reflectance of a surface. The higher the albedo, the more incoming radiation is reflected and can pass through the "greenhouse" gases and out of the atmosphere. The lower the albedo, the more radiation is absorbed, reradiated as heat and trapped in the atmosphere. Snow and ice have a very high albedo; i.e., they are efficient reflectors of solar energy (45%–85%). Bare ground, fields and forests have intermediate albedos ranging from 3%–25%. Unlike land, the oceans (and water in general) have a variable albedo; very low (2%) for radiation striking from low angles of incidence (i.e., with the sun high in the sky), but high for that striking from high angles (i.e., with the sun low on the horizon). This is caused by the growing proportion of the light that is transmitted into the water at decreasing angles of incidence. Thus the equatorial seas at midday are good absorbers of solar energy, but the arctic seas are not. The significance of this in the Panhandle is that coastal waters receive more heating through insolation in summer, not only because of the increase in sunlit hours from the longer day, but also from an even greater increase of the time the radiation strikes from high angles. Other local effects of albedo differences are common, as anyone who has stood on an asphalt parking lot on a clear summer day can attest.

Another difference between the effects of insolation on land and water is caused by the difference in the specific heat of dry soil or rock and that of water. Water requires nearly five times as much heat energy as does rock to raise its temperature the same amount. This, coupled with the increased evaporative cooling found at the surface of water bodies, explains the more extreme diurnal and seasonal temperature regimens found over land as compared to that over or near large bodies of water.

### 3.4.2 Anthropogenic Influences

Human activities increasingly influence climate, although the line dividing natural and anthropogenic influences is not always clear. Global warming due to changes in the atmospheric greenhouse effect is one of the most notable results of human activities (Hansen et al. 1981, Weiss et al. 1981, Broecker and Peng 1982, Edmonds and Reilly 1982). This change is primarily a result of increasing concentrations of atmospheric carbon dioxide from combustion of fossil fuels as well as from the logging of enormous areas of forest, with the resultant release of $CO_2$ through the burning or decomposition of the carbon bound up in the organic matter (Charney 1979); of atmospheric methane (Rasmussen and Khalil 1981a, 1981b, Kerr 1984); of atmospheric nitrous oxides (Donner and Ramanathan 1980); and of chlorofluorocarbons (Ramanathan 1975). There was a 9% increase in atmospheric carbon dioxide between 1958 and 1985 (Figure 33).

A conference was held in 1982 in response to articles in popular literature (Boyle and Mechum 1982) concerning a theory ascribing recently reduced rainfall and increased temperature in south Florida to reduced albedo and evapotranspiration resulting from the draining of area wetlands. The results of this conference are summarized in Gannon (1982). Though evapotranspiration from land masses may account for only 5% of the precipitation in south Florida (the bulk arriving with air masses from over the Atlantic), evapotranspiration increases the buoyancy of the continental air masses. It is probable that this increases mass convergence, bringing in more moisture from the adjacent oceans and acts as a trigger to increase convection and, therefore, the convection-induced rains. Rainfall of this nature is found year round but is especially common in summer. A 70 inch rainfall deficit which accumulated between 1962 and 1982 along the St. Johns River in northeast Florida has also been attributed to the draining by 1972 of approximately 72% of the once vast wetlands through which the river flowed (Barada 1982). If this relationship between evapotranspiration and rainfall is confirmed, a similar mechanism probably exists in the Panhandle, where similar patterns of convective rainfall are found. Future development which reduces wetland and vegetated areas might induce similar reductions in summer rainfall.

Short-term cooling trends have been attributed to insolation screening by dust, smoke, and debris thrown into the upper atmosphere by large volcanic eruptions such as Krakatoa in 1883 (Humphries 1940) and Mount St. Helens in 1980 (Searc and Kelly

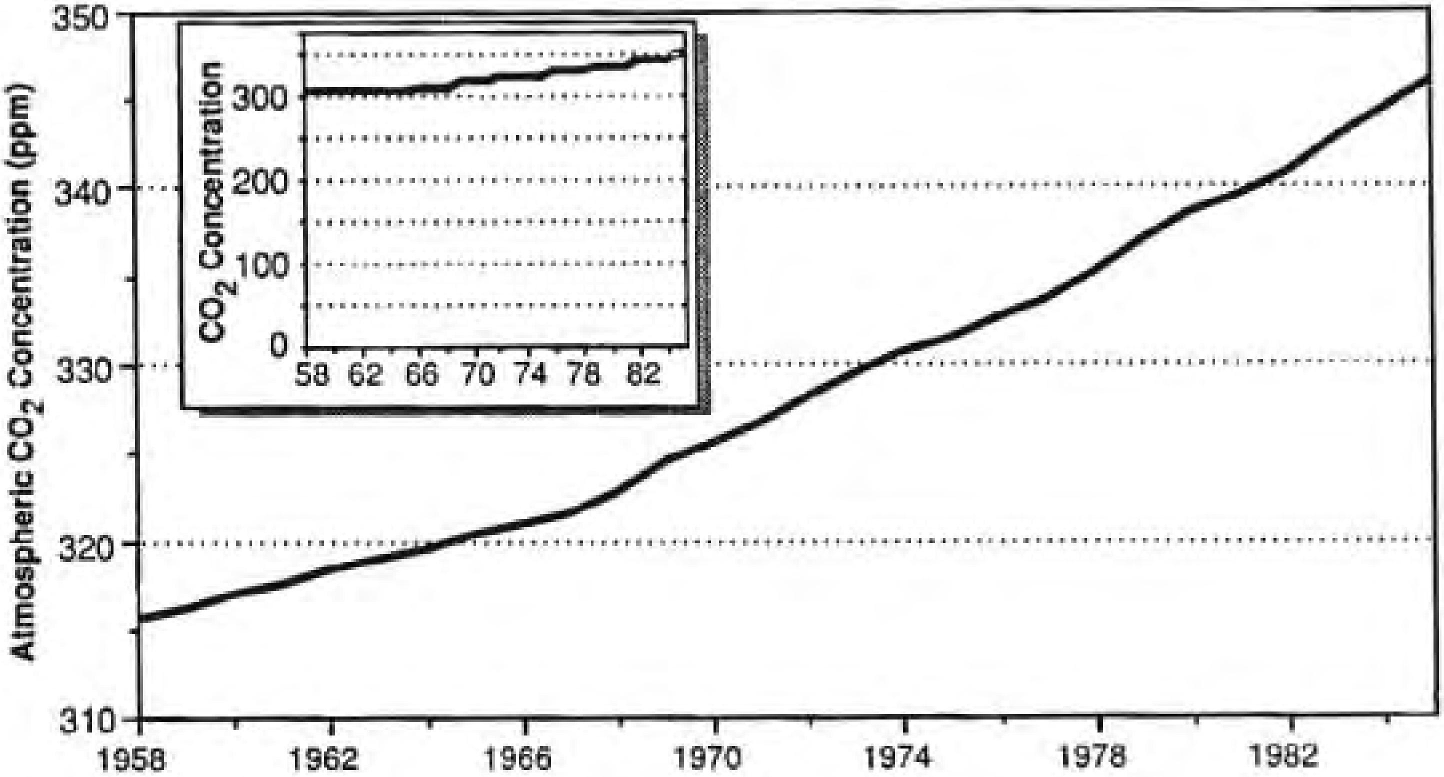


**Figure 33. Increasing atmospheric carbon dioxide as measured atop Mauna Loa, Hawaii (data from Charles Keeling, Scripps Inst. of Oceanography).**

1980). Smaller eruptions have a weaker cooling effect. It is thought that this short-term cooling may be partially masking the long-term global warming caused by increasing concentrations of atmospheric $CO_2$ (Bell 1980).

## 3.5 Summary of Climatic Concerns

The Florida Panhandle has three present and near-future climatological concerns. Two of these result from the present global warming trend. While all effects of this warming are not predictable with our present understanding of the ecosystem, certain effects in the Panhandle are probable. A major impact resulting from global warming is a predicted substantial rise in sea level, significant effects of which are expected within 25 years. This impact is discussed more fully in section 4.8. The second concern relating to atmospheric warming is a probable change in weather patterns. A possible 5 °F increase in the mean global temperature by the latter part of the next century is projected to yield a similar increase in mean Panhandle temperature and a few percent increase in local precipitation (Revelle 1982, National Research Council 1983). The present understanding of meteorology is not, however, sufficient to permit reliable prediction of these changes. This is particularly true of climate changes over a relatively small area the size of the Panhandle.

A final climatic concern for the future is the possibility of reduced summer (convective) rainfall. Unlike the previous two problems, the causes have not yet been widely initiated and are preventable. Convective summer thundershowers provide the majority of summer rainfall. Summer rains, in turn, supply the majority of the total annual rainfall (Figure 17). The convective mechanism causing these rains is similar to that found in south and east Florida. Since the "rain machine" in these regions may have been weakened by extensive wetland draining, it is possible that future terrain alteration in the Panhandle—including drainage and development of large wetland areas—could cause a similar effect.

Predicting the occurrence and effect of climate changes is very difficult since the understanding of the meteorological and oceanographic systems that provide climatic feedback and checks-and-balances is incomplete. With these constraints, even the sea level predictions, which are based on an intensive program of study, include necessarily wide margins for error. Unexpected or unexpectedly strong feedback mechanisms may exist to damp the warming trend. One possible example of such feedback is that the increase in size taking place in our deserts (especially the Sahara) may be a result of global warming; however, the increased dust blown into the atmosphere from the larger desert area may be increasing insolation screening and therefore tending to reduce that warming. The possible existence and "strength" of similar feedback mechanisms make accurate prediction of future climate difficult; however, the National Academy of Sciences (Charney 1979) was unable to find any overlooked physical effect that could reduce the estimated temperature increase to negligible proportions. The accuracy of the predictions is increasing through research into the major climatic factors.

## 3.6 Areas Needing Research

Research on numerous aspects of the Panhandle climate is needed concerning questions which, of course, affect much wider areas, but are applicable to this area. Research is especially needed on the changing greenhouse effect; the effects of increasing world-wide average temperatures on area climate; the mechanisms controlling coastal convective rainfall; and rates of evapotranspiration and their connection to rainfall and runoff.

# Chapter 4. HYDROLOGY AND WATER QUALITY

## 4.1 Introduction

Water quality is, in many ways, dependent on hydrology and frequently the forces affecting one also affect the other. This chapter will discuss each of these areas, their interrelationships, and their status in the Florida Panhandle. An excellent source of general information on the water resources of the Panhandle and all of Florida is the *Water Resources Atlas of Florida* (Fernald and Patton 1984). The *Hydrologic Almanac of Florida* (Heath and Conover 1981) has very good discussions of different hydrologic and water quality factors as well as containing good, if occasionally dated, records on Florida.

Panhandle surface water supplies and its ground water supplies are normally inseparable. In many places water flows from the surface into the ground and back again many times as it makes its way to the coast. Any changes in the hydrology or the quality of one is likely to affect the other. The entire supply of potable ground water in Florida floats on deeper layers of saline ground water that are connected with the Atlantic Ocean and the Gulf of Mexico. This layer of fresh water floats because it is ~2.5% less dense than the salt water. As water is removed from the fresh-water aquifer, the underlying salt water tends to push the upper surface of the fresh-water aquifer higher as the aquifer gets lighter. As a result, "permanently" lowering the upper surface of the freshwater aquifer by 1 ft over a broad area requires withdrawing a volume of water equal to nearly 40 ft of the aquifer thickness. Thus, simplistically, for every foot our pumping of the fresh-water aquifers lowers the upper surface and is not replaced in a reasonable period of time by rainwater, the deeper saline layers rise 40 ft. The Florida Panhandle, and all of Florida, has tremendous volumes of fresh water stored beneath the ground; however, it cannot be used at a rate greater than the average rate at which it is replaced by rainfall. Otherwise, saltwater intrusion will render the coastal wells useless because the depth to the underlying saline layer is much less near the oceans.

### 4.1.1 Hydrology

Hydrology is the study of the water cycle, including atmospheric, surface, and ground waters. The basic hydrologic cycle (Figure 34) includes water vapor entering the atmosphere as a result of evaporation, transpiration, and sublimation. This vapor condenses to form fog, clouds, and, eventually, precipitation. In the Florida Panhandle precipitation normally reaches the ground in the form of rain. Snow and hail occur infrequently. Upon reaching the ground, the water either evaporates, soaks into the soil and thence into the groundwater system, or (if the ground is saturated or the rate of rainfall exceeds the ground's ability to absorb it) runs off or pools, forming streams, rivers, lakes and other wetlands.

The fundamental organizational unit of surface hydrology is the drainage basin. In its most basic form, a drainage basin, or watershed, consists of that area which drains surface runoff to a given point. Thus the mouth of a river has a drainage basin that includes the basins of its tributaries. The drainage areas discussed in this document are based upon the basins described by the U.S. Geological Survey (Conover and Leach 1975) (Figure 35). Most of these consist of the Florida portion of the drainage basin of a single coastal river. A large portion of many of these basins actually extends well into Georgia and Alabama (Figure 36). Some, however, represent coastal drainage areas where lands drain to coastal streams and marshes on a broad front rather than to a single discharge point.

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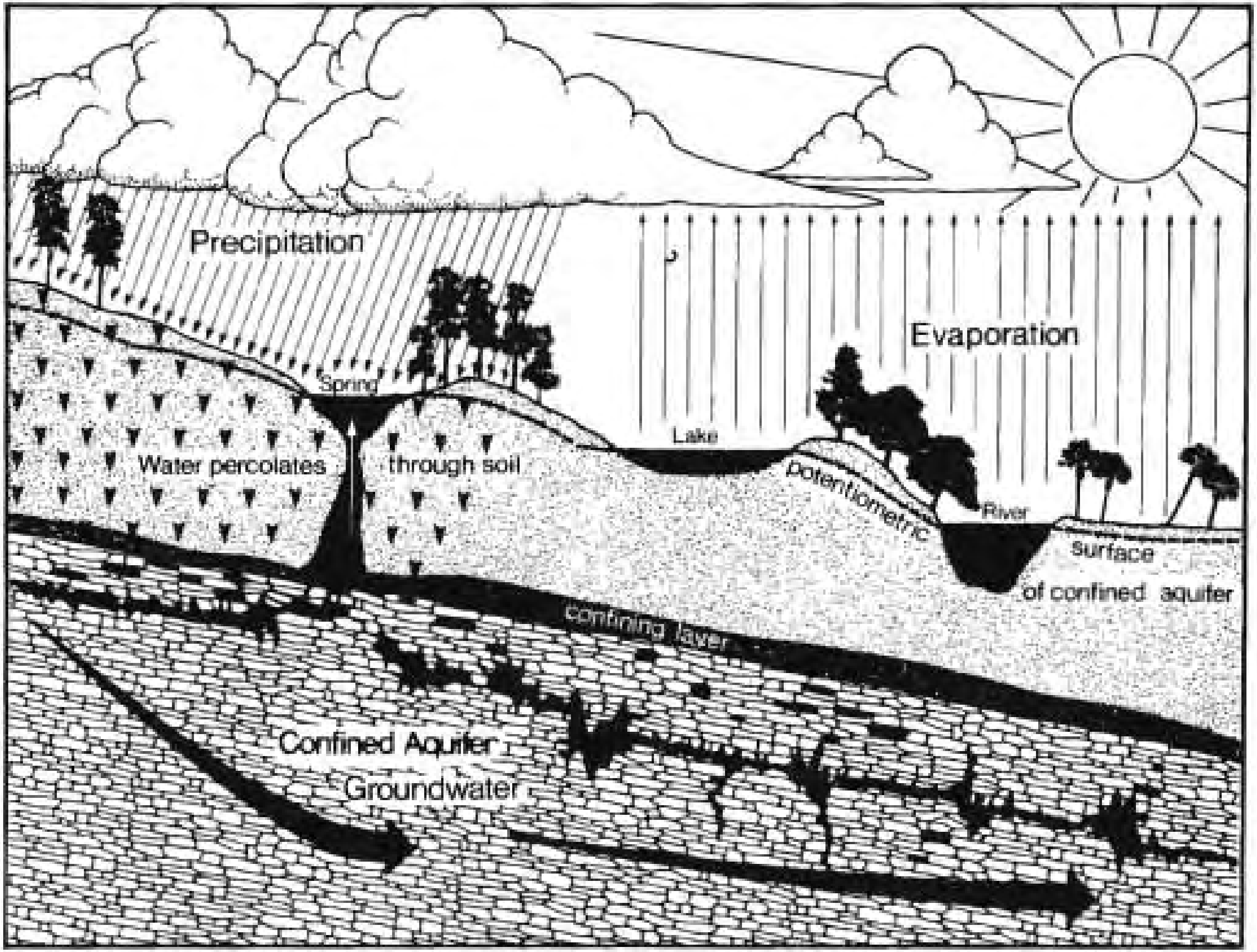


Figure 34. The basic hydrologic cycle.

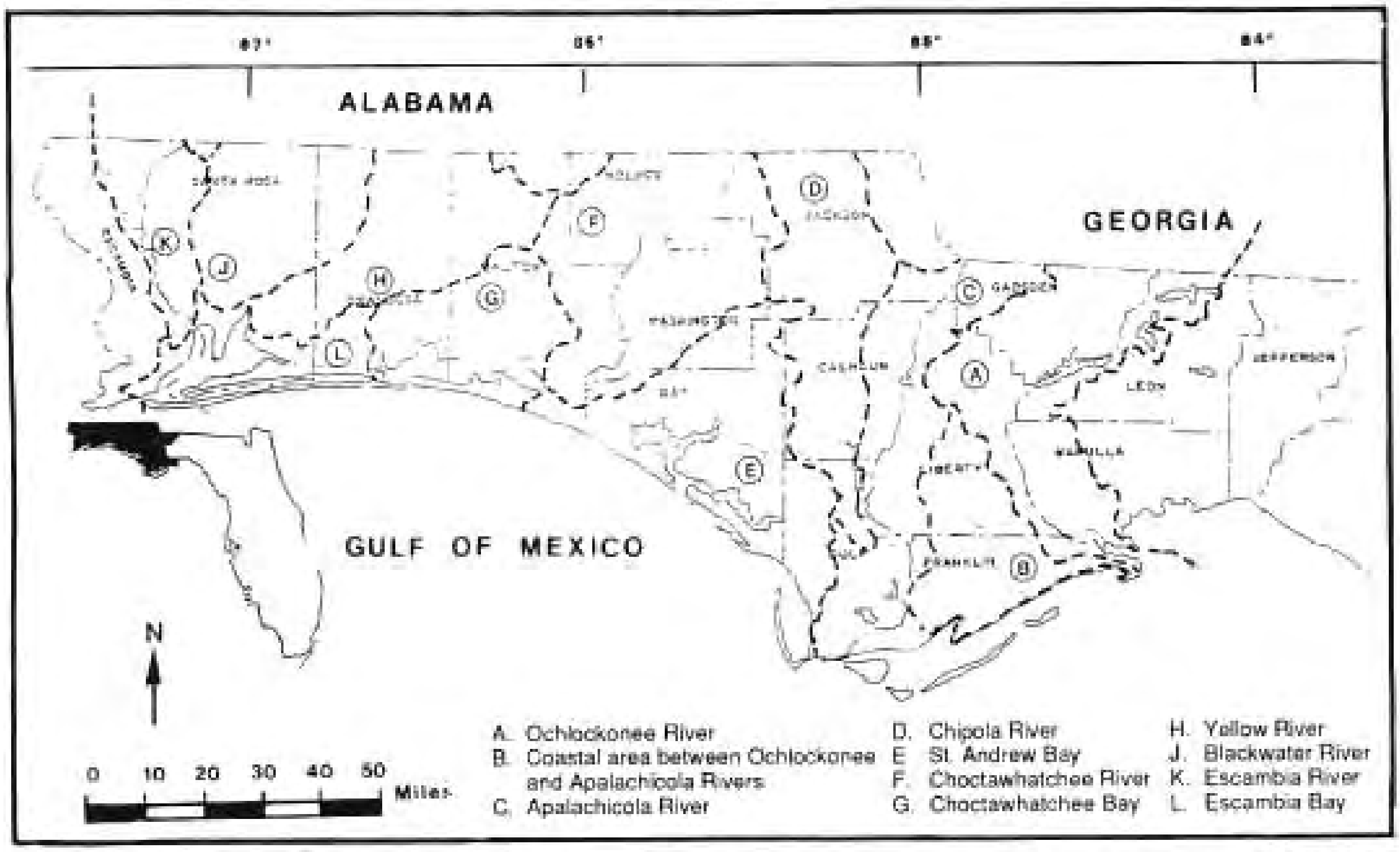


Figure 35. Panhandle drainage basins discussed in this document (after Conover and Leach 1975).

Ground water in the Florida Panhandle is contained primarily within two overlapping reservoirs: the Floridan aquifer underlying the entire Panhandle; and the Sand and Gravel aquifer which overlies the Floridan west from Okaloosa County (Figure 37). A shallow surficial aquifer is found overlying the Floridan aquifer in many parts of the eastern Panhandle (Figure 38).

Panhandle aquifers are recharged by five means: (1) drainage of surface runoff into areas where the aquifer is unconfined (i.e., not overlain with a low-permeability stratum) and located at or near the ground surface; (2) drainage of surface runoff into sinkholes and other natural breaches into the aquifer; (3) percolation of rainfall and surface water through the upper confining beds; (4) percolation through the confining layers of water from aquifers overlying or underlying the one in question but with a greater potentiometric surface ("pressure"); and (5) lateral transport from areas within the aquifer with a higher potentiometric surface (Figure 39). Areas within the Panhandle recharging the Floridan aquifer are presented in Figure 40.

### 4.1.2 Water Quality

The availability of water has always been an important factor in selection of sites for human activities. The primary concern of the past—securing needed quantities of water—has, in recent years, increasingly been replaced by concerns about the quality of that water. Water quality affects people directly by influencing water's suitability for drinking, cooking, bathing and recreation, and indirectly by its effect upon the ecosystem within which humanity exists. Factors affecting water quality include the physical makeup of the local ecosystem (e.g., the presence of limestone generally prevents acidic water), seasonal changes in that ecosystem, direct discharges from human sources, and indirect discharges from human sources (e.g., acid rain).

Society judges water quality based upon its usefulness to people and those animals and plants

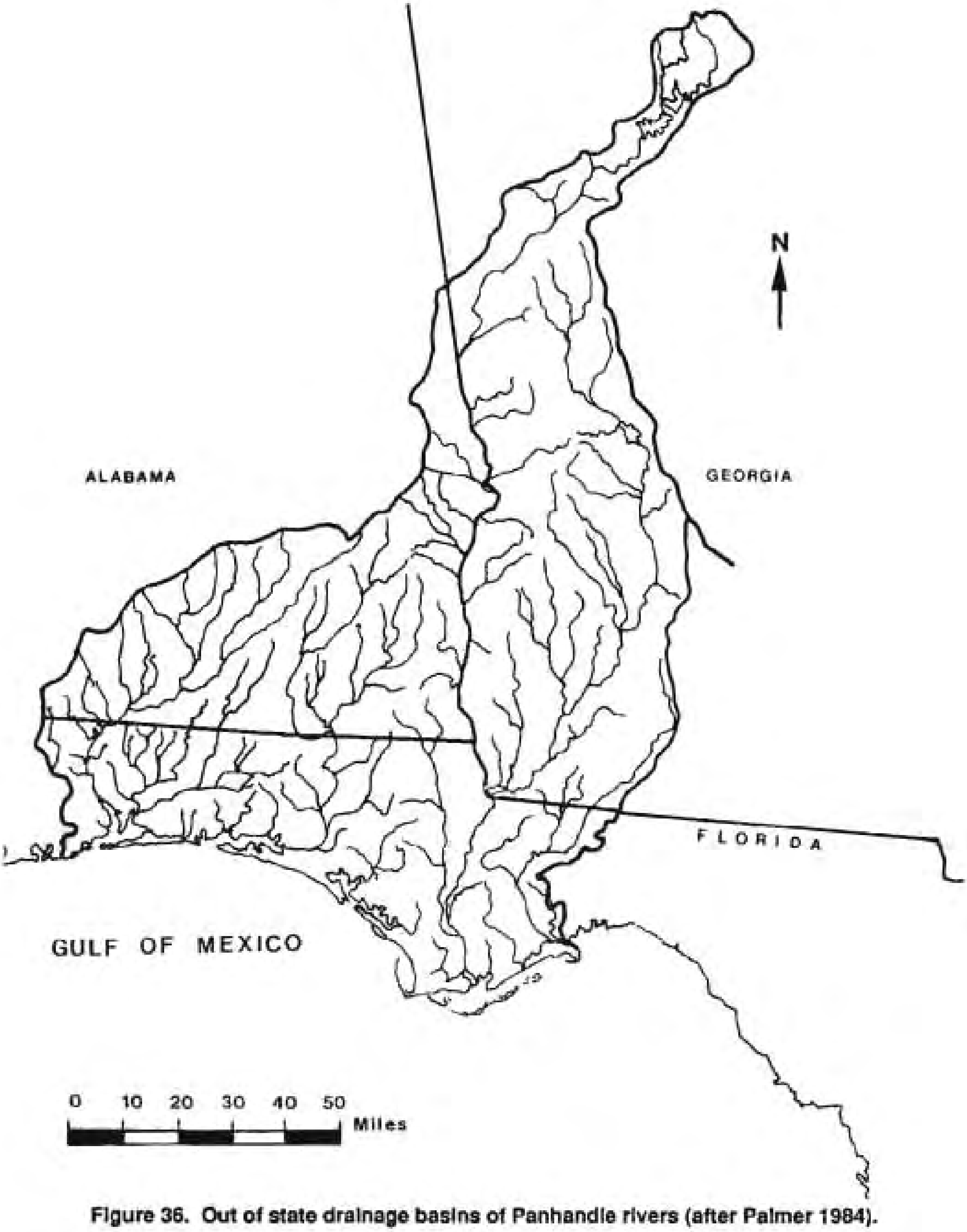


Figure 36. Out of state drainage basins of Panhandle rivers (after Palmer 1984).

Figure 37. Primary Panhandle aquifers used as water sources (after Hyde 1975).

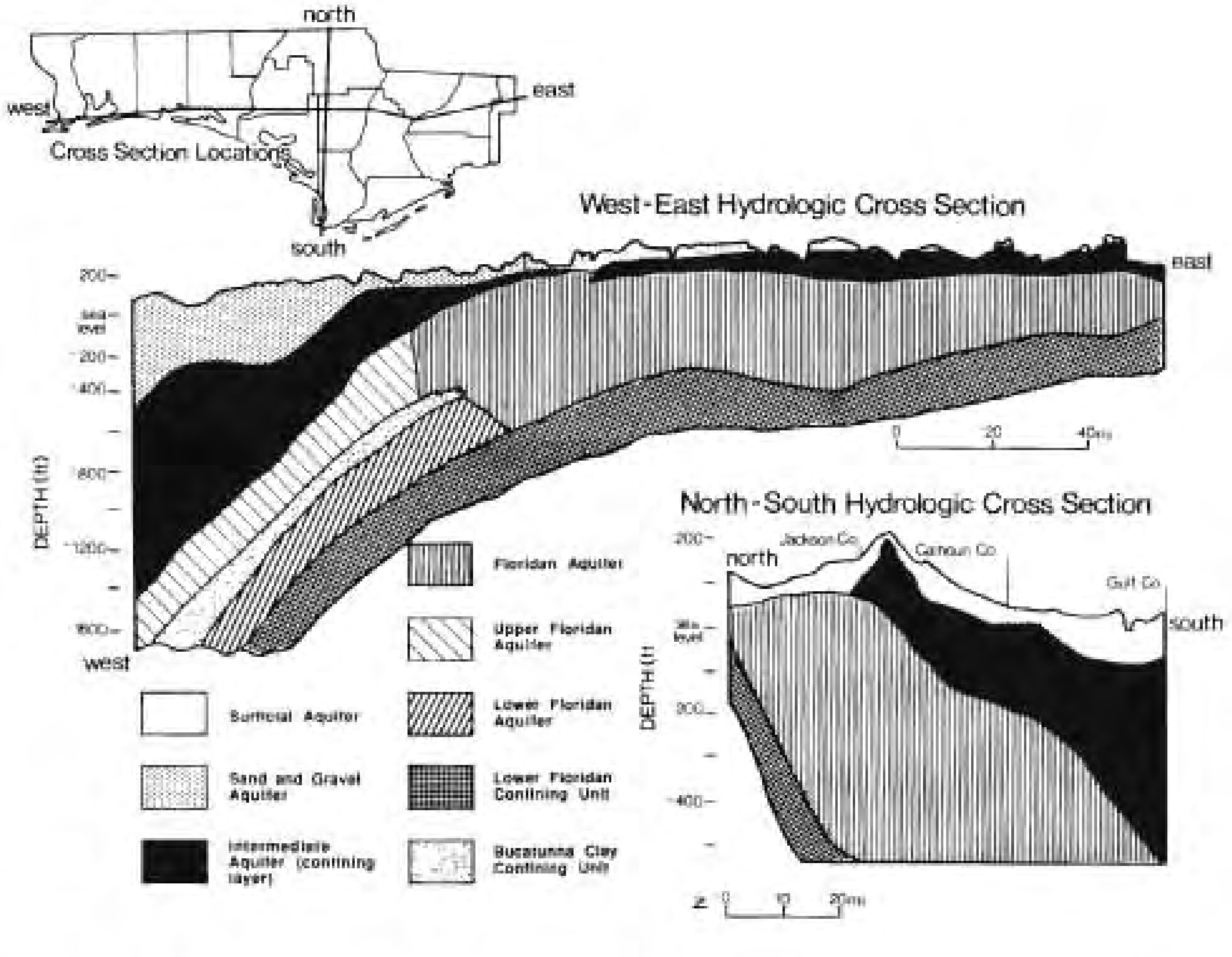


Figure 38. Hydrologic cross sections of the Panhandle (after Wagner et al. 1984).

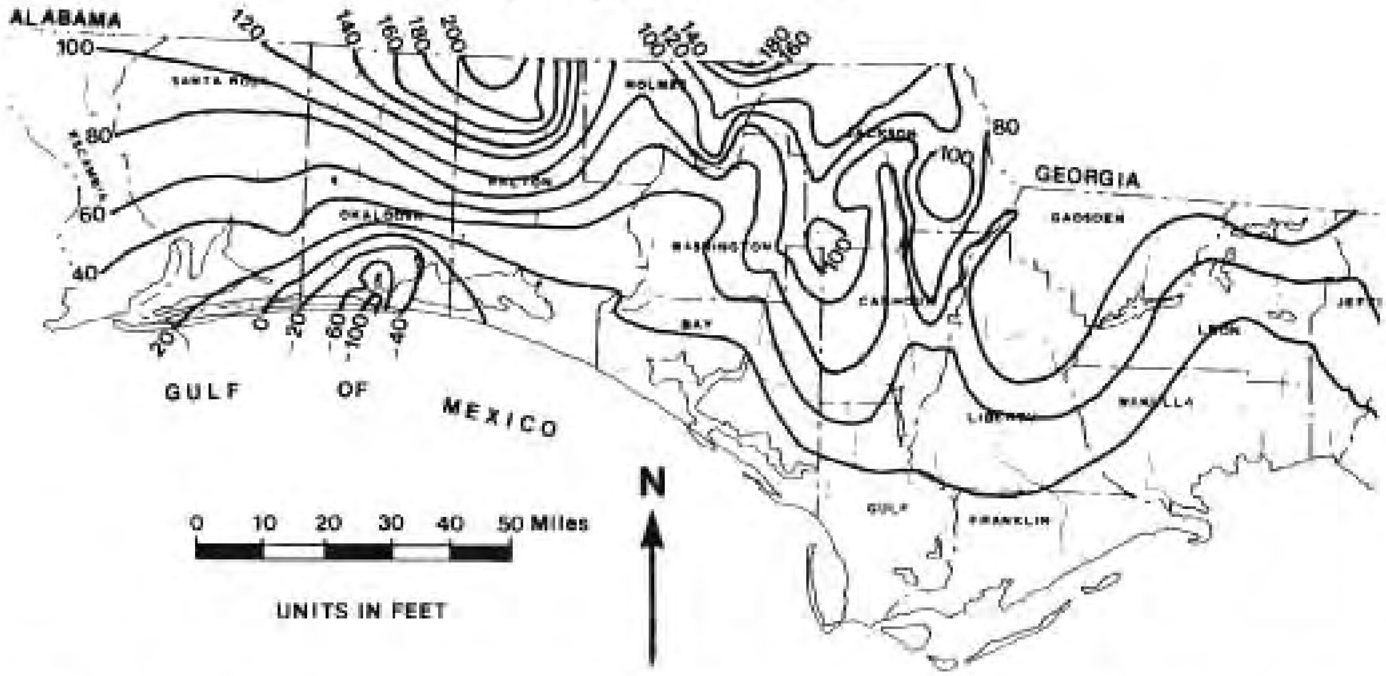
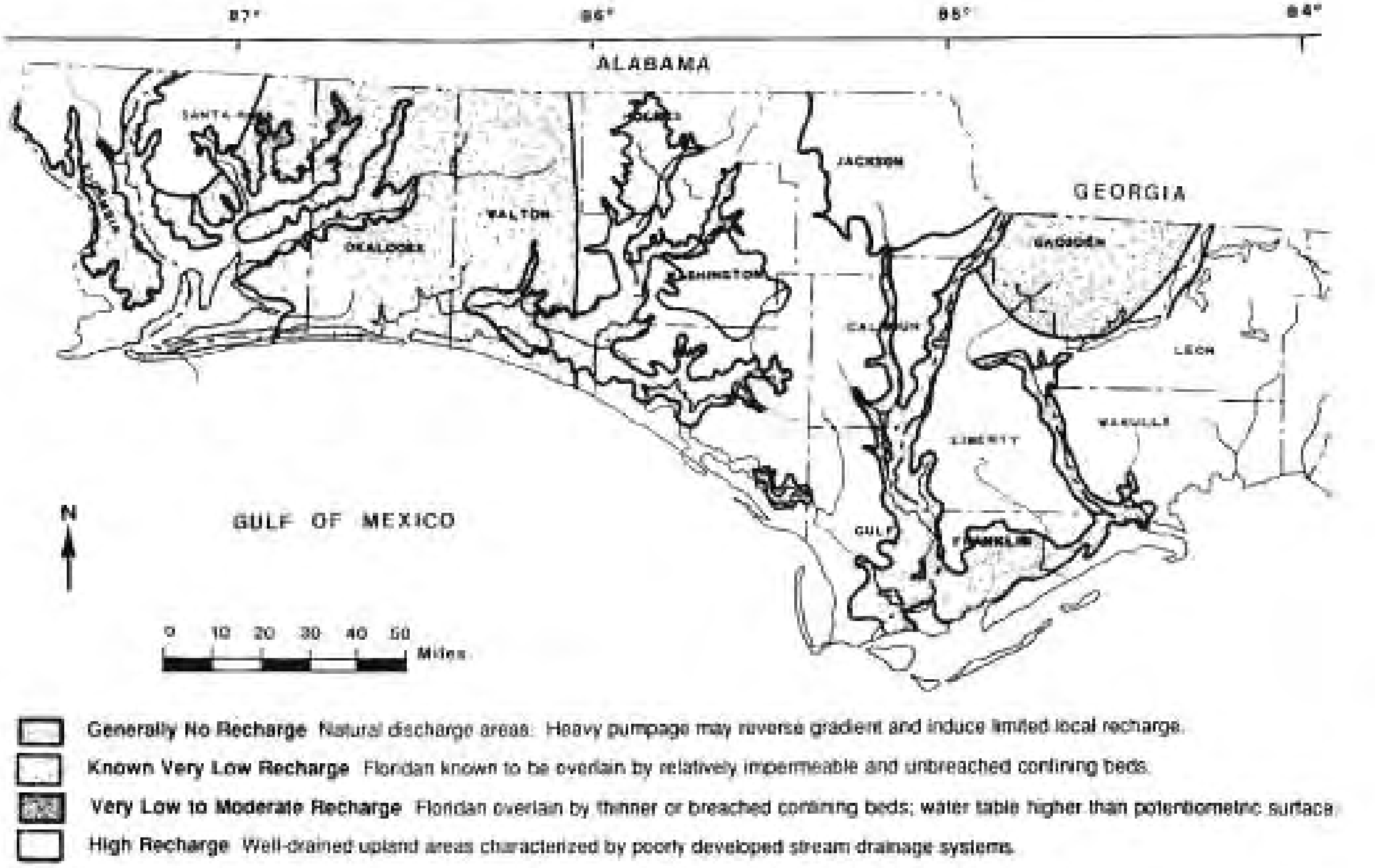


Figure 39. Potentiometric surface of the Floridan aquifer in the Panhandle in May, 1980 (after Healy 1982).



▭ **Generally No Recharge** Natural discharge areas. Heavy pumpage may reverse gradient and induce limited local recharge.

▭ **Known Very Low Recharge** Floridan known to be overlain by relatively impermeable and unbreached confining beds.

▨ **Very Low to Moderate Recharge** Floridan overlain by thinner or breached confining beds; water table higher than potentiometric surface.

☐ **High Recharge** Well-drained upland areas characterized by poorly developed stream drainage systems.

Figure 40. Recharge areas to the Floridan aquifer in the Panhandle (after Stewart 1980).

we value. Since our society has come to recognize the value of a healthy ecosystem, we try to measure this health in addition to the physical and chemical water quality parameters. Increasingly this is done by examining the number and diversity of the species and individuals present in the water body. Various indices have been developed and used including numerous species diversity indices and what are known as biotic indices, which measure the presence of key species judged to be indicators of high water quality. Combinations of these indices aid in quantifying the degree of ecological health, but results from any one index must be viewed with caution. Each method, because of the manner with which it weighs different factors, generally has situations in which it gives a poor representation of the actual conditions.

**a. Direct Importance.** The first concerns about water quality were directed toward the transmission of disease through drinking water. Even this concern is relatively new. The desirability of separating human wastes from sources of water for drinking and food preparation was not understood in western civilizations until the mid-1800's and this separation was not effected on a wide scale until the early 1900's.

Until the early 1970's, drinking water was routinely examined and treated primarily for disease pathogens. Only recently has an awareness of the health and environmental impacts of toxicants become widespread. The majority of these substances are metals or synthetic organic compounds. Metals from natural sources in sufficient concentrations to cause problems are uncommon. Most of the organic hydrocarbons contaminating waters do not occur naturally. The vast majority of toxic substances found in the planet's waters are anthropogenic, products of modern industrialized society.

Efforts to locate, identify, and remove these substances from our waters are greatly hindered by their enormous number and variety, their difficult detection, and the lack of knowledge concerning both their short- and long-term effects. Some are toxic at levels below which their concentrations can be reliably measured. Increasing the problem of controlling these hazards is the daily discovery or synthesis of additional chemical compounds, many of which are a potential threat to water supplies. In addition to exposure through contaminated drinking water, some of these substances are being found in human foods following uptake by food plants or animals.

A secondary problem is the need for water of sufficiently high quality to meet industrial needs. Though most industrial water uses are for cooling, steam generation, material transportation, and similar tasks not requiring potable water, preventing scale buildup in steam and cooling equipment and using water for product makeup and certain chemical processes may require that specific aspects of the water quality be high.

**b. Indirect Importance.** The quality of water, both the physical characteristics and the presence or absence of toxic components, is a factor controlling ecosystem constituents (e.g., productivity, species diversity). Just as climate and water availability exert control upon floral and faunal composition, so does the quality of the available water. An area of poor water quality may support little or no life or, alternatively, populations of undesirable species.

Humanity is at the apex of a food web pyramid and is, therefore, dependent upon the soundness of the base of that pyramid for existence. If pressed, we may be capable of treating sufficient quantities of contaminated water to supply humanity's direct water needs; however, water of the quality necessary to support all levels of the ecosystem must be available, otherwise the food web pyramid may erode from beneath us.

### 4.1.3 Hydrology and Water Quality Regulation and Management

Though attempts are being made to treat drinking waters for contaminants, the removal of contaminants from the natural surface waters to which people are exposed during work or recreation is much more difficult to manage. It is impractical to treat surface waters to remove contaminants or alter physical parameters; rather, contaminant removal and physical changes must be performed prior to discharge of domestic or industrial effluents. To this end, State and Federal regulations have been enacted in an attempt to control effluent discharges into surface waters. Under the Federal Clean Water Act, point source discharges into surface waters of the United States are regulated by the National Pollutant Discharge Elimination System (NPDES). Under this system dischargers are given permits to discharge effluents meeting certain standards based upon the types of waste generated. The discharger is required to monitor the effluents and report periodically. In Florida, all NPDES permit applications and reports are reviewed by the Florida Department of Environmental Regulation (FDER). Under NPDES regulations, effluents should meet State water quality standards. The NPDES program, however, does not regulate dischargers in such a way that cumulative impacts are controlled. Hence, while a river may have numerous discharges into it, each meeting water-quality standards, the cumulative effect of all the discharges upon the river may cause its water quality to fail to meet standards. The NPDES program primarily is aimed at conventional pollutants, including bacteria, nutrients, and materials decreasing dissolved oxygen (DO) concentrations.

Surface waters have been monitored by the FDER since 1973 using Permanent Network Stations (PNS), though this monitoring network has been substantially reduced in recent years. The responsibility for management of regional water resources is held by the Northwest Florida Water Management District (NWFWMD). This responsibility includes regulation of water consumption and long-range planning to help ensure the continuing availability of high quality water. The water management district also has its own network of monitoring stations. At the request of the State Legislature, the NWFWMD in 1979 formulated a water resources management plan (NWFWMD 1979a) and a regional water supply development plan for the Panhandle coast (Barrett, Daffin and Carlan, Inc. 1982).

Waste load allocation studies have been performed by the FDER and, in earlier years, the U.S. Geological Survey to attempt to determine the amount of effluent discharges, including those of sewage treatment plants and private sources, that can be discharged into water bodies without degrading them. It should be pointed out that present methods of wasteload allocation rely primarily on models of DO and nutrient concentrations, are aimed at allocation of nutrient loads from public and private sources to maintain DO levels necessary for a healthy aquatic system, and are therefore incapable of predicting or allowing for effects from toxic discharges. The FDER conducts a program of acute and chronic toxicity bioassay testing on selected private and municipal effluent discharges that are recommended to them. Results of the tests are available as reports from the FDER Biology Section, Tallahassee.

Primarily because of cost considerations, most data collected from the various monitoring networks and stations is physical or chemical in nature. The biological baseline studies and monitoring needed to enable accurate determination of the overall "goodness" of the water quality of a particular water body is generally lacking. Additionally, all the large Panhandle rivers are interstate rivers originating in Georgia or Alabama. Thus, their hydrology and water quality is influenced by factors outside their Florida drainage basins. With the notable exception of Apalachicola Bay, data limitations due to changing sampling methods and uncharacterized ambient conditions have prevented long-term trend analysis in these river basins (FDER 1986c). Lack of baseline data in most instances and lack of continuing data collection in many instances prevent accurate detection of changes in surface-water quality and hinders interpretation of data gathered in short-term studies and laboratory simulations performed to predict effects on area ecology (e.g., chronic toxicity bioassays) (FDER 1985a, Livingston 1986a).

Following the discovery in the early 1980's of the toxic pesticides aldicarb (Temik®) and ethylene dibromide (EDB) in Florida ground waters, the Florida Legislature passed the Water Quality Assurance Act of 1983 which included steps to address the ground-water contamination problem. One major aspect of this act was the institution of a ground-water quality monitoring network to be administered by the FDER. This consists of a network of existing wells plus new wells where existing ones are insufficient to permit adequate ground-water sampling,each sampled on a regular basis. In its first phase, nearing completion at the time of this writing, the FDER's Bureau of Ground Water Protection performed extensive chemical testing of ground-water samples as a pilot operation to establish the necessary locations for the monitoring wells, to gather mapping and water quality information (aquifer locations and water flow, areas of saline intrusion, ambient ground-water chemistry), and to help locate the main areas with water quality problems. Upon completion of this step, the preliminary locations of permanent monitoring wells and the frequency of sampling needed will be determined. The ensuing program will be altered as dictated by sampling results. The ground-water monitoring network was envisioned as the source of a computerized data base helping to (1) determine the quality of water provided to the public by major well fields in the state, (2) determine the background or unaffected ground-water quality, and (3) determine the quality of ground water affected by sources of pollution. A biennial report describing Florida's ground-water quality will be made available to the public and governmental bodies to help in decision making.

## 4.2 Water Quality Parameters

### 4.2.1. Dissolved Oxygen

**a. DO capacities.** The amount of oxygen dissolved in water can be a limiting factor for aquatic life. Dissolved oxygen levels below approximately 3–4 ppm are insufficient for many species to survive. Alternatively, supersaturated levels of DO can result in embolisms (bubbles forming within the animal's tissues) and death. The amount of oxygen necessary to saturate water is temperature dependent. Higher temperatures reduce the saturation concentration (amount of oxygen the water can hold) and lower temperatures increase it (Figure 41). At 2 °C, freshwater (at sea level) is saturated at a DO of 13.8 ppm. At 30 °C, saturation occurs at 7.5 ppm. Another major factor influencing saturation levels is salinity; high salinities reduce saturation concentrations and low salinities increase them (Figure 42). While freshwater at 2 °C is saturated at 13.8 ppm, seawater (35 ppt) at the same temperature is saturated at 9.9 ppm. To provide a clearer picture of the ability of a water body to absorb more oxygen, the concentration is sometimes expressed as percent saturation—the percentage of that DO concentration at which the water would be saturated.

**b. Oxygen uptake—respiration.** As a result of these factors, during hot weather, when the metabolic rates of aquatic lifeforms are highest and their oxygen demands greatest, the oxygen carrying capacity of water is lowest. This situation is accentuated in confined water bodies, such as canals, where poor circulation minimizes aeration and maximizes water temperature.

The problem of the reduced oxygen capacity of warm water is compounded by two factors: algal respiration and biochemical oxygen demand (BOD). "Fish kills" caused by low DO (which may include many organisms other than fish) generally occur at night or during periods of cloudy weather. The net oxygen production by the algal population during sunlit hours changes to a net oxygen consumption during dark hours when algal photosynthesis ceases but respiration by the algae and other sources continues.

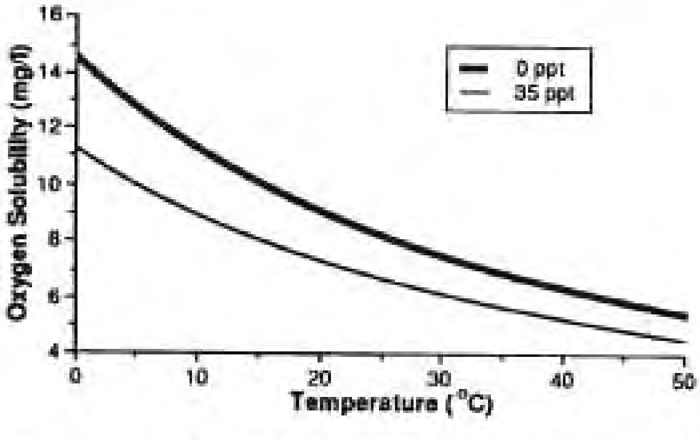


**Figure 41.** **Oxygen solubility as a function of temperature.**

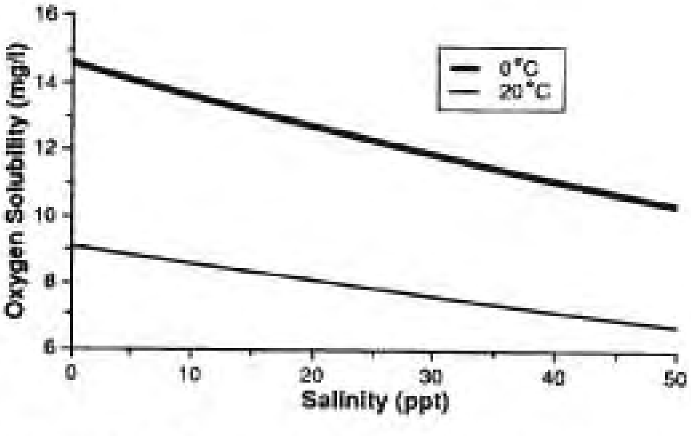


**Figure 42.** **Oxygen solubility as a function of salinity.**

**c. Oxygen uptake—Biochemical Oxygen Demand (BOD).** BOD results from microbial and chemical consumption of oxygen during the degradation of organic compounds in the water column and bottom sediments. BOD becomes a problem when excessive organic wastes enter an aquatic system. Oxygen uptake from high BOD can reduce DO levels to near zero. Even relatively low levels of BOD can contribute significantly towards low DO levels and resulting problems if that BOD combines with floral and faunal respiration and temperature-salinity interactions. As a result, fish and invertebrate kills from low DO are not uncommon, especially during summer months. Most of the oxygen dissolved in water results from gas exchange with the atmosphere except during periods of heavy algal growth. The rate at which a water body absorbs oxygen from the atmosphere is influenced by its circulation. If the oxygen must diffuse through the entire water column to reoxygenate depleted bottom waters (i.e., the water body is stagnant) then this rate is very slow. Bottom waters in canals and other enclosed water bodies, particularly those with a high ratio of depth to width and having organic bottom sediments, are especially vulnerable to oxygen depletion. If the depleted waters are circulated to the surface, the rate of oxygen uptake from the atmosphere is greatly enhanced and pockets of anaerobic water are less likely to develop.

### 4.2.2 pH

The concentration of hydrogen ions in water is measured in pH units. Waters of low pH (<7) are acidic, those with pH = 7 are neutral,and those with high pH (>7) are basic. The pH scale is inverse (in terms of $H^+$ ions) and logarithmic; hence water of pH 6 has 100 times as many $H^+$ ions as does that of pH 8. The pH of water is important biologically and chemically. Below a pH of approximately 6 harmful biological effects are felt, especially in sensitive life stages such as eggs. Below a pH of about 4, only a few specialized species can survive.

The biological effects of low pH are strongly linked to other factors, particularly the nonhydrogen ionic content of the water. Thus pH exerts a strong effect on the form of many of the other contents in the water. Ammonia, for instance, is found in the form of ionized ammonia ($NH_4^+$) and unionized ammonia ($NH_3$). The ionized form in which most ammonia is found in acidic waters is several orders of magnitude less toxic than the unionized form found in basic water. This is the reverse of the general rule of thumb that the ionic forms of substances (which often form in low pH waters) tend to be more toxic (Cairns et al. 1975).

Biologically, most of the direct effects of low pH upon aquatic fauna appear to be related to problems with disruption of osmoregulation (regulating blood and tissue fluids) and control of the ionic balance of blood and vascular fluids (Leivestad et al. 1976,1980, McWilliams and Potts 1978). The pH of blood (as well as plant vascular fluids) exerts strong effects on the ionic speciation of its components (i.e., the form in which the ion is found—e.g., $CO_2$ may be found in solution as $CO_2$, carbonic acid, carbonate, and/or bicarbonate, depending upon several factors, the major one being pH). Since pH exerts strong effects on metabolic chemistry, blood and vascular pH must be maintained within relatively narrow ranges. The blood of aquatic fauna is typically separated from the surrounding water by a thin semipermeable cell wall in their gills. Species or life stages that have a high ratio of gill (or in the case of eggs, chorion) surface area to body volume generally have the most difficulty compensating for ambient pH outside the nominal range for their blood chemistry (Lee and Gerking 1980).

In the Florida Panhandle, surface waters of low pH are generally found in swamps and swamp drainages. Figure 43 gives the normal pH levels of Panhandle surface waters. Rain water is generally slightly acidic due to the presence of dissolved $CO_2$ (forming carbonic acid) picked up from the atmosphere. Rainwater is, however, poorly buffered (i.e., possesses few ions that tend to stabilize pH levels). Concerned that Panhandle rainwater may be becoming more acidic due to powerplant emissions, the State and the Florida Electric Power Coordinating Group (an organization formed by the powerplants within Florida) have undertaken broad-scope acid rain studies. These studies are attempting to determine whether the unique conditions found in Florida increase or decrease the likelihood of acid rain formation, whether these conditions increase or decrease the sensitivity of the ecosystem to acid rain stress, and areas in or out of the State where the effects of Florida-caused acid rain may be felt (FDER

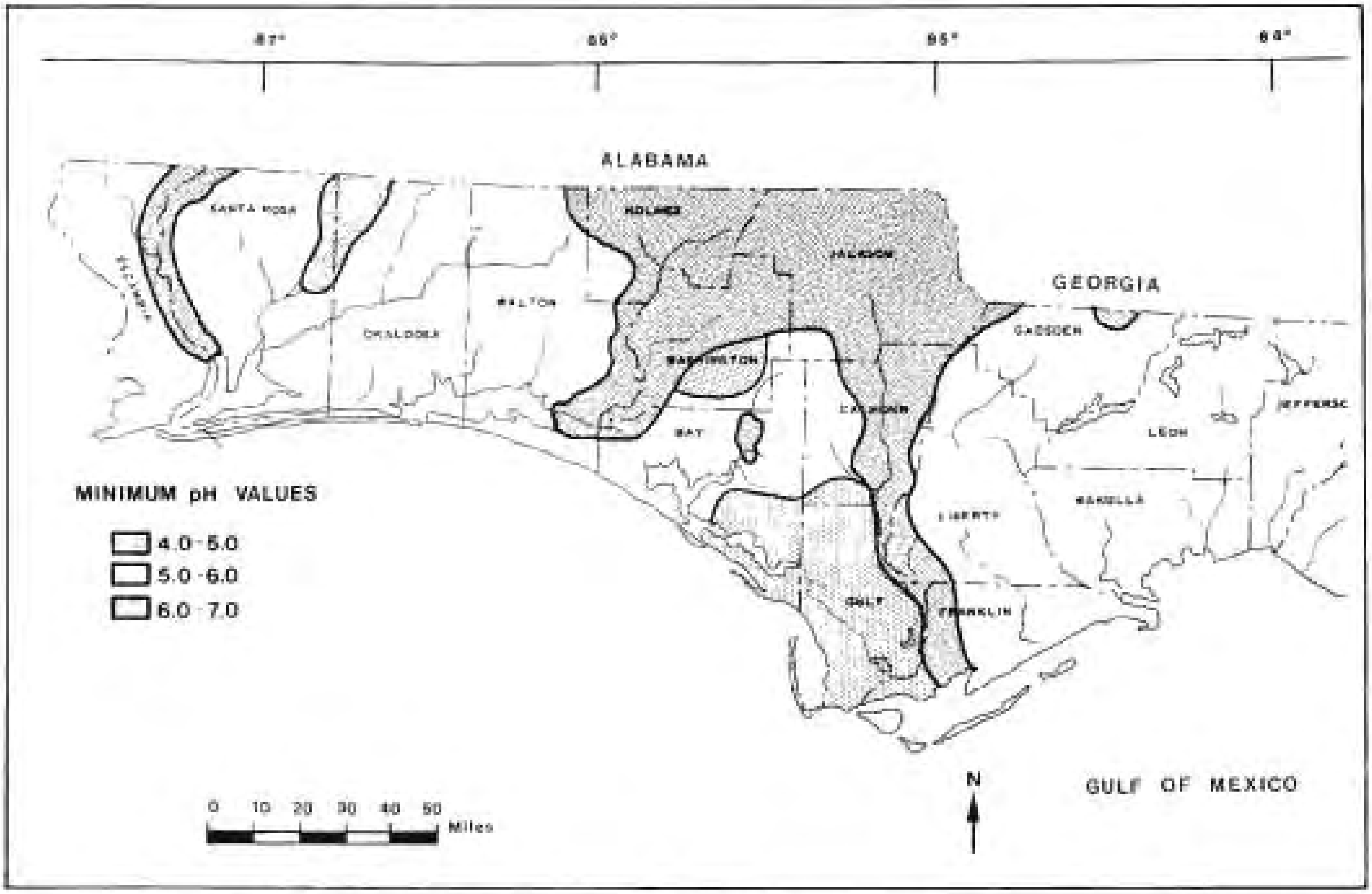


Figure 43. Minimum pH of Panhandle surface waters (after Kaufman 1975a).

1985b). If the rainwater contacts a substrate composed of a buffering material (in the Panhandle this is usually limestone—calcium carbonate, $CaCO_3$), then the pH moves toward what is known as the equilibrium pH for that buffering reaction, that is, toward the pH at which water in contact with that particular buffer will eventually stabilize. However, if the water contacts only organic and insoluble substrates (e.g., swamps and marshes), then it becomes quite acidic (pH 4 or below) from the organic acids created by the decomposition of the vegetation, and the entire system stabilizes at a low pH. These conditions yield community structures entirely different from those found in water of higher pH, since many species are excluded by their lack of tolerance for the acidic conditions.

The pH of water bodies originating in these organic wetlands often increases downstream because of the input of buffering ground water or surface drainage (or both) or from contact with a buffering streambed. Carbonate buffering in north Florida ground water is sufficiently strong that the addition of 5%–10% of a moderately alkaline ground water (pH approximately 8.0, alkalinity approximately 120 mg/l) has been shown to raise swamp water with a pH of 4.0 and an alkalinity of 0 mg/l to a pH of 6–6.5 and alkalinity of 6–12 mg/l (FDER 1985a). Since the pH scale is inverse logarithmic, the 5%–10% ground-water addition, as a result of chemical buffering reactions, reduced the concentration of hydrogen ions by 99% or more. In the Florida Panhandle, pH is almost entirely controlled by the water's carbonate concentration (Kaufman 1975a).

Because of the substantial buffering effect of the high ion content of saltwater, marine pH levels are generally near 8. Thus problems from low pH are rare in estuarine and marine waters.

### 4.2.3 Turbidity and Sediments

Turbidity is the result of particulate and colloidal solids suspended in the water and is measured as the proportion of light that is scattered or absorbed rather than transmitted by a water sample. High levels of turbidity are found in streams that carry heavy sediment loads. This sediment is derived from runoff and much of it, particularly that present during periods of light to moderate rainfall, is commonly the result of human influences on the terrain along the tributaries (e.g., land clearing, urban stormwater drainage, farming without erosion control). In the absence of these anthropogenic influences, heavy rains may still temporarily increase turbidity by washing larger particles into streams, rivers, and lakes. These, however, tend to settle rapidly.

High levels of turbidity may kill aquatic organisms by clogging gill structures, causing suffocation. Hard-bottom benthos can lose habitat if settling sediment creates a mud bottom. Aquatic plants are often affected by increases in turbidity by being buried in deposited sediments or by reduced light levels. Turbidity is a concern in drinking water because it can harbor pathogens and protect them from sterilizing efforts (e.g., chlorination). High turbidity in drinking water sources, therefore, usually necessitates that the particles be removed prior to sterilization.

### 4.2.4 Dissolved Solids

The term "dissolved solids" refers to the total amount of organic and inorganic materials in solution. The dissolved materials found in Florida surface and ground waters are primarily the carbonate, chloride, and sulfate salts of calcium, sodium, and magnesium. Dissolved solids in both surface and upper ground waters are usually below 200 mg/l except for ground water along the coast (Shampine 1975a, Swihart et al. 1984) (Figure 44). Deeper

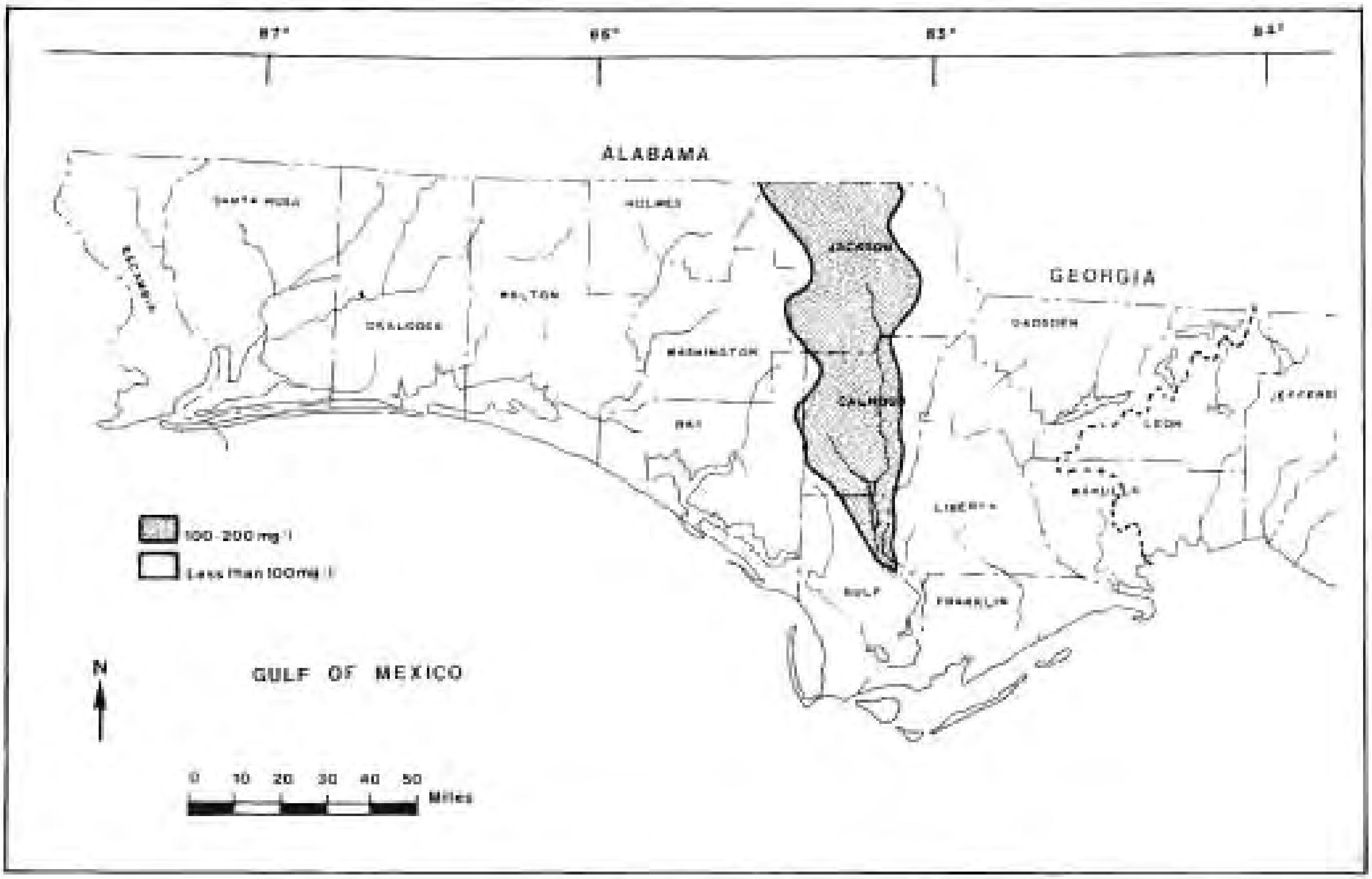


**Figure 44. Concentrations of dissolved solids in Panhandle surface waters (after Dysart and Goolsby 1977).**

ground-water layers usually contain more dissolved solids than the upper layers.

The major ions commonly found in Panhandle waters are those often measured as alkalinity ($HCO_3^-$ and $SO_4^=$, bicarbonate and sulfate ions), hardness ($Ca^{++}$ and $Mg^{++}$, calcium and magnesium ions), and salinity. The total dissolved-solids concentration in surface water is generally highest during low-flow conditions (Kaufman 1975b, Dysart and Goolsby 1977).

Conductivity is a commonly used measurement which is indicative of the concentration of dissolved solids. Distilled water is a very poor electrical conductor and ions in the water improve this conductivity. Dissolved solids concentrations can usually be reliably estimated by multiplying the conductivity in µmhos by a factor ranging from 0.55 to 0.75, depending on the water body (Dysart and Goolsby 1977).

**a. Alkalinity.** The concept of alkalinity is simple, though the chemistry involved can be quite complex. Alkalinity is a measure of the ability of a water sample to neutralize acid, in terms of the amount of $H^+$ (acid) that can be added to the water before the pH is lowered to some preset value (depending upon which type of alkalinity measurement is being performed). For the most common type of alkalinity measurement (total alkalinity), this pH is 4.5. Ions in the water that tend to keep the pH high increase alkalinity and thus "buffer" the pH.

Buffering ions commonly found in Panhandle surface and ground waters include carbonate (usually as bicarbonate) and sulfate. These components are generally the result of the dissolution of the limestone matrix with which the water has been in contact. The ready solubility of limestone and the frequent input of ground water (which has generally had significant contact with limestone) to the surface waters tends to result in Panhandle surface waters of at least moderate alkalinity.

As mentioned in the discussion of pH, alkalinity in Panhandle water is very highly correlated to pH. The various forms of carbonate found in the waters are by far the predominant pH buffering agent; sulfate and other buffering ions are substantially less common (Kaufman 1975a,b, Shampine 1975a).

Since the alkalinity of Panhandle waters is overwhelmingly a function of the carbonate concentrations, many studies (particularly of ground water) do not measure alkalinity as such, but rather record bicarbonate concentrations. In surface waters total alkalinity is more commonly measured because of the increased likelihood that they may contain additional buffering ions caused by surface drainage and input of human effluents. Alkalinity is not a water quality factor of importance in marine waters because, though high, it is constant.

**b. Hardness.** The hardness of water, like the alkalinity, is generally of concern in freshwater only. Hardness is a measure of the cation (positive ion) content of water. In the Panhandle the major freshwater cation is $Ca^{++}$, with $Mg^{++}$ a distant second. Since calcium carbonate (limestone) supplies most of the dissolved ions in surface and ground waters, total dissolved solids, alkalinity, and hardness are often highly correlated. The hardness of natural Panhandle waters can be reliably estimated from the total dissolved-solids values (Figure 44). Hardness is usually reported as equivalent concentrations of calcium carbonate (e.g., 120 mg/l as $CaCO_3$). High levels of hardness (> approximately 2,000 mg/l) are unpalatable but not generally harmful, except for a laxative effect in first time users (Shampine 1975c). One aspect of hardness that is of interest is its relationship to soap and detergent usage. Soap combines with and precipitates hardness ions until they are removed. Only then do lathering and cleansing occur. Harder water, therefore, requires use of more soap than does soft water. Hard water also increases the rate of lime formation within plumbing and heating equipment and, where high, may necessitate the use of chemical softening techniques to minimize maintenance.

**c. Salinity.** Salinity is the concentration of "salts" dissolved in water. This term is generally used to describe estuarine and marine waters, though very low concentrations of salts are present in freshwaters. Sodium ($Na^+$) and chloride ($Cl^-$) ions provide about 86% of the measured salinity; magnesium ($Mg^{++}$) and sulfate ($SO_4^=$) account for another 11%, with the remaining 3% consisting of various minor salts (Quinby-Hunt and Turekian 1983). Technically, the measurement of salinity has been defined based upon the chlorinity, or chloride

($Cl^-$) content of seawater. This was done because of the ease and accuracy with which $Cl^-$ concentrations can be measured, and because the proportions of all the different salts present in seawater are very constant. The total concentrations of these salts are approximately $10^3$ to $10^4$ times those found in freshwaters. As a result, the chemistry of the freshwater flowing into an estuary does not significantly affect the proportions of the salts in the estuarine waters.

Salinity is a factor in water quality since salinity tolerance can limit the species found in a given salinity regime. Additionally, sudden or large changes in salinity can be stressful or fatal to the biota. The salinity tolerances of aquatic biota separate them into three main groupings: freshwater (salinities below 0.5 ppt), estuarine (0.5 to 30 ppt), and marine (greater than 30 ppt) (Cowardin et al. 1979).

In general, the freshwater and marine species have narrow salinity tolerances while estuarine species are characterized by their tolerance to changing environmental conditions, including salinity. Estuaries, where fresh river waters mix with salt water, regularly present rapidly changing salinity conditions. As a result, this habitat has lower species diversity than do more stable ones, although this does not imply fewer individuals. Despite the harsh physical regime, abundant dissolved nutrients promote high primary productivity that can support a large number of individuals of tolerant species. Separation of populations based on salinity tolerance applies equally to coastal wetlands.

The salinity of Panhandle coastal and estuarine waters is extremely variable. These waters function as a mixing zone for freshwater runoff from surface and ground waters (0 ppt) and the offshore marine waters (35 ppt). In general, estuarine salinities range from 0 ppt throughout the estuary during high river stages, to 32–35 ppt within the estuary (but away from the river mouth) during periods of low river discharge. The coastal waters between the estuaries often receive some freshwater runoff during rainy periods; however, the salinity regime is much more stable than that of the estuaries, and diurnal salinity changes are minimal or nonexistent.

**d. Nutrients.** The nutrient content of water primarily affects water quality when high concentrations promote excessive growth of algae and higher plants. Too much eutrophication (i.e., nutrient enrichment) causes excessive plant growth and the resulting increased organic load depletes dissolved oxygen, rendering the water less suitable for species considered desirable to people. The primary limiting nutrients (i.e., those that, when lacking, commonly limit algal and plant growth) are nitrogen (as ammonia, nitrite, and nitrate), phosphate, and, for diatoms (which often constitute the majority of fresh and salt water phytoplankton), silica. There are many more required nutrients; however, their availability is normally such that they do not prevent growth. In addition to excessive plant and algal growth, high concentrations of nitrates in drinking water also cause a serious and occasionally fatal poisoning of infants called methemoglobinemia (Slack and Goolsby 1976, Phelps 1978a).

In a natural surface-water system, nitrogen as a nutrient is derived from organic debris that is carried by runoff from surrounding terrain and from aquatic species of nitrogen-fixing plants and bacteria, and is regenerated within the system through the decay of dead plants and animals. These sources are often augmented, sometimes heavily, by human effluent discharges. The most common of these are sewage treatment plants, septic tanks, and runoff from fertilized fields.

Phosphate and silica are derived, in an undisturbed system, from the weathering of continental rock. They are both recycled repeatedly through the cycle of death, decay, and subsequent uptake. Florida has extensive areas of phosphorus rich limestone matrix deposited during periods when the State was covered by shallow seas. The dissolution of this rock and its transport into both ground and surface waters provide a ready source of this nutrient in many Florida waters. The major anthropogenic contributors include municipal sewage treatment discharges (less of a problem since the mandatory reduction of phosphate concentrations in detergents), runoff from fertilized agricultural fields, and effluent from phosphate mining operations. There is little input of anthropogenic silica.

The limiting nutrients are not needed by algae and plants in equal proportions. While the proportions utilized vary widely between species and depend upon environmental conditions, an average ratio of N:P = 10:1 for higher plants and algae and N:P:Si = 15:1:50 for diatoms can be used.

### 4.2.5 Temperature

Temperature affects water quality by acting as a limiting factor if too high or too low for survival of a specific organism, and by influencing the rate of many biological and chemical processes including metabolism. In general, higher temperatures increase the rate of metabolic functions (including growth) and the speed of other chemical reactions. This tends to increase the toxicity and rate of metabolic uptake of toxicants (Cairns et al. 1975). Therefore, for those toxicants which are bioconcentrated (accumulated within the tissues), higher temperatures will result in higher concentrations in living organisms.

Depending upon the size of the water body and how well mixed it is, the water temperature may take minutes or weeks to adjust to the average air temperature. This lag time damps water temperature fluctuations relative to air temperature fluctuations and helps minimize the stress on aquatic lifeforms.

In addition to the seasonal fluctuations, there are often diurnal fluctuations, particularly where turbid or dark, tannic swamp waters are exposed to sunlight. When the angle of incidence is small, water, as well as many of its contents, absorbs solar energy very efficiently. Dark coloration improves the efficiency slightly, but restricts light penetration, and therefore heating of the water, to near the surface. As a result, surface water can become quite warm, while much cooler water may exist below a shallow thermocline. Freshwater surface temperatures vary depending upon season and the volume, depth, and location of the water body. Estuarine areas show the most complex and rapid variations in water temperatures. The dynamics of freshwater inflow temperatures, coastal marine water temperatures, density stratification, tide, and wind determine the proportions of fresh water and saltwater present at a site within an estuary and may expose the inhabitants to very rapid temperature fluctuations.

Locally, surface-water temperatures may be strongly influenced by ground-water input. Ground-water temperatures tend to remain very near the mean annual temperature of the above-ground climate. This is another example of temperature damping on a larger scale, the result of the slow rate at which the earth changes temperature. Where ground water flows into surface waters, the temperature of the water near the ground-water input will be relatively stable.

Temperature becomes a water quality problem when it is too cold or warm to support a normal ecosystem. Low-temperature kills are almost exclusively a natural product of winter cold spells and are of short duration and temporary effect. High temperatures, however, can become a long-term problem when large quantities of water used to cool power plants and other industrial operations are discharged into surface waters. It is not uncommon for thermal effects to be felt over a large area where substantial quantities of heated water are discharged.

### 4.2.6 Other Contents

This catchall grouping includes many parameters of great concern. Among these are: toxic substances such as ammonia, pesticides, and metals (e.g., lead, mercury); carcinogens (cancer-causing agents), mutagens (DNA-altering agents), and teratogens (agents causing abnormal growth or structure); and infectious agents (bacteria and viruses). Many substances fit within two or more of these categories.

Metals and many of the toxic compounds in water are often found in ionic forms. Most pesticides and toxic organic compounds, however, do not require ionization to be toxic. Many toxicants, ionic or not, interfere with normal metabolic processes by displacing critical metabolites and thereby blocking reactions necessary for the maintenance of life.

While many ions are not toxic (at least at the concentrations at which they are normally found), the ionic forms of many elements and compounds are generally more reactive than are the nonionic forms. Additionally, different ions of the same substance may vary in their toxicity. Generally, the higher the valence number (i.e., the number of charges on the ion), the more toxic the ion. As a rule, low pH increases ionization and, therefore, the toxicity of many substances.

The total concentration of the subject compound, along with other factors such as pH, temperature, ionic strength (i.e., the concentration of all ionic forms present), and the presence of natural (and anthropogenic) chelating agents such as tannins and lignins, combine to determine the concentrations at which the various ionic and nonionic forms of a compound will be found. Since the toxicity (if any) of that compound is affected by its exact form and availability for uptake, and since the mode of that uptake varies widely between species, predicting the toxicity of effluents being discharged to surface and ground waters is very difficult. The conditions found in the area of each discharge play an important role in determining the effect of an effluent on area ecology. This is further complicated by the long period after exposure which may elapse before the onset of symptoms, especially common in the carcinogens, teratogens, and mutagens. Since these conditions typically fluctuate, sometimes widely, during the year, it can be seen that predicting pollutant impacts can be very difficult.

## 4.3 Major Influences on Surface Water

### 4.3.1. Major Influences on Surface-Water Hydrology

**a. Natural factors affecting inland surface-water hydrology.** In drainage basins not subjected to major human alterations, such factors as climate, season, geology, and surface features control the hydrology. In the Florida Panhandle, climate and season combine to control precipitation, evaporation, and evapotranspiration rates, thereby determining the proportion of water contained in each step of the hydrologic cycle. The geology and topography control flow rates by determining surface porosity, slope, and erosion features. These flow rates are further modified by the presence and types of vegetation that impede runoff.

Flooding is one of the most striking hydrologic events. Panhandle rivers flood primarily during the frontal rainfalls of late winter and early spring (February–May ) (Palmer 1984) (Figure 45). While this difference is partially due to the winter rainy period, Figure 17 in the climate chapter shows that the total rainfall during the summer is much greater. The vast quantities of water evaporating from the warm surface waters and transpired from the lush foliage return most of summer rainfall to the atmosphere (Mather et al. 1973), thereby minimizing flood-inducing runoff. While the large Panhandle rivers show this relationship (Figure 46), they also show reduced flow during the summer rainy season because much of their drainage basins are sufficiently far inland that they receive little of the convection-induced summer rains. The reduced foliage present in winter and early spring allows a greater proportion of the rain falling during the winter rainy season of the northern regions to run off and may result in flooding.

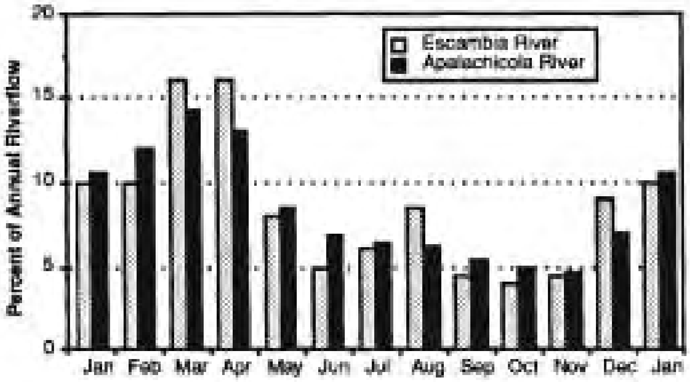


**Figure 45. Seasonal riverflow in two Florida Panhandle rivers (data from Livingston 1983, Palmer 1984).**

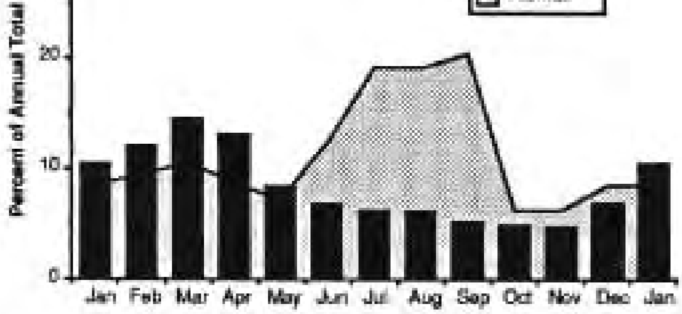


**Figure 46. Apalachicola River flow and rainfall at city of Apalachicola (data from Livingston 1983).**

Periodic floods are a necessary and important part of wetland energetics. Seasonal inundation of river flood plains and coastal marshes flushes organic matter produced by these wetlands into streams, rivers, and estuaries where it provides a substantial portion of the energy driving the food chain. The goal of minimizing property damage from flooding while maintaining high water quality in surface waters is best achieved by discouraging development in river flood plains and controlling construction of what development does take place to minimize damage to the resulting structures and to the flood plain (e.g., requiring that buildings be constructed on pilings above flood levels and that flood plain terrain and vegetation be maintained).

Maps delineating the 100-year flood plains in Florida were drawn by the U.S. Geological Survey and are currently distributed by the Florida Resources and Environmental Analysis Center (FREAC) at Florida State University. These maps are based upon the USGS topographic quadrant maps and have too much detail to present here. It is probable that, because of changes from continuing development and other factors, these maps underestimate the areas that would be inundated by 100-year floods.

Panhandle springs moderate the flow of those rivers and streams receiving their waters. The ground-water levels controlling the rates of spring flow and ground-water seepage tend to respond slowly to rainfall changes, thereby establishing a minimum streamflow ("base flow") when surface runoff is minimal. This moderating tendency is less noticeable during periods of high runoff and streamflow. However, many springs become siphons under these conditions and carry surface water directly to the aquifers (Ceryak et al. 1983), thereby reducing the peak streamflow somewhat. First and second magnitude springs (>30 $m^3/s$ and 3–30 $m^3/s$, respectively) (Figure 47) are most numerous in the

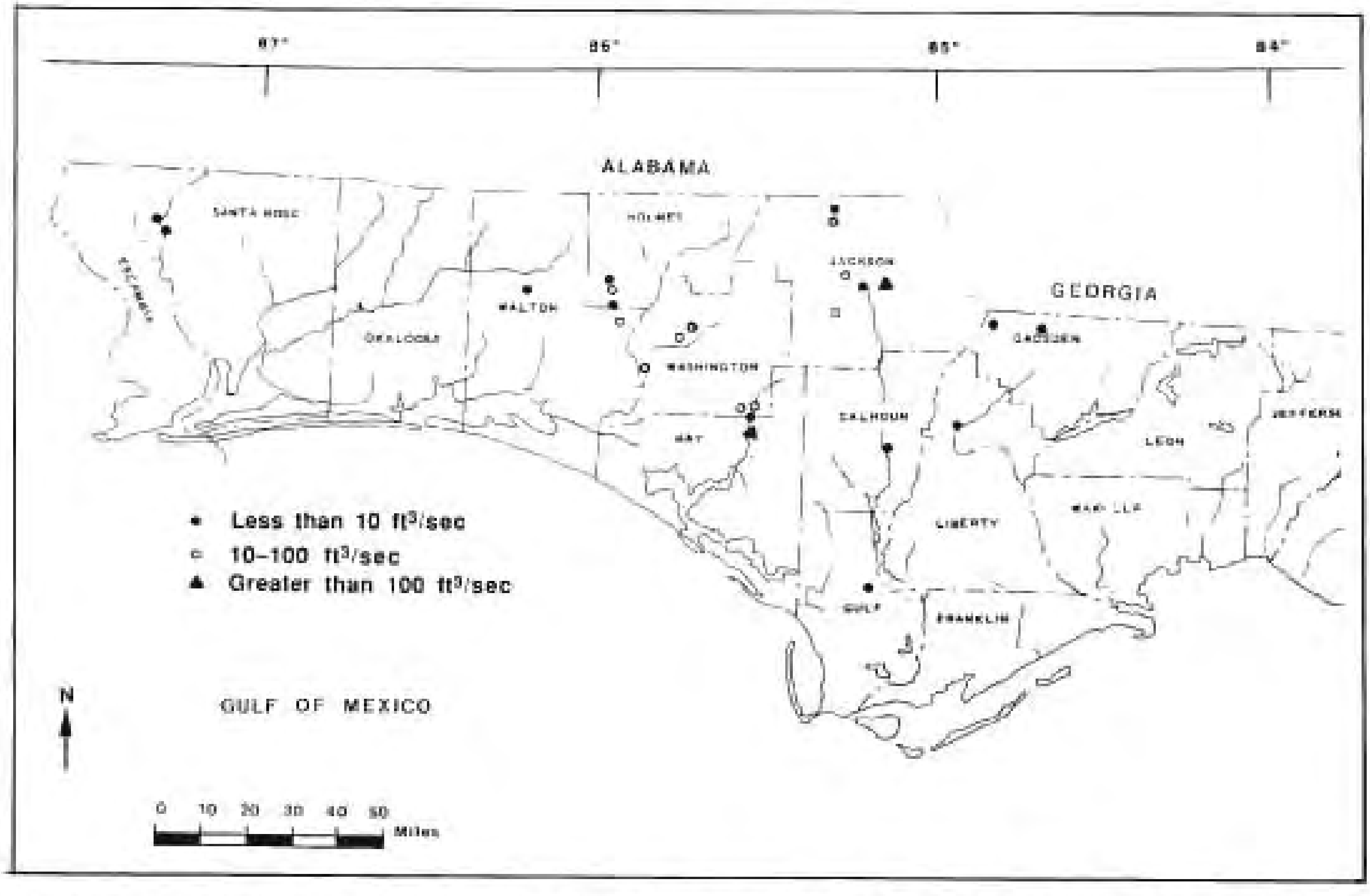


Figure 47. Locations and magnitudes of major Panhandle springs (after Rosenau and Faulkner 1975).

central Panhandle and are located primarily along the Choctawhatchee and upper Chipola Rivers and Econfina Creek. Third magnitude springs (<3 $m^3/s$) are less concentrated but are generally more common east of Walton County.

**b. Natural factors affecting coastal surface-water hydrology.** Coastal waters are affected by several forces that have little affect on the freshwaters inland. In shallow nearshore areas such as those common along the eastern Panhandle coast and in estuaries, wind is the major factor driving water circulation (Williams et al. 1977, Livingston 1983). This results in a net long-term movement of water west along the coast during the late spring, summer, and early fall and east along the coast during the winter months. Short-term currents are quite variable and depend primarily upon: (1) local wind direction, (2) tide-induced currents, (3) proximity to river mouths and the estuarine currents resulting from the density differences of the mixing fresh and salt water, and (4) the possible presence of eddies spun off of the Loop Current in the Gulf of Mexico.

(1) During much of the year, local wind direction is affected by the convective phenomenon driving the land breeze and sea breeze. Wind strength and direction and the resulting force exerted on the surface waters often changes over short periods of time. Chapter 3 contains more information on seasonal changes in wind strength and direction.

(2) The Panhandle coast experiences unequal semidiurnal tides; i.e., two high and two low tides daily, each of different magnitude. This pattern is the result of a complex combination of forces, the gravitational pull of the Moon and the Sun being the primary ones. The period of the tides is such that they are approximately one hour later each day. The net tide-induced current is weakly west along the coast (Battisti and Clark 1982). Of more importance to the nearshore hydrology and water quality, the (normally) four times daily change of direction of this movement of water induces substantial mixing of the nearshore and offshore waters.

(3) A number of current-producing and -affecting forces are in action at the mouths of rivers. Among them are (a) the friction of the river flow upon the salt water it enters, (b) salt-wedge circulation, and (c) geostrophic forces. The friction of the flow exiting the river mouth attempts to "drag" adjacent salt water along with the body of river water, inducing eddies along the transition zone between the two water masses. A salt wedge forms because fresh water flowing out of the rivers is less dense than the salt water into which it flows; thus the fresh water tends to form a layer flowing over the top of the denser salt water (Figure 48a). This underlying layer of salt water is called a salt wedge, and since the upstream end of this wedge has a lower salinity (is less dense) from mixing with the overlying river water, pressure from the denser salt water behind it forces the wedge upstream. In shallow, so-called well-mixed estuaries (the type found along the Panhandle coast), turbulence and other mixing forces tend to minimize the distance over which these two water masses remain unmixed. However, the mechanism is still functioning and an important part of estuarine hydrology. As the saltwater mixes with the overlying fresh water at their interface, the brackish water formed is less dense than the salt water and is caught up in the outward flow of fresh water and carried out toward the gulf. This loss of saltwater from the wedge induces a flow of saltwater from the gulf to replace it. Thus the estuary experiences a net outflow in the surface waters, and a net inflow in the bottom waters. This inflow can be several times the volume of the riverflow before it enters the estuary (Knauss 1978). What are perceived as small changes in river flow can result in large changes in estuarine and nearshore circulation.

Others factors in estuarine circulation are those caused by Coriolis and geostrophic forces. The Coriolis "force" in the northern hemisphere is felt as a force directed to the right of the direction of water flow. The result of this force, when applied to an estuary exhibiting stratified salinity, is that inflowing fresh surface water tends to collect on the right side (relative to the direction of flow) of the estuary (Figure 48b). In the Panhandle, the resulting thicker layer of fresh water is then forced west along the coast by geostrophic forces caused by the pressure from the denser, more saline waters to the south or east. These two forces, in the absence of strong coastal currents, cause the outflow of rivers in the Panhandle to tend to curve to the right once they reach

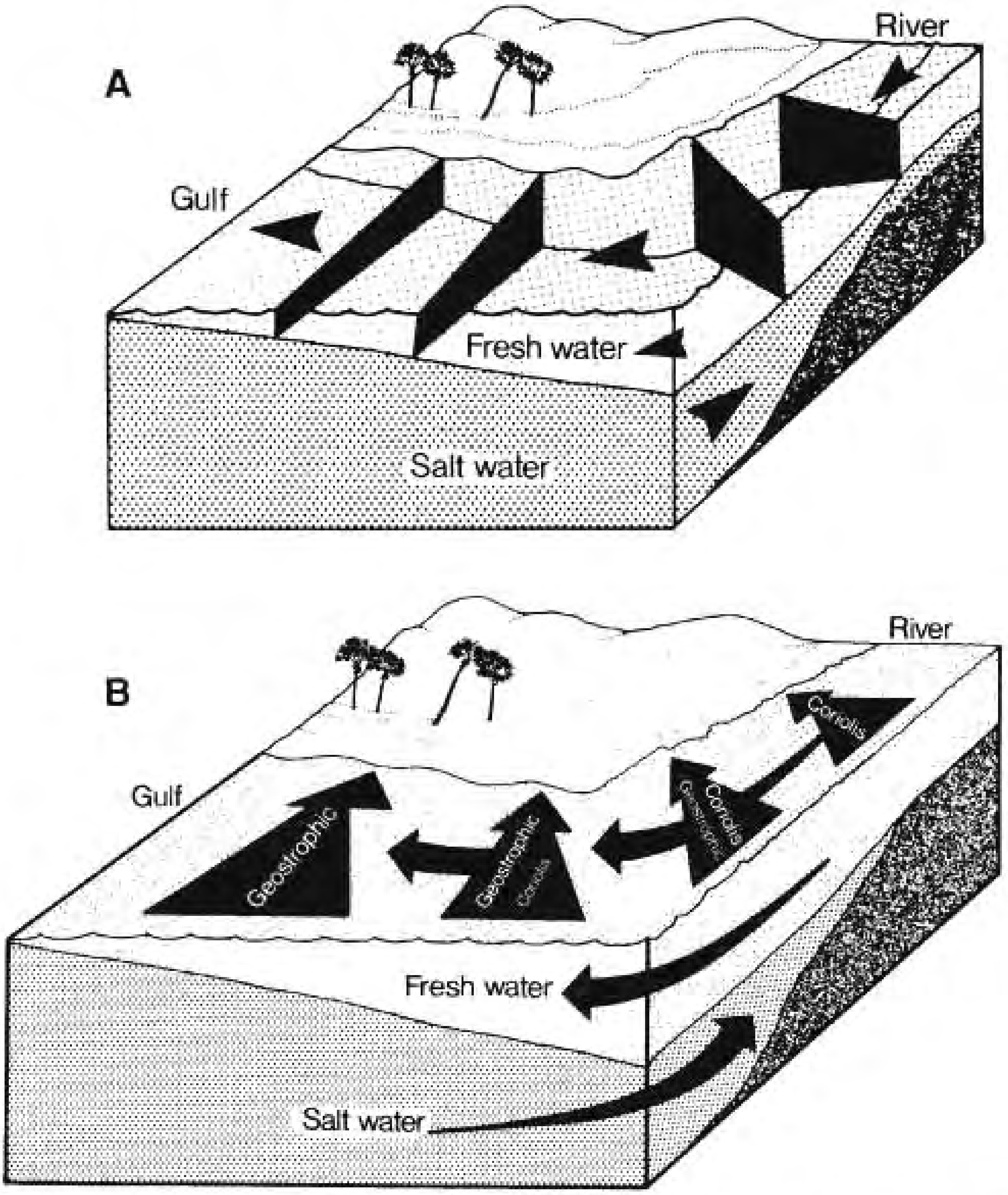


Figure 48. (A) Formation of a salt wedge and "stacking" of freshwater layer to right of flow direction at river mouths. (B) Coriolis and geostrophic forces affecting fresh water flowing from river mouths.

the ocean (Knauss 1978). Once free of the river banks, these forces will tend to keep the surface layer of freshwater "pinned" to the coast and force it west along the coast until mixing destroys the stratification. The magnitude of the effect of these forces on coastal and estuarine circulation depends strongly on the presence or absence of mixing forces at the time, thus they are continually in a state of flux.

A final influence on coastal hydrology is wave mixing and erosion. Wave motion does not result in significant lateral movement of water; however, vertical mixing takes place to a depth approximately twice the wave height. In shallow areas such as the eastern Panhandle nearshore region, large storm-induced waves caused the waters to be well mixed top to bottom. During periods of wave heights greater than approximately 1 m, therefore, the eastern Panhandle coastal waters would be expected to exhibit very little temperature or salinity stratification.

**c. Anthropogenic factors affecting inland surface-water hydrology.** Development often substantially alters surface drainage. In the Panhandle these alterations include river damming, streamflow diversion, river channelization, dredge-and-fill activities, "terraforming," increasing runoff (e.g., stormwater drainage), wetland draining, floodplain development, and extensive landclearing activities. The most common results of these alterations are increased magnitude and duration of flooding and the decreased water quality of runoff. Undeveloped uplands in drainage basins act as a buffer to runoff, absorbing the initial rainfall and impeding the rate at which excess water runs off. Developed lands generally have a much reduced ability to absorb rainfall due to the reduced amount of absorptive "litter," reduced permeability of the land surface, and reduced evapotranspiration due to lower foliage densities. In addition, most development includes measures such as regrading of the terrain and installation of drainage ditches and culverts, all aimed at speeding the rate of runoff. As a result, the streamflow in developed basins following periods of rainfall tend to peak rapidly and at a much higher level than it does in undeveloped basins. This is caused by a greater total volume of water draining into the stream or river over a shorter total period of time. This problem is further exacerbated by the tendency of developed drainage basins to restrict the area through which the stream or river flows during high water conditions. This area, the floodplain, is the width of river channel required to carry the runoff during periods of heavy rainfall in the basin. After this floodplain is developed, which commonly includes reducing its width by dumping fill along its borders, the increased runoff resulting from the development must now flow through a more restricted channel. As a result the height of flooding is increased even more. The increased rate of runoff in developed basins also increases erosion, which further reduces landcover and retention of rainwater.

**d. Anthropogenic factors affecting coastal surface-water hydrology.** Human alteration of freshwater input can also alter coastal estuarine systems. Diversion of surface waters to different drainage basins and alteration of the dynamics of the hydrologic cycle by anthropogenic activities (e.g., consumptive water use) can cause profound changes in patterns of freshwater flow to estuaries and coastal marshes, with potentially devastating results. It has been previously described how river outflow induces circulation and mixing in water masses many times greater than the volume of water discharged. Thus the size of an estuary is controlled by the volume of fresh water inflow, but any decrease of inflow causes a much larger decrease in the volume of the estuary. If average flow into an estuary decreases, then decreases in estuarine productivity disproportionate to the volume of fresh water diverted can be expected.

### 4.3.2 Major Influences on Surface-water Quality

**a. Natural factors affecting inland surface-water quality.** The major natural influence governing surface water quality is the progression of the seasons. Surface waters are commonly composed of some mixture of excess rainwater drained from surrounding lands, flow from the Surficial Aquifer, and artesian flow from the Floridan Aquifer. Seasonal factors which affect surface water quality include rainfall, air temperature, and nutrient sources.

"Normal" rainwater is slightly acidic with a very low concentration of dissolved minerals (i.e., soft water). The water is poorly buffered and the pH is easily changed by the materials it contacts. During the rainy seasons, surface streams, rivers, and lakes are composed primarily of rainfall runoff, with ground water constituting a relatively small proportion. The rainwater picks up tannic and other organic acids through contact with organic debris during runoff, particularly that encountered during the relatively long periods of retention provided by swamps and marshes. This swamp runoff is acidic (pH 4–5) and highly colored, with a relatively low DO and a very low concentration of dissolved minerals.

During periods of low rainfall, ground water makes up an increased proportion of most surface waters. Since ground waters are frequently highly filtered and have spent time in contact with the minerals composing the aquifer matrix (primarily limestone), they are generally colorless, moderately alkaline, and contain moderate to high levels of dissolved minerals. Since surface runoff often has weak organic acids acting as buffers, the pH of surface water mixed with a small amount of ground water can change radically. As a result of these factors, surface water chemistry (especially pH) tends to reflect seasonal rainfall patterns.

In addition to the direct correlation between air temperature and water temperature, air temperature has many indirect influences on surface water. As discussed previously, ambient temperatures affect chemical reaction rates and equilibria reactions in water. As a result, rates of bioconcentration of toxics are higher in warmer water, as are rates of nutrient production and utilization. Another factor influenced by air temperature is plant growth.

Seasonal change in ambient temperature is one of the primary factors controlling plant and often animal growth and reproduction, both in the drainage basin and within water bodies. The growth and death of biota are major factors in nutrient cycling and in the levels of dissolved nutrients found in surface waters. Nutrient levels tend to decrease during periods of maximal population growth and increase during periods when deaths (and therefore nutrient regeneration) exceed reproduction and growth.

Surface runoff leaches nutrients from upland litter, which are then carried to downstream water bodies. Additionally, some of the litter is carried into the water, where it settles to the bottom and decays, providing shelter and food for detrital feeders as well as nutrients for primary production.

**b. Natural factors affecting coastal surface-water quality.** The water quality of nearshore waters is subject to many of the same climate induced changes that affect inland waters; however, by virtue of their volume, the coastal waters are more resistant to change. Nearshore water quality is primarily determined by the mixing dynamics resulting from the previously discussed hydrologic factors. These factors control the mixing of the fresh water draining off the land and the marine waters offshore. One relatively common event which is harmful to the ecology occurs when conditions encourage plankton blooms. The exact causes triggering these blooms are not fully understood; however, the dense blooms introduce metabolic byproducts that are toxic to many species and can produce fish kills. The BOD from these kills, along with the enormous respiratory oxygen demand of the plankton at night and during overcast periods, can result in low levels of dissolved oxygen, increasing the kill. These problems are worst in constricted waters near shore.

**c. Anthropogenic factors affecting inland surface-water quality.** Until recently, point-source pollutant discharges have been the major human-induced cause of water quality changes. In the Panhandle, much of which is relatively undeveloped, private and municipal sewage and discharges are the most common point-source effluents. Industrial activity is generally found in the western portions of the area. These sources, fewer in number but which may have substantial local impact, include discharges from powerplants, chemical factories, paper mills, and mining operations. Discharges from powerplants are primarily in the form of thermal effluents, i.e., water that has been used to cool the generators.

Nonpoint-source pollution is considered by the FDER to be a major, but largely uncontrolled, cause of surface water degradation. It is estimated from studies that nonpoint sources contribute 450 times more suspended solids, 9 times more oxygen-depleting materials, and 3.5 times more nitrogen than point sources (FDER 1986c). The major nonpoint-source pollutants in Panhandle rivers are pesticides, animal wastes, nutrients, and sediments. The major causes of nonpoint-source pollution in southeastern U.S. river basins are agriculture (affecting 62% of basins) and urban stormwater runoff (affecting 57% of basins), with silviculture (tree farming), landfills, and septic tanks affecting 33% of the basins (U.S. EPA 1977). Nonpoint-source pollution is expanding and has the potential to nullify water-quality gains being made through the reduction of point-source emissions.

**d. Anthropogenic factors affecting coastal surface-water quality.** The primary impact of human activities on coastal water quality results from the restriction of water circulation in dredged or otherwise altered areas. This may result in high temperatures, low DO, and salinity alterations. One of the greatest effects of human activities results from salinity alterations caused by the changes in hydrology previously described in 4.3.1(d). The factors affecting inland surface-water quality may affect local coastal water quality, particularly in the estuaries.

## 4.4 Major Influences on Ground Water

### 4.4.1 Major Influences on Ground-water Hydrology

**a. Natural factors affecting ground-water hydrology.** In the absence of cultural impacts, ground-water levels are a function of rainfall. Ground-water levels respond to area-wide rainfall with a lag time of up to several weeks (Ceryak 1981). Since substantial lateral transport is possible, levels tend to follow fluctuations in rainfall averaged over substantial areas (up to thousands of square kilometers). Ground water movement is from areas of high to those of low potentiometric surface (Figure 39).

Recharge of the Floridan Aquifer from rains and infiltration of surface water depends on the permeability and thickness of the overlying strata and, where there is a surficial aquifer, depends upon the difference in head pressure between this overlying aquifer and the Floridan Aquifer as well as on the permeability of the confining layer separating them. During periods when the Floridan Aquifer's potentiometric surface is locally low, rains may cause the Surficial Aquifer's pressure to be greater than that of the Floridan, with subsequent downward percolation to the Floridan. At other times, however, the potentiometric surface of the Floridan may be greater than that of the Surficial Aquifer and no recharge to the Floridan takes place. In this situation, water from the Floridan Aquifer may seep upward into the Surficial Aquifer. In instances where the Floridan Aquifer is confined and its potentiometric surface is above the land surface or above the level of overlying surface water, springs and seeps may flow from the aquifer and find their way into surface waters. High surface water levels (i.e., floods) and/or low ground-water levels may convert the springs into siphons, thereby draining surface waters directly into the aquifer (Ceryak et al. 1983) (Figure 49). This is common for the springs along many rivers and, in the instances of springs flowing through large underground passages, may allow substantial volumes of surface water to mix with ground waters, increasing the opportunity for large-scale contamination of ground waters with surface pollutants.

**b. Anthropogenic factors affecting ground-water hydrology.** Ground-water levels are affected, often extensively, by human activities. Four major impacts presently exist in the Panhandle: (1) ground water withdrawal; (2) drainage wells; (3) pressure injection wells; and (4) surface hydrology alterations.

(1) Ground water withdrawal tends to lower the potentiometric surface in the immediate vicinity of a well. As a result, ground water tends to flow laterally toward the pumped well to fill the potentiometric "hole," or cone of depression. The rate of this flow depends upon the local permeability of the aquifer and the pressure gradient between the well and the surrounding aquifer. Another factor affected by ground-water pumping is the depth to the saline layer underlying the fresh-water aquifers. Especially near the coast, excessive pumping of ground water results in saline intrusion into the potable aquifer. Because the density difference between the fresh-water aquifers and the deeper saline ground waters is minimal, the permanent lowering by 1 ft of the upper surface of the Floridan fresh water indicates that approximately 40 ft of of the fresh water was removed and that the upper surface of the underlying saline aquifer rose nearly 40 ft.

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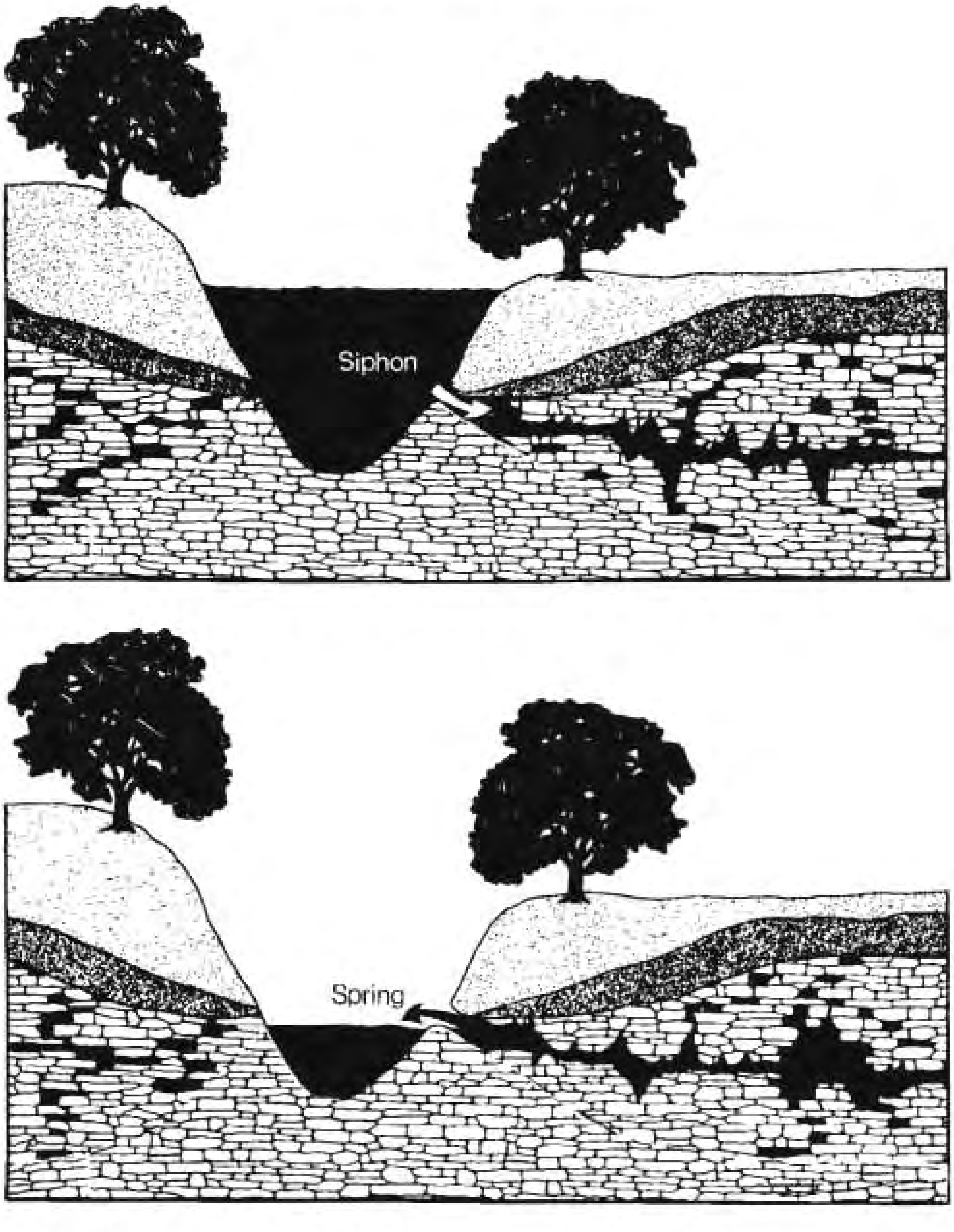

Figure 49. Generalized relationship of surface water to ground water for springs and siphons.

(2) Drainage wells have been used extensively in some areas to drain perennially-wet or flood-prone areas. These wells are drilled into an aquifer and the boreholes left open. "Excess" surface drainage is then directed to the holes. It is also common, in suitable areas, that sink holes connecting to ground water are used in place of drilled wells. The use of drainage wells has decreased markedly because of concerns about the poor quality of water draining into the aquifers. Attempts by the water management districts to locate these wells to help in water management planning have been hindered by the age of many of them and by poor records of their existence. At the time of this writing the USGS is preparing a map of known drainage wells (Kimrey, in prep). It is unlikely that most of the drainage wells in the Panhandle and in the State will be located.

(3) Pressure injection wells are used in various locations throughout the State as a means of wastewater and storm-water disposal. These techniques, when used with storm water and with appropriate caution towards their potential for ground-water contamination, may help recharge the aquifer with water that would otherwise evaporate or run off. Pressure injection wells are of two primary types, those injecting into the fresh-water aquifers and those injecting into the saline-water aquifers. Injection into many potable water zones yields little increase in storage since the artesian aquifers are already full, so this type of injection well is little used.

Liquid wastes are being injected into saline waters in the deeper zones of the Floridan Aquifer as a storage and disposal method. There is evidence that this use is expanding, especially in storing or disposing of secondarily treated sewage effluent (Hickey 1984). The USGS has mapped the general locations of deep saline aquifers that might be suitable for liquid waste disposal (Miller 1979). Waste water is also injected into nonpotable areas of saline intrusion to create a back pressure and slow further intrusion (Stewart 1980). Because of concern over the long-term effects of this practice, the USGS is involved in extensive investigations into this practice (e.g., Kaufman 1973; Pascale 1976; Pascale and Martin 1978; Ehrlich et al. 1979; Hull and Martin 1982; Vecchioli et al., in press; Merritt, in press) and chemical changes in the wastes following injection. Temporary storage of freshwater (storm water) in saline aquifers is being evaluated by the USGS in south Florida.

(4) The surface hydrology of aquifer recharge areas serves to channel water to or away from recharge areas (Figure 40). Recharge through sinkholes and other breaches of the confining layer, and by percolation through porous soils can be easily altered by human activities. Wetlands may serve to hold water over areas of low porosity, thereby increasing the amount of water percolating to the aquifer. Diversion of surface drainage to, or away from, sinkholes and wetlands, as well as speeding surface drainage away from recharge areas as a flood prevention measure, affects the amount and quality of water recharging the aquifer. Development activities, especially in recharge areas, must be performed carefully to ensure protection of ground-water supplies.

### 4.4.2 Major Influences on Ground-water Quality

**a. Natural factors affecting ground-water quality.** Many areas in the Panhandle function as recharge areas for the Floridan Aquifer (Figure 40), and the Floridan Aquifer, being unconfined in much of the Panhandle, is recharged throughout most of the area where it exists. There is often a general perception that surface water contacts ground water only after it has very slowly percolated through purifying layers of soil and rock. In Florida, including the Panhandle, this perception is generally incorrect. In many ground-water recharge areas, the surface bodies of water and surface runoff are directly connected to the ground water by channels through the intervening rock. Below the surface of the land, Florida is largely a sponge of karstic limestone penetrated by innumerable solution channels and sand beds. Though these porous layers of limestone are often separated by confining layers of clay and rock, their connections to the surface and to surface waters is evident in the numerous springs and sinkholes which dot Florida's landscape. Many sinkholes act as drainage gutters, providing direct contact between contaminated or uncontaminated surface runoff and the ground-water aquifers. The Sand and Gravel aquifer is just a layer of fine-to-coarse quartz sand sometimes mixed with small quartz or chert gravel (Hyde 1975) lying on top of a confining layer and exposed at the ground's surface.

Percolation of surface waters into this aquifer is fast and relatively unobstructed.

Ground water from the Floridan Aquifer is characterized by high pH, alkalinity, and hardness. This results from contact with the limestone within which the Floridan is found. Water from the Sand and Gravel Aquifer is acidic and has low concentrations of dissolved solids. The normal ground water characteristics in the shallower aquifers are affected by surface water hydrology. During periods of high surface water, substantial quantities of often dark, acidic swamp runoff find their way into and mix with (or replace) the ground water, rendering the quality of water from shallow wells similar to that of the surface waters.

**b. Anthropogenic factors affecting ground-water quality.** Anthropogenic effects on ground-water quality takes three forms: (1) contamination via surface waters and leaching of surface contaminants; (2) contamination via direct means, i.e., drainage wells and injection wells; and (3) increasing intrusion of saline waters into potable aquifers through excessive pumping of ground waters.

(1) The Surficial Aquifer, the Sand and Gravel Aquifer, and the Floridan where it is unconfined (not covered by a stratum of low permeability) are often at or near the surface and are by their proximity easily contaminated. Even where beds of low permeability overlie the aquifer (Figure 50), surface contaminants are relatively easily introduced. The terms "confining beds" and "low permeability" were drafted by hydrologists describing the movement of ground water. For purposes of water consumption, an overlying or surrounding stratum of low permeability may slow local ground-water recharge sufficiently to prevent large withdrawals of water from an area. Percolation rates measured in inches per day are very slow in terms of aquifer recharge, but all too fast in terms of movement of contaminants toward potable aquifers.

(2) Drainage wells have been in use for some time, sometimes for the disposal of sewage and other effluents, usually for the disposal of unwanted surface water. Concerns have been raised over the possible health effects of such activities, and their use is being actively discouraged. Injection wells are relatively new and, as is discussed in 4.4.1(b), their effects are being studied intensively by the USGS and they are heavily regulated by the U.S. Environmental Protection Agency (EPA) and the FDER.

(3) Salt water intrusion is becoming an increasing problem, especially in coastal areas. Withdrawal of excessive volumes of ground water increases intrusion of saline waters, as discussed in 4.4.1(b). One aspect of this that is often overlooked is that intrusion of saline waters into the shallow ground waters along the coasts (where the potable aquifers are thinnest) can change the makeup of overlying vegetation by killing species that are not salt tolerant.

## 4.5 Area-wide Surface-water Hydrology and Water Quality

The seven major Panhandle coastal rivers originate in Georgia or Alabama. Changing land use in these States, as well as in the Panhandle, is directly affecting the rivers' hydrology and water quality (FDER 1986c). There has been some successful cooperation among the States in investigating the interstate drainage basins (e.g., U.S. Dept. of Agriculture 1977), but less in instituting interstate corrections to problems.

Table 3 gives major drainage basin and water-body sizes as well as streamflows for Panhandle lakes and rivers. Foose (1980) gives drainage basin, river, and lake areas for Florida including the Panhandle. His later work (Foose 1983) includes further statistics concerning flow characteristics of Florida rivers. The Northwest Florida Water Management District (NWFWMD) has published reports on the flood damage potential of the district (NWFWMD 1977); on the availability of water for industrial uses within the district (NWFWMD 1980a); on the availability of water resources in the peninsula area of southern Santa Rosa County (NWFWMD 1979b) and southern Okaloosa and Walton Counties (Barr et al. 1981); summarizing available rainfall data for the Panhandle (Kennedy 1982); and an exhaustive statistical summary and inventory of Panhandle lakes and streams which should answer most questions concerning hydrologic regimes and the frequency with which a given hydrologic condition occurs (Maristany et al. 1984).

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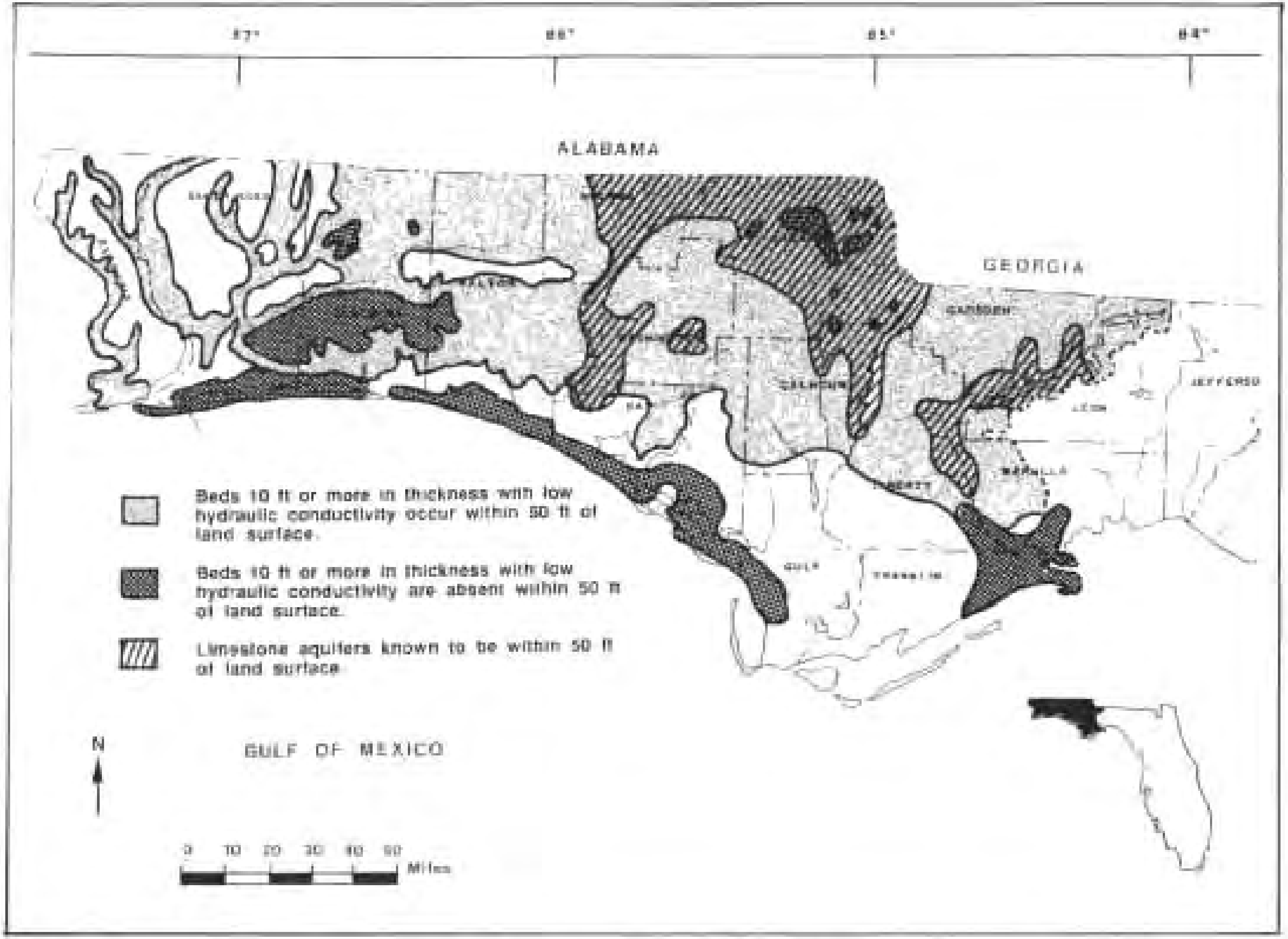

Figure 50. Location of limestone aquifers known to be within 50 ft of land surface and of surficial beds of low water permeability (after Healy and Hunn 1984).

### Table 3. Drainage basin statistics for Florida Panhandle.

| Basins | Main tributaries | Length (km) | Drainage area (km²) | % of basin by state Fl | Al | Ga | Discharge gauging site and distance above mouth (km) | Mean annual discharge (m³/s) | Mean annual Runoff (cm) |
|---|---|---|---|---|---|---|---|---|---|
| Ochlockonee River | Telogia Creek (FL)<br>Sopchoppy R. (FL)<br>Crooked R. (FL) | 331 | 5,830 | 48 | 0 | 52 | Bloxham (105) | 51 | 36.47 |
| Coastal Area between Ochlockonee and Apalachicola Rivers | New R. (FL)<br>Crooked R. (FL) | — | 1,440 | 100 | 0 | 0 | — | — | — |
| Apalachicola River | Flint R.(GA)<br>Chattahoochee R.(AL,GA)<br>Chipola R. (FL)<br>Jackson R. (FL) | 843 | 50,765 | 13 | 14 | 73 | Blountstown (126) | 701 | 48.54 |
| Chipola River | Dry Creek (FL) | 115 | 3,205 | 82 | 18 | 0 | Altha (87) | 42 | 65.99 |
| St. Andrew Bay Coastal Area | Wetappo Creek (FL)<br>Sandy Creek (FL)<br>Bear Creek (FL)<br>Econfina Creek (FL)<br>Big Cedar Creek (FL) | — | 3,500 | 100 | 0 | 0 | — | — | — |
| Choctawhatchee River | Pea R. (AL)<br>Wrights Creek (AL,FL)<br>Sandy Creek (FL)<br>Holmes Creek (AL,FL)<br>Pine Log Creek (FL) | 370 | 12,033 | 31 | 69 | 0 | Bruce (34) | 204 | 56.62 |
| Choctawhatchee Bay Coastal Area | Lafayette Creek (FL)<br>Alaqua Creek (FL)<br>Rocky Creek (FL)<br>Turkey Creek (FL) | — | 1,190 | 100 | 0 | 0 | — | — | — |
| Yellow River | Shoal R.(FL) | 177 | 3,540 | 63 | 37 | 0 | Milligan (64) | 33 | 65.23 |
| Blackwater River | Panther Creek (FL)<br>Big Juniper Creek (FL)<br>Big Coldwater Creek (FL)<br>Pond Creek (FL) | 100 | 2,230 | 81 | 19 | 0 | Baker (56) | 10 | 67.56 |
| Escambia River | Murder R. (AL)<br>Conecuh R. (AL)<br>Canoe Creek (FL)<br>Pine Barren Creek (FL) | 386 | 10,960 | 10 | 90 | 0 | Century (84) | 178 | 56.97 |
| Escambia Bay Coastal Area | East Bay River (FL) | — | 1,410 | 100 | 0 | 0 | — | — | — |

The FDNR formulated a beach protection and preservation plan which also addresses hurricane protection (Henningsen and Salmon 1981). Panhandle water resources are discussed in a report by the U.S. Army Corps of Engineers (1978).

In the Florida Panhandle, pH is almost entirely controlled by the water's carbonate concentration (Kaufman 1975a). Almost all bodies of surface water have a maximum pH of 6–6.5. The minimum pH levels, however, vary substantially, ranging from 4–5 to over 7 (Figure 43). Most natural waters with a minimum pH of 4–5 are upstream of alkaline groundwater input, drain noncarbonate lands, and/or receive drainage from swamps (especially during periods of high flow). Natural waters of low pH tend to be characterized by low alkalinity (buffering capacity), low conductivity, low calcium concentrations (soft water), and some iron content. In the eastern portion of the Panhandle, they also have a greater tendency to be highly colored. Additionally, they tend to be corrosive and unstable, exhibiting wide, rapid fluctuations in pH. The pH of most Panhandle surface waters varies with rainfall and ground-water levels. Periods of heavy rainfall correlate with generally lower pH levels while periods of drought allow a higher proportion of ground water to increase the pH of most surface waters. Research into the possible existence of acid rain effects in the State suggest that rainfall in some parts of the State may be more acidic than could be expected because of powerplant and other emissions, but effects on the ecosystem have not yet been identified. The Panhandle and north-central Florida have the most acidic rainfall in the state, the pH averaging below 4.65 (Environmental Science and Engineering, Inc. 1984). The Panhandle stations tend to have a slightly higher pH than did those to the east.

Surface water temperatures across the Panhandle tend to follow seasonal patterns reflecting the air temperatures (Figure 51). The changes in water temperatures lag changes in air temperature. Freshwater surface temperatures in the Panhandle may vary from freezing in the winter to near 40 °C in the summer, depending upon the volume, depth, and location of the water body. Nearshore marine surface temperatures generally reach minimum

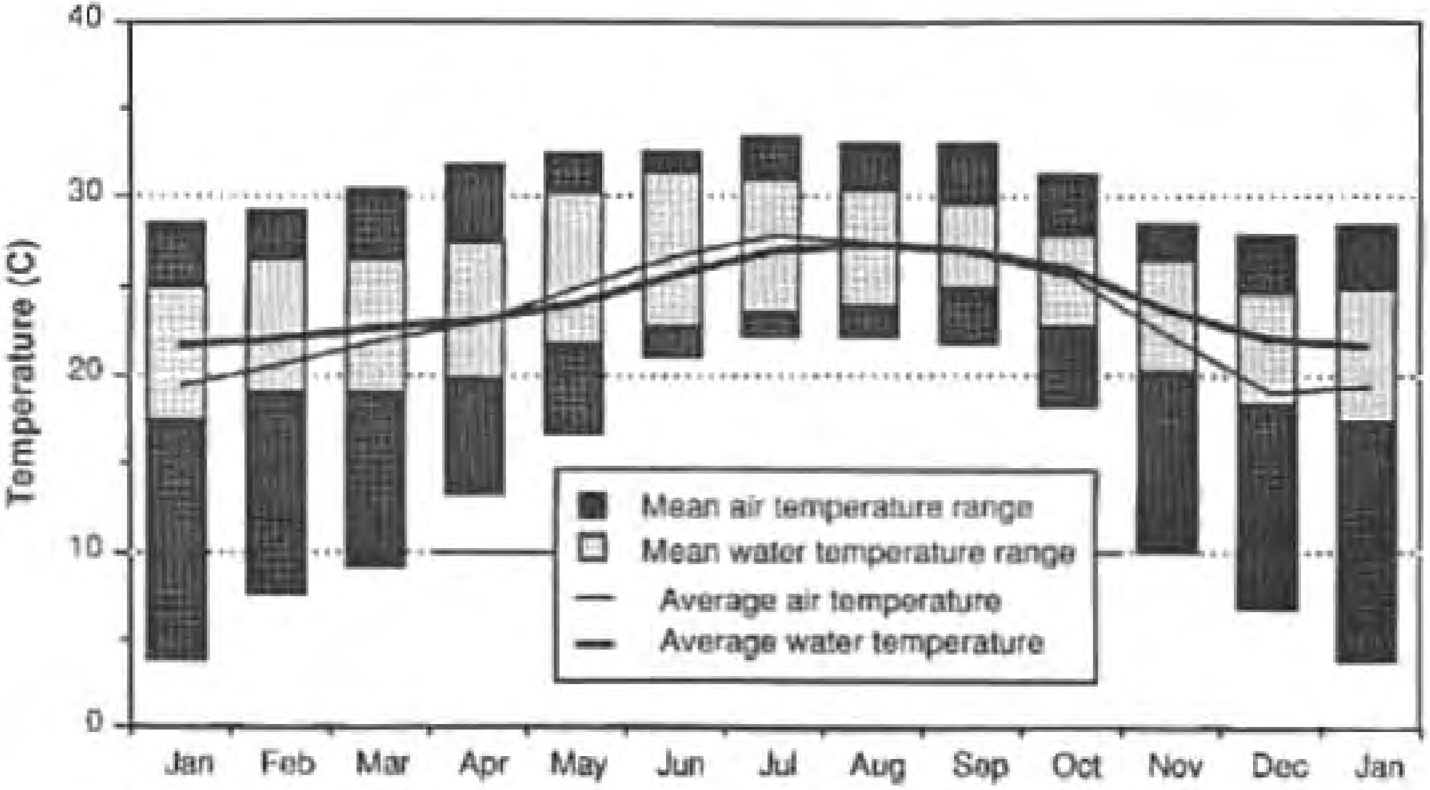

**Figure 51. Seasonal fluctuations in air temperature at Tallahassee and Sanford Fire Tower and in water temperature of Sopchoppy River, June 1964 to September 1968 (after Anderson 1975).**

temperatures near 10 °C in winter and maximum temperatures near 30 °C in summer. Shallow sheltered embayments and other areas with minimal mixing with offshore waters may, however, have greater temperature ranges than these.

The FDER ranked Florida lakes, based primarily upon their trophic state, in an effort to objectively determine those most in need of restoration and those most in need of preservation (Myers and Edmiston 1983). This ranking was based largely upon a report by the University of Florida, Department of Environmental Engineering Sciences (1983). Results pertaining to the Panhandle drainage basins are included in the following sections; however, since this ranking was performed on lakes where prior studies provided sufficient data, and since public interest was a factor weighed in assigning rank, it is not a definitive statement of the relative conditions of all lakes in Florida.

## 4.6 Area-wide Ground-water Hydrology and Water Quality

Ground water within the Florida Panhandle is influenced by the hydrology and water quality of the overlying surface water; however, the flow of ground water is little affected by the flow constraints of the overlying drainage basins. As a result the discussion of some aspect of ground water often includes factors from more than one drainage basin. Although ground water is discussed in the following drainage basin sections, each discussion is largely restricted to the effects of the surface waters in that particular basin upon the ground water. Studies looking at the aquifers on a larger scale and across more than one drainage basin are covered in this section.

The Floridan Aquifer contains most of the nonsaline ground water in the eastern portion of the Panhandle and is the primary potable water source in this area. Beginning in Okaloosa County and continuing westward, the Floridan is located deeper and its water becomes highly mineralized; therefore the Sand and Gravel Aquifer is more commonly used in these areas (Figure 37). The approximate thickness of the potable-water zone in the Floridan is shown in a USGS map (Causey and Leve 1976). Parts of Bay County use Deer Point Lake as a water source since the Floridan in that area has relatively low transmissibility and does not support large well fields (U.S. Army Corps of Engineers 1980a).

The Surficial Aquifer consists of a porous, sandy surface layer recharged locally and is separated from the underlying Floridan Aquifer by a clay-containing layer of low permeability—a confining layer or aquitard. The Surficial Aquifer varies in thickness and, where the underlying Floridan or the confining layer are at the surface, may not exist at all. To the west the Surficial Aquifer thickens and deepens and becomes the Sand and Gravel Aquifer (Figure 38). Additional small but usable quantities of water exist in some areas within the clay and sandy-clay confining layer separating the aquifers; however, except in rural areas with small requirements, these are little used because of the larger volumes available in the major aquifers. Because of the occurrence of this ground water within the confining layer, it is sometimes called the Intermediate Aquifer. Its primary action, however, is to restrict the movement between the Surficial or Sand and Gravel Aquifers and the underlying Floridan Aquifer.

The average temperature of the top 25 m of ground water in the Panhandle range is approximately 21 °C, varying about 4 °C throughout the year (Heath 1983). The shallow aquifers vary more than the deeper ones.

The USGS has conducted numerous investigations of the water resources of the Panhandle (Table 4). These include an examination of ground-water levels and water quality along the coast from Walton to Escambia Counties (Barraclough and Marsh 1962) and a later more detailed look at the water resources of Walton County (Pascale 1974). Both the Sand and Gravel Aquifer and the Floridan Aquifer are important in this county, with the Sand and Gravel storing water for stream baseflow and recharging the underlying Floridan. The Sand and Gravel is also used as a rural water supply. The Floridan is the primary water supply in the county. Transmissivity within the aquifer is highly variable. The Floridan is exposed in Alabama north of the Walton County where it is recharged by rainfall. Ground water within the Floridan moves south, discharging by springs and seeps along the Choctawhatchee River and by leakage to Choctawhatchee Bay and the gulf.

## Table 4. U.S. Geological Survey Maps for the Florida Panhandle

### Surface-water Hydrology

1. Runoff from hydrologic units in Florida (Hughes undated).
2. Runoff in Florida (Kenner 1966).
3. Annual and seasonal rainfall in Florida (Hughes et al. 1971).
4. Surface water features of Florida (Snell and Kenner 1974).
5. Water-level fluctuations of lakes in Florida (Hughes 1974).
6. Low streamflow in Florida—magnitude and frequency (Stone 1974).
7. Seasonal variation in streamflow in Florida (Kenner 1975).
8. The difference between rainfall and potential evaporation in Florida (Visher and Hughes 1975).
9. Average flow of major streams in Florida (Kenner et al. 1975).
10. An index to springs of Florida (Rosenau and Faulkner 1975).
11. River basin and hydrologic unit map of Florida (Conover and Leach 1975).
12. Florida: Satellite image mosaic (U.S. Geological Survey 1978).
13. Long-term streamflow stations in Florida, 1980 (Foose and Sohm 1983).
14. Hurricane Frederic tidal floods of September 12–13, 1979 along the Gulf coast, Oriole Beach, Garcon Point, Holley, south of Holley, and Navarre quadrangles, Florida (Franklin and Bohman 1980).
15. Hurricane Frederic tidal floods of September 12–13, 1979 along the Gulf coast, Gulf Breeze-Fort Barrancas quadrangles, Florida (Franklin and Scott 1980).
16. Hurricane Frederic tidal floods of September 12–13, 1979 along the Gulf coast, Perdido Bay quadrangle, Florida (Scott and Franklin 1980).
17. Wetlands in Florida (Hampson 1984).
18. Sinkhole type and development in Florida (Sinclair and Stewart 1985).

### Surface-water Chemistry

1. The pH of water in Florida streams and canal (Kaufman 1975a).
2. Specific conductance of water in Florida streams and canals (Slack and Kaufman 1975).
3. Dissolved solids in water from the upper part of the Floridan aquifer in Florida (Shampine 1975a).
4. The chemical type of water in Florida streams (Kaufman 1975b).
5. Color of water in Florida streams and canals (Kaufman 1975c).
6. Generalized distribution and concentration of orthophosphate in Florida streams (Kaufman 1975d).
7. Temperature of Florida streams (Anderson 1975).
8. Nitrogen loads and concentrations in Florida streams (Slack and Goolsby 1976).
9. Dissolved-solids concentrations and loads in Florida surface waters (Dysart and Goolsby 1977).

### Ground-water Hydrology

1. Top of the Floridan artesian aquifer (Vernon 1973).
2. The observation-well network of the U.S. Geological Survey in Florida (Healy 1974).
3. Piezometric surface and areas of artesian flow of the Floridan aquifer in Florida, July 6–17, 1961 (Healy 1975).
4. Principal aquifers in Florida (Hyde 1975).
5. Estimated yield of fresh-water wells in Florida (Pascale 1975).
6. Potentiometric surface of the Floridan aquifer in the Northwest Florida Water Management District, May 1976 (Rosenau and Meadows 1977).

(continued)

Table 4. Concluded

### Ground-water Hydrology (concluded)

7. Potential subsurface zones for liquid-waste storage in Florida (Miller 1979).
8. Areas of natural recharge to the Floridan aquifer in Florida (Stewart 1980).
9. Estimated pumpage from ground-water sources for public supply and rural domestic use in Florida, 1977 (Healy 1981).
10. Potentiometric surface of the Floridan aquifer in the Northwest Florida Water Management District, May 1980 (Rosenau and Milner 1981).
11. Potentiometric surface of the Floridan aquifer in Florida, May 1980 (Healy 1982).

### Ground-water Chemistry

1. Quality of water from the Floridan aquifer in the Econfina Creek basin area, Florida, 1962. (Toler and Shampine 1965).
2. Fluoride content of water from the Floridan aquifer of northwest Florida, 1963. (Toler 1965).
3. Chloride concentration in water from the upper part of the Floridan aquifer in Florida (Shampine 1975b).
4. Hardness of water from the upper part of the Floridan aquifer in Florida (Shampine 1975c).
5. Sulfate concentration in water from the upper part of the Floridan aquifer in Florida (Shampine 1975d).
6. Depth to base of potable water in the Floridan aquifer (Klein 1975).
7. Thickness of the potable-water zone in the Floridan aquifer (Causey and Leve 1976).
8. Chemical quality of water used for municipal supply in Florida, 1975 (Phelps 1978a).
9. Quality of untreated water for public drinking supplies in Florida with reference to the National Primary Drinking Water Regulations (Hull and Irwin 1979).

### Water Use

1. Estimated water use in Florida, 1965 (Pride 1975).
2. Principal uses of freshwater in Florida, 1975 (Phelps 1978b).
3. Freshwater use in Florida, 1975 (Leach 1978).
4. Estimated water use in Florida, 1980 (Leach 1982a).
5. Consumptive use of freshwater in Florida, 1980 (Leach 1982b).
6. Estimated irrigation water use in Florida, 1980 (Spechler 1983).
7. Projected public supply and rural (self-supplied) water use in Florida through year 2020 (Leach 1984).

The USGS also carried out similar investigations of water resources in Okaloosa County in a study which included portions of western Walton County (Trapp et al. 1977). This study was prompted by the declining level of the upper Floridan Aquifer within the area. This area depends almost entirely upon this aquifer for its water supply. The study concluded that levels would continue to decline until wells were better distributed, and alternate water sources, such as the Sand and Gravel Aquifer or surface waters, were placed into operation. This report includes a good description of the drainage conditions throughout the region. These conditions vary widely because a number of different physiographic regions and soil types are found within the area.

These USGS studies on the western Panhandle were updated by later publication of a hydrologic budget for Escambia County (Trapp 1978), of hydrologic and water quality data for Okaloosa, Walton, and southeastern Santa Rosa Counties (Wagner et al. 1980) and in a study of the hydrology of the coast of Okaloosa and Walton Counties (Barr et al. 1985).

The USGS has produced many maps depicting ground-water hydrology and water quality in the Panhandle. These are listed in Table 4. In addition to the USGS studies, the NWFWMD has performed ground-water studies of the quality and availability of water from the Sand and Gravel Aquifer in southern Santa Rosa County (Pratt and Barr 1982), the hydrogeology of the Sand and Gravel Aquifer in southern Escambia County (Wilkins et al. 1985), and the hydrogeologic effects of solid-waste landfills in northwest Florida (Bartel and Barksdale 1985). The NWFWMD has also compiled a ground-water bibliography with geological references for the district (Wagner 1985).

The lack of separation between surface and ground water in most of the Panhandle, especially in those areas where springs abound, cannot be over emphasized. The direct connections can easily be verified by observing local wells and springs during moderate to high water periods. At these times, well waters and springs are often brown from the tannic acid of surface waters, and some springs can be seen to be acting as siphons, draining surface waters to the underlying aquifer (Figure 49).

Within the Panhandle, ground-water pumping has lowered the potentiometric surface of the Floridan Aquifer significantly only in coastal Okaloosa County (Figure 52). In this region, the surface of the aquifer declined approximately 27 m between 1940 and 1961 (Barraclough and Marsh 1962) and another 12 m between 1961 and 1972 (Healy 1982). This permitted saltwater intrusion and contamination of area water supplies. Relocation of wells farther inland and other measures reducing the withdrawal of ground water have resulted in a partial rise in the surface of the aquifer in this area. However, water levels in 1980 were still as much as 33.5 m below 1940 levels (Wagner et al. 1984). Ground-water pumping for irrigation in southwest Georgia increased 500% between 1973 and 1980 (U.S. EPA 1983); this withdrawal has been documented as affecting nearby wells and surface water flow, including that of Panhandle rivers with basins in that area (FDER 1986c).

Ensuring continuing water supplies requires regulation by governmental authorities because the hydrology and water quality of Panhandle ground waters are wide-reaching phenomena which do not respect private boundaries. We encourage the continuing public purchase of major ground-water recharge areas as the best long-term solution to maximizing recharge while protecting water quality.

## 4.7 Basin Hydrology and Water Quality

### 4.7.1 Ochlockonee River Basin (Figure 53)

The Ochlockonee River and its numerous tributaries drain approximately 5,830 km², of which 52% (3,030 km²) is in Georgia and 48% (2,800 km²) in Florida (Foose 1980). Within Florida, the Ochlockonee River basin cuts through two physiographic divisions, the red clay of the Tallahassee Red Hills in the north and the sandy Gulf Coastal Lowlands in the south (Puri and Vernon 1964). The Ochlockonee and its major Florida tributary, the Sopchoppy, have been designated Outstanding Florida Waters (OFW—no significant degradation permitted).

Approximately 105 km down the river's 180-km course through Florida, the Jackson Bluff Dam backs the river up to form Lake Talquin. This dam was operated as a hydroelectric generation plant from 1930 to 1970 and was reactivated in 1985. The operation of the powerplant turbines can cause substantial drops in lake level over short periods of time; as a result their use is being limited to that producing drops of less than 1 ft below normal (nongenerating) levels. Lake Talquin is listed by Myers and Edmiston (1983) as one of the top 50 lakes in the State needing preservation and protection. The river drops about 27 m from the Georgia border to the coast (Pascale and Wagner 1982). Above the dam the river is characterized by sharp bends and low banks with an average fall of 0.14 m/km. Below the dam the river widens and passes through wide bottomlands and marshes, becoming tidal 19 km from the mouth. Much of the river basin below the dam (about 910 km²) is contained in the Apalachicola National Forest and a portion (about 65 km²) near the mouth is in the St. Marks National Wildlife Refuge.

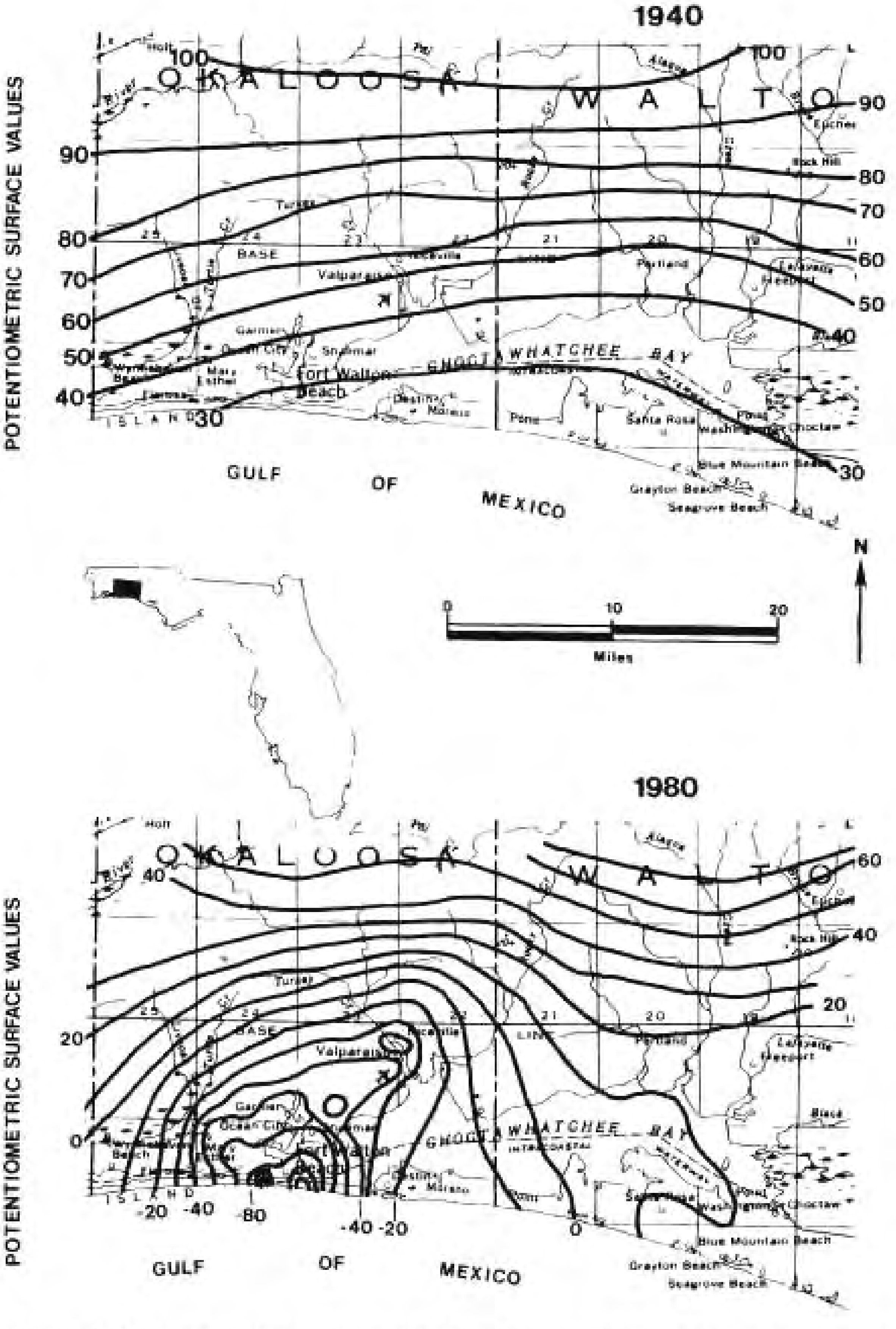

Figure 52. Potentiometric surface of the Floridan aquifer (in ft above MSL) in 1940 and 1980, before and after increased ground–water pumping in the area of western Choctawhatchee Bay (after Wagner et al. 1984.)

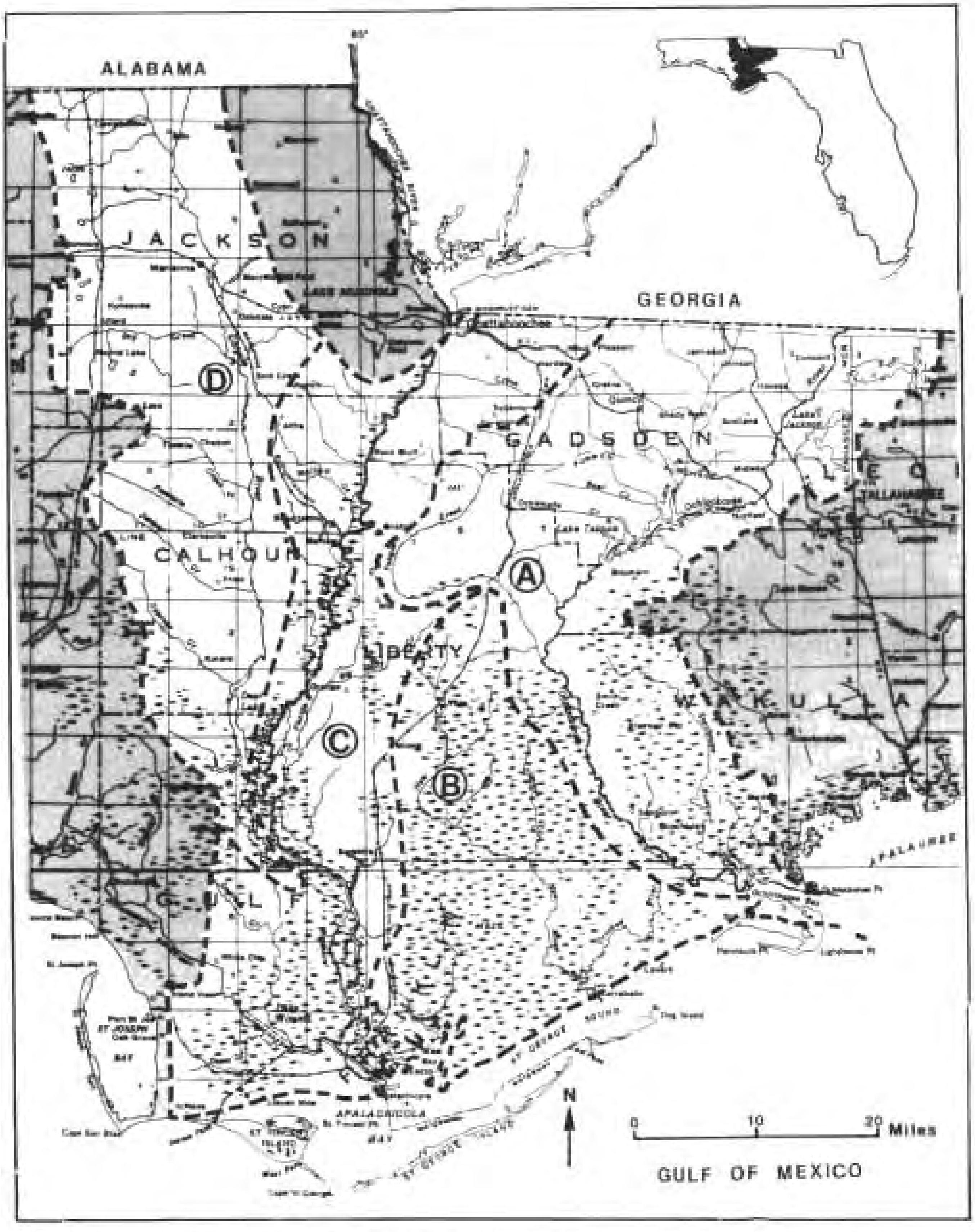

Figure 53. Eastern Panhandle drainage basins—(A) Ochlockonee River, (B) Coastal area between Ochlockonee River and Apalachicola River, (C) Apalachicola River, and (D) Chipola River (after Conover and Leach 1975).

East of the river near the Florida-Georgia border lie two large lakes whose water level is loosely affected by ground-water levels (Sellards 1917, Hendry and Sproul 1966). Lake Iamonia and Lake Jackson were formed by the the coalescence of sinkholes caused by solution and collapse of the area limestone (Hutchinson 1957). The lakes are poorly connected to the Floridan Aquifer through numerous completely or partially plugged sinkholes in their lake beds. Lake levels normally are 11–14 m above the potentiometric surface of the Floridan Aquifer (Pascale and Wagner 1982) and, as a result, leak to the aquifer, thereby recharging it. They sometimes drain completely following extended dry spells when the aquifer has dropped several feet. Lacking the ground water's support of the overlying limestone and sediments, either sinkholes form as the lake bed collapses into the now air-filled cavities, or the sediment plugs which block pre-existing sinkholes collapse. The remaining lake water may then rush "down the drain" over a few days or weeks. The last two occurrences in Lake Iamonia were in 1931 and 1981; the last two in Lake Jackson were in 1956 and 1982. The lakes refill when the water table returns to normal levels, and the sinkholes eventually plug with new sediments. The hydrologic significance of flooding in Lake Jackson during 1960 was reported on by the USGS (Hughes 1969). A hydrologic assessment of the 1982 draining was performed by the NWFWMD (Wagner 1984).

Until recently Lake Iamonia was connected to the Ochlockonee River by a natural channel which allowed river flood waters to flow to the lake and lake flood waters to flow to the river's flood plain. A structure was built to regulate this flow in 1976 (Pascale and Wagner 1982). Since 1977 efforts have been underway to drain the lake through a sink located on the north shore in an effort to control the growth of aquatic vegetation. A hydrologic assessment of the lake and the sink was performed by the NWFWMD (Wagner and Musgrove 1983).

The Lake Jackson basin has been increasingly developed with the resulting sediment and nutrient input accelerating eutrophication and degrading the lake's water quality and habitat (Babcock and Rousseau 1978). Harris and Turner (1974) studied the lake's water quality and characterized the northern sections of the lake from good to excellent while the southern sections, including Megginnis Arm, Ford's Arm, and a small part of the open lake, were fair to poor and highly variable. Following Harris and Turner's study, the water quality was monitored by the Florida Game and Fresh Water Fish Commission (Babcock 1977) and then by the FDER. Algal assays were performed by FDER on two occasions to determine the nutrients limiting algal growth in Megginnis and Ford's Arms and in the northern mid-lake (FDER 1980). They found that, at the times of sampling, the water of Megginnis Arm was primarily phosphate limited and secondarily nitrogen limited. The water in Ford's arm and the mid-lake north station were nitrogen and phosphate colimited. In all instances the growth was below that expected. This was tentatively attributed to the phosphate available for biological uptake being less than the orthophosphate concentrations found by chemical analysis. In an effort to slow this degradation, a number of local, State, and Federal agencies cooperated in the installation in 1984 of a stormwater retention and treatment facility using some relatively untried methods (NWFWMD 1984). The facility's use of retention ponds and aquatic plants for sediment and nutrient removal is still being evaluated and adjustments are still being made, but initial results show improved water quality in the water being discharged to Megginnis Arm (Tuovila et al. in press). However, substantial improvement in the overall water quality of the arm has not been demonstrated, possibly because of the release of nutrients bound up in lake bottom sediments.

West of the river and away from the coasts, surface runoff forms myriad tributary streams. Many of these, including Little River, Bear Creek, and Ocklawaha Creek, drain into Lake Talquin. The land east of the river in this area is a porous karstic limestone that provides a quick path for rainfall to recharge the aquifer. As a result, the familiar dendritic pattern of stream runoff is absent. The ground and surface water resources of the Little River basin have been examined by the NWFWMD (Wagner 1982, Maristany 1983).

The Ochlockonee River receives very little ground water contribution in its upper reaches (Pascale and Wagner 1982), thus its flow is dependent on rainfall patterns and is highly variable. Ochlockonee Bay and possibly the lower river receive ground-water flow as the rocks of the Floridan Aquifer outcrop and the aquifer potentiometric surface is above the surface of the river. Cray's Rise, on the north shore of Ochlockonee Bay, is an example of aquifer discharge. Bradwell Bay, a large marsh east of the river's lower reaches, has formed because of poor soil permeability and lack of a sufficient relief to promote drainage. The Sopchoppy River flows alongside and east of the lower Ochlockonee River into the Ochlockonee Bay estuary. The Sopchoppy River is often considered a tributary of the Ochlockonee River (NWFWMD 1979); however, the USGS feels that the flows are sufficiently separated to merit listing them as independent rivers (Pascale and Wagner 1982). Hand and Jackman (1984) reported naturally low pH levels in several of the basin tributaries, particularly the Sopchoppy River, caused by the swampy drainage lands. Hydrologic, geologic, and water quality data for the Ochlockonee River basin was compiled by Pascale et al. (1978). The USGS reported on severe flooding in Gadsden County during 1969 (Bridges and Davis 1972).

The water quality of the upper river has been deteriorating in recent years (Hand and Jackman 1984, FDER 1986a). Forestry and agriculture are the predominant land uses in the basin; however, fuller's earth (clay) is mined in Georgia and Florida near the border and sedimentation from the mining has reduced benthic community diversities in the upper section of the river. Bacteria and nutrients from point sources in Georgia have historically damaged the quality of the river water entering Florida. In Florida, Attapulgus and Willacoochee Creeks are the major contributors of sediment-laden water to the Ochlockonee (FDER 1986c). The Little River and its upstream tributary Quincy Creek have historically shown bacteria, nutrient, and turbidity problems from upstream sources including the City of Quincy Sewage Treatment Plant and Fuller's earth mining at the Floridan strip mine (Hand and Jackman 1984). Additionally, below the Georgia-Florida border the river water quality has historically had DO, bacteria, nutrient, and turbidity problems. Twenty-three major permitted point source dischargers operate in the basin. Thirteen of these are sewage-treatment plants (eight in Georgia and five in Florida) and ten are industrial dischargers. High bacteria and nutrient concentrations and low macroinvertebrate diversity continue to be problems. The water quality of the Ochlockonee River improves downstream from this area. Hand and Jackman (1984) and FDER (1986a) attributed these problems to Georgia point sources. According to Georgia's 1982 305(b) report (reporting status of the State's water quality to EPA) these problems should decrease because of treatment plant upgrading.

Five stations within the basin were examined during 1973–78 for biological indications of water quality (Ross and Jones 1979). A station in the Ochlockonee River near the Georgia border was sampled only a few times. Macroinvertebrate species diversities appeared high, though Biotic Index values suggested the possibility of problems with low dissolved oxygen during summer low flow. At a station below the Talquin Dam, too few macroinvertebrate samples were taken to make judgments, but bacteria counts were occasionally high, probably from runoff. A station in Lake Jackson appeared to improve during the study period; however, nutrient and silt inputs from urban and residential runoff had degraded apparent water quality and contributed to nuisance growth of aquatic weeds. A station in the Sopchoppy River at SR 375 was in an area primarily of swamp drainage; macroinvertebrate diversity was high from the three samples taken. The final station in Ochlockonee Bay west of Bald Point had consistently high macroinvertebrate diversity.

The water resources in the area from Quincy in Gadsden County southeast to the Ochlockonee River above Lake Talquin have been studied for their ability to support industry (NWFWMD 1980a). This study showed that the water quality of the Surficial and Intermediate Aquifers is generally good, but bacterial levels in the Surficial Aquifer, caused by its proximity to the surface, require that the water be treated before use. The Surficial Aquifer in this basin is presently important primarily for its water storage capacity (approximately $1.25x10^9$ $m^3$), its maintenance of streamflow, and its recharge of the Intermediate and Floridan Aquifers (Pascale and Wagner 1982). The Intermediate Aquifer (which is also known as the water bearing zone of the upper confining unit of the Floridan) in the northern basin consists of a low-permeability layer of sandy clay and sandy limestone of variable thickness (from 0 to a maximum of about 60 m in the Greensboro-Quincy area) confined above and below by layers of clay. The extent of this aquifer diminishes southward through Gadsden County and is discontinuous south of Lake Talquin. These shallow aquifers are suitable only for very small demands. The clay layer separating the Intermediate Aquifer from the Floridan is approximately 6 m thick in Gadsden County (NWFWMD 1980a). The Floridan at this location is of relatively low porosity and is recharged locally by leakage through the confining layer. The low rate of recharge allowed by the confining layer has prevented thorough flushing of the Floridan locally, and residual sea water from the last period during which the area was below sea level is still present at relatively shallow depths within the aquifer. The water quality of this aquifer is acceptable, with the concentration of dissolved solids increasing rapidly with depth. Wells tapping the Floridan yield as little as 75 l/min in Gadsden County to as much as 17,000 l/min in Leon County.

The USGS has mapped the flood-prone areas (i.e., those inundated by a 100-year flood) of Gadsden County (Rumenik et al. 1975). As would be expected most of these areas are along the rivers and streams of the county; however, numerous spots are unattached to these drainageways.

Ground-water pumping for the town of Panacea from two wells drilled in 1965 resulted in saltwater intrusion by 1970. Subsequent investigation by the USGS determined that the aquifer discharges to the bay and river, and that the upward movement of aquifer flow in the area tends to bring deeper salty water into the upper zone of the aquifer (Pascale and Wagner 1982).

Ground-water movement in the northern part of this basin tends to be towards the southeast west of the river and to the south east of the river toward Wakulla Springs, 16 km south of Tallahassee.

### 4.7.2 Coastal Area between Ochlockonee and Apalachicola Rivers (Figure 53)

This 1,440 km$^2$ area is poorly drained and consists of two main regions. The eastern portion of the basin (830 km$^2$) is the area drained by the New River and its tributaries, which discharge into St. George Sound at the town of Carrabelle. The western portion is Tate's Hell Swamp, a large, densely wooded and vegetated swamp which drains to East Bay in Apalachicola Bay. Whiskey George Creek is the stream within Tate's Hell with significant flow to East Bay.

The construction within the swamp during the early 1970's of logging roads and drainage ditches to direct surface water to the Apalachicola River is reported to have altered the drainage patterns sufficiently to result in dry areas, substantially altering wildlife habitat and increasing fire hazard (Bruce Means, Coastal Plains Institute, pers. comm.).

The major causes of water quality problems in this basin are the discharges to the coast from the sewage treatment plants in Carabelle and Eastpoint and surface runoff from forest clearcutting by Buckeye Cellulose Corporation. The City of Eastpoint Water and Sewage District Waste and Treatment Facility is being upgraded and the system expanded to replace many of the septic tanks in the area. The City of Carabelle Wastewater Treatment Plant is the only plant in northwest Florida providing only primary treatment (Florida Rivers Study Committee 1985). The highly chlorinated sewage which is discharged degrades the water in the vicinity of the outfall to St. George Sound and settles to form putrescent sludge deposits. Overly enriched waters produce plankton blooms and excessive growth of filamentous algae, bacteria, viruses, and fungi that are pathogenic to the sea grasses of St. George Sound. This plant has been under some form of enforcement action for years.

The effects of runoff from forest clearcutting operations upon the New and Crooked Rivers was investigated by Hydroscience, Inc. (1977). They calculated minimal long-term effects upon the rivers and the bay into which they discharge, but felt that short-term nutrient, turbidity, and color spikes could be a problem. Their investigation was, however, aimed at effects in the rivers, and not at the effects upon the wetland hydrology in the swamps. The purposeful draining of the wetlands to ease timber harvesting was the source of changes documented by their study.

This basin has been studied very little. No stations examining the biological indications of water quality were located in this basin during the period analyzed by Ross and Jones (1979).

### 4.7.3 Apalachicola River Basin (Figure 53)

The Apalachicola River is the 21st largest river in flow in the conterminous United States and is by far the best studied river system in the Panhandle. The Apalachicola, together with its main out-of-State tributaries, the Chattahoochee and Flint Rivers (together often called the A-C-F basin) and its main in-state tributary, the Chipola River (separately addressed in 4.7.4), drains approximately 51,000 km² of Georgia, Alabama, and Florida. Of this basin only 13% (~6,500 km²) is in Florida, and the Florida portion, excluding the Chipola River basin, is less than 8% (~3,830 km²) of the total. The majority of the remaining 44,500 km² consists of Georgia's Flint River watershed, which drains into Lake Seminole on the Georgia-Florida border. River flow normally varies from 250 to 2,800 m³/s (FDER 1984a) and the mean flow from 1958 to 1980 was 690 m³/s (Leitman et al. 1983). The river width at mean discharge varies from 75 to 300 m (FDER 1984a). Seasonal river stage fluctuations are 3 times greater in the upper river than in the lower and peak floods are most likely to occur during January through April (Leitman et al. 1983). Low flows are usually found during September through November. Georgia rainfall has much greater influence on flow in the upper Apalachicola than does Florida rainfall. Georgia rainfall is slightly higher in winter and much lower in summer than is Florida rainfall. Both experience similar quantities of rain in spring and minima in October–November.

When the Apalachicola is high the Chattahoochee River contributes most of the flow as it is steeper than the Flint River and has abundant rainfall in its upper basin. This results in large pulses in the Chattahoochee contribution. The Flint River basin is flatter and receives much spring flow, providing a more stable flow regime. During low flow conditions in the Apalachicola, these two tributaries contribute more equal flow. During extreme low flow the Flint is the major contributor (Leitman et al. 1984). The Chattahoochee contribution is becoming more stable because of the Army Corps of Engineers' dams and flow regulation. During the next 20 to 30 years growth of the Atlanta area and the resulting increased use of the Chattahoochee River as a water supply could reduce the volume of its contribution to the Apalachicola River and Bay (Livingston 1983). This has the potential to seriously alter the salinity regime within the bay, thus reducing the fisheries potential. The Apalachicola River discharge peaks in winter and early spring and declines until fall (Figures 45 & 46). The average winter–early spring flow is 2 to 3 times the average summer flow. The Florida basin rainfall averages 147 cm while the mean annual potential evaporation is 99–114 cm (U.S. Dept. Agriculture 1969).

From Chattahoochee to Blountstown the river has long straight stretches and gentle bends. This part of the basin is characterized on the east side by steep bluffs backed by relatively high and rugged terrain. Small tributary streams have incised deep channels producing the most hilly area of Florida. On the west side the basin consists of gently rolling, lower land containing a 1.5–3 km wide flood plain (Leitman et al. 1983). Ocheesee Pond, west of the river in Jackson County, is the largest natural lake in the area. From Blountstown to Wewahitchka the river channel meanders with large loops and many small tight bends to the south, and the flood plain is 3–4.5 km wide. Below Wewahitchka the river has long straight stretches with a few small bends and the flood plain widens to 4.5–8 km. A map of the Apalachicola River flood plain and data on the associated hydrologic conditions are presented in Leitman (1984).

At the Chipola Cutoff (just below Dead Lake), approximately 25% of the Apalachicola flow diverts to the Chipola River (Ager et al. 1983). The Chipola River flow measured above the Chipola Cutoff averaged 10% of that of the Apalachicola River during 1979–80 at Sumatra (Leitman et al. 1983). A similar situation exists farther downstream where the Brickyard Cutoff diverts Apalachicola flow to near the head of the Brothers River. This diversion involves sufficient quantities of water that the water chemistry of the Brothers River is controlled by that of the Apalachicola River (Ager et al. 1983).

Lake Wimico is located in the southern part of the basin west of the Apalachicola and receives runoff from numerous streams draining the southwestern portion of the Apalachicola River Basin. From here the water flows 5.5 km via the Jackson

River to the Apalachicola River, near its mouth. Lake Wimico is one of the 50 lakes in the State listed in Myers and Edmiston (1983) as most in need of preservation and protection.

Land use in the basin is diverse and includes agriculture, forestry, and manufacturing. The basin hydrology has been substantially altered by dredging, spoil disposal, and construction of navigational aids. The Corps of Engineers constructed four cutoffs in 1956–57 and three more in 1968–69, straightening oxbow river bends to ease barge traffic. These cutoffs have shortened the river by 3 km. About 765,000 $m^3$/yr are dredged from the river and placed in and along the river in an effort to maintain the Federally authorized 9 ft by 100 ft channel (Eichholz et al. 1979). Effects on water quality within the river were felt for only a short distance below the dredging activity and impacts were minor because the dredging usually takes place in areas with unstable bottoms and hence low productivity. Additionally, much of the dredged material is medium to coarse sand, the suspension of which produces little and short lived turbidity (Leitman et al. 1984). The Corps of Engineers reported that turbidity in the dredging plumes dropped to ambient within 18 m of the discharge pipe.

Dredge material disposal sites along the lower river have been studied to assess their effects (Eichholz et al. 1979, Leitman et al. 1984). Army Corps of Engineers dredging of the river shipping channel has affected river and floodplain hydrology and biota. Effects from dredging extend into habitats beyond the river bed. Spoil deposited in floodplains adjacent to the river, in addition to killing the trees and other plant growth within the spoil area, altered the hydrologic flow patterns in the floodplain and therefore, in some instances, the habitat. Eichholz et al. (1979) recommended spoil disposal between the river banks in areas where the bottom was unstable already and therefore low in productivity. Leitman et al. (1983) found that the river stage at Chattahoochee was lower than before channel alterations. Lake Seminole serves as a sediment trap and tends to adsorb metals and other potential pollutants from upriver and prevent their migration downriver. It is estimated that Lake Seminole traps 65%–70% of the sediment flowing into it. Heavy metals in dredged sediments were low except for iron, which was primarily in an insoluble form (Leitman et al. 1984). Pesticides in the sediments were generally below detection levels and those detected—Archlor 1254 (a DDT breakdown product) and 2-4 D—were in the upper river.

The bed of the Apalachicola River is undergoing degradation, whereby it erodes away, lowering its elevation and exposing bedrock outcroppings. The rate of this process in the upper river has been increased by the construction of the Jim Woodruff Dam (Leitman et al. 1984). The State of Florida, after many conflicts over the A-C-F basin with Alabama and Georgia, entered into a Memorandum of Agreement with those States in 1979 to cooperate in a long range water budget and management plan. As part of the Agreement, required by the other States prior to their consenting to having Apalachicola Bay designated a National Estuarine Sanctuary, Florida promised to cooperate in efforts to increase the availability of a 9-ft channel, and subsequently gave the Corps of Engineers permission in 1984 to remove a number of rock outcroppings (USACE 1984). Removal of outcroppings, which slow river flow, destroys valuable fishery habitat (Eichholz et al. 1979). Before this work was completed the Corps suggested other areas for removal (Florida Rivers Study Committee 1985). Navigation projects in the Apalachicola are incrementally altering the river ecosystem. Each project since 1954 has been justified as maintaining the Federally permitted 9-ft deep channel. To date, little overall improvement has been noted. The 9-ft controlling depth is available an average of 80% of the time and in 1981 (a dry year) was available less than 10% of the time (Florida Rivers Study Committee 1985). It appears that this depth will also be available very little during 1986 following the record spring drought. It seems that during some portions of the year a 9-ft by 100-ft channel in the Apalachicola River requires a greater volume of water than the river can provide without sacrificing the river basin habitat, and that the goal of 95% availability of this depth is not realistic.

Water resource projects (dams and other flow-control structures) are common. The Corps of Engineers has constructed and operates a network of five large dammed impoundments in the Chattahoochee River subbasin alone. Sixteen dams exist in the river basin, including those in Georgia and

Alabama; the five largest influence seasonal, weekly, or daily flows; the other eleven have no effect on flow (Leitman et al. 1983). The southernmost dam in the Apalachicola watershed, the Jim Woodruff Lock and Dam, which became operative in 1954, is located near the Florida-Georgia border and marks the beginning of the Apalachicola River. Lake Seminole, formed behind the dam, is located at the Florida-Georgia border and receives flow from the Chattahoochee and Flint Rivers. The dam was constructed primarily to aid upstream navigation and to generate power, and secondarily to regulate streamflow and for recreation and conservation (Maristany 1981). Normal dam operations restrict lake level fluctuations to 1 ft. Maristany (1981) concluded that the dam has practically no flood control capability because its working storage is equal to approximately 1 day of average river flow. Additionally, it has limited use for low flow regulation because the working storage could only augment downstream river flow by 10% of the average river flow for 10 days. He further concluded that the dam has exhibited practically no effect on annual mean flows. More detailed information on the Chattahoochee and Flint Rivers is available in a comprehensive report compiled by the States of Alabama, Georgia, and Florida in cooperation with the Mobile District of the Army Corps of Engineers (USACE 1984). The Florida Department of Administration (1977) prepared a report on the Apalachicola River and Bay System prior to the State's designating it an Area of Critical State Concern. This report examines the potential impacts of various basin alterations including additional dams and locks, channelization, and levees.

The Florida portion of the Apalachicola River and Apalachicola Bay have been designated Outstanding Florida Waters (OFW); that portion below the northern Gulf County line since 1979 and that above it since 1985. The Florida Defenders of the Environment wrote a persuasive report describing the upper Apalachicola basin and nominating it for OFW status (Florida Defenders of the Environment 1982). One mile of the 107 river miles in Florida was not designated OFW because of preexisting industry: one-half mile adjoining the Jackson County Port Authority and one-half mile below SR 20 (FDER 1984a). The OFW designation was further altered to exempt Army Corps of Engineers' maintenance of a shipping channel. The effects on the hydrology and ecology of the basin from the dredging and rock removal planned and carried out as part of this maintenance are discussed in Leitman et al. (1984). Following the Federal purchase of substantial quantities of surrounding lands, the lower river and Apalachicola Bay was named a National Estuarine Sanctuary. They have also been designated a State Aquatic Preserve and an International Biosphere Reserve. The head of the river basin is north of Atlanta in the Blue Ridge Mountains and parts of the Georgia and Alabama portions of the basin are urbanized. These areas include Gainesville, Atlanta, Columbus, Thomaston, and Albany in Georgia, and Phoenix City, Eufaula, and Dothan in Alabama. The Florida portion is sparsely populated with four population centers: Chattahoochee, Marianna, Blountstown, and Apalachicola. However, runoff from steep terrain in Chattahoochee, Sneads, Blountstown, and Bristol could be the source of future problems (FDER 1984a).

Apalachicola Bay is dependent upon the transport of nutrients from the river's flood plain (Livingston 1981, Mattraw and Elder 1983). This transport takes place as both dissolved nutrients and detritus, with detritus playing the most important role. The Jim Woodruff dam stops detrital transport from further upriver; therefore Apalachicola Bay depends upon its floodplain in Florida for most of its nutrient input. The water flowing from Lake Seminole does not contain a substantial nutrient load, either dissolved or as detritus (Elder and Cairns 1982). The height of natural river bank levees and the size and distribution of breaks in the levees have a major controlling effect on the floodplain hydrology (Leitman et al. 1983). Much of the lower river floodplain is permanently or semipermanently flooded; Leitman et al. (1983) and Leitman (1984) detail floodplain locations and descriptions. Nutrient and detritus transport in the Apalachicola River has been analyzed (Mattraw and Elder 1980, Elder and Mattraw 1982, Mattraw and Elder 1983). Annual floods cause appreciable surges in nutrient transport, especially as detritus. In an 86 day flood in 1980 they found that half of the annual outflow of organic carbon, nitrogen, and phosphorus, along with 60% of the annual detritus load, passed their sampling station closest to the bay. The total organic carbon outflow at this station was 50% greater than the inflow to the river at Jim Woodruff Dam and 25% greater than the increase in streamflow. The nitrogen and phosphorus increases were proportional to the streamflow increase. On an areal basis, they found the Apalachicola basin to export greater quantities of carbon and phosphorus than most watersheds. In an earlier study it was found that the Apalachicola floodplain produces dissolved nutrients at approximately the same rate it consumes them, but that it is an exporter of detrital matter (Elder and Cairns 1982). The Apalachicola wetlands produce some net increases in organic carbon and phosphate transport, but no net change in nitrogen concentrations (Mattraw and Elder 1983). Elder and Cairns (1982) discuss in detail the quantities and nutrient makeup of the floodplain detritus. The FDER (1984a) concluded that "Significant alterations in the form or amount of substances which reach the [Apalachicola] estuary could influence productivity of the bay. Alterations which would block the transport of detritus and nutrients out of the floodplain or which limit the variations in flow volume of the river could have negative impacts on Apalachicola Bay."

Best et al. (1983) investigated the feasibility of using Apalachicola wetlands for wastewater recycling beginning in 1981. They investigated various aspects of the wetland ecology and attempted to model the system so as to enable calculation of the effects of wastewater effluents released into the wetlands.

Little information has been gathered to address impacts of toxic substances or nonpoint-source pollutants. The Apalachicola River has been found by researchers from Florida State University to have higher concentrations of germanium than most of the rivers in the world (Froelich and Mortlock 1984). Little is known of germanium toxicology. The major source of germanium in water is coal-fly ash from upwind coal-burning powerplants (FDER 1984b). High nutrient levels in Lake Seminole have caused problems with eutrophication and resulted in excess growth of aquatic plants. This growth is controlled with herbicide applications, which contributes to water quality degradation in the lake. The U.S. Army Corps of Engineers (1982) completed a comprehensive study of water quality in Lake Seminole and part of the Apalachicola. Numerous Federal- and State-permitted point sources discharge into the Apalachicola, Chipola, and Flint Rivers and their tributaries. These include municipal sewage treatment plants, industrial and agricultural facilities,and nuclear and fossil-fueled powerplants. In addition, large agricultural areas contribute nonpoint-source discharges. Nutrient enriched water pumped from and running off of grazing lands resulted in M/K Ranches being the only nonpoint discharger in the basin which has been regulated by the FDER (Esry 1978, FDER 1984a). This drainage from the M/K canal system reduced visibility in the river as measured by a secchi disk to 30–45 cm (USACE 1981). Streams with the greatest amount of degradation include Double Bayou, Clark Creek, Murphy Creek, and Scipio Creek.

Agriculture within a drainage basin often contributes nutrients, coliform bacteria, sediments, and pesticides to the river system. The FDER established a nonregulatory nonpoint source management program for agricultural interests that is administered by the Florida Department of Agriculture and Consumer Services in cooperation with the U.S. Department of Agriculture and the Soil and Water Conservation Districts. While this program has been fairly successful in parts of Florida, the largest resistance to it has occurred in northwest Florida, including the Apalachicola watershed (Florida Rivers Study Committee 1985). The effects of silviculture in the basin upon the water quality and biota of Apalachicola Bay were investigated in a report to Buckeye Cellulose Corporation (Hydroscience, Inc. 1977).

The primary problems detected by monitoring stations along the river are high fecal coliform counts and low DO below sewage treatment plants and industrial discharges. Before entering Florida, Apalachicola River tributaries receive numerous discharges from Atlanta and other urban areas, from textile mills, paper mills, sewage treatment plants, steam powerplants, a nuclear powerplant, and extensive agriculture areas of Alabama and Georgia (Hand and Jackman 1984). The USGS has examined the effects of flooding on the sources of pathogenic bacteria in the Apalachicola River and Estuary from 1982 to 1985 and is analyzing their data for publication in the near future (Elder, in prep). The Florida State Hospital at Chattahoochee discharges to Mosquito Creek, then to the Apalachicola. High phosphate concentrations from detergents (Doherty

1980) and high fecal coliform counts (Nicol 1979) have historically been continuing problems in the creek. The Hospital failed static acute toxicity bioassays performed by the FDER in 1982 and 1983 (FDER 1982, 1983). A 1984 FDER study of Mosquito Creek showed low total phosphorus levels but fecal and total coliform concentrations much above standards (McKnight 1984). Additionally, 5-day BOD could not be determined due to some bacterial inhibitor in the effluent. Sutton Creek, an Apalachicola River tributary, has experienced DO violations caused by the Blountstown sewage treatment plant (Kobylinski 1981). While this problem is expected to improve with scheduled plant upgrades, there remains the need to eliminate hydraulic overloads during wet weather. Apalachicola Bay has experienced problems with high coliform bacteria levels, which sometimes cause the bay to be closed to fishing. Much of this results from septic tank seepage in coastal communities and from poorly treatment discharges from area sewage treatment facilities. The City of Apalachicola Wastewater Treatment Plant has a long history of poor performance and environmental problems. New facilities are under construction and are expected to solve problems of poor discharge quality.

During 1982–83, DO concentrations were above 4.0 ppm at all sites sampled by the Florida Game and Freshwater Fish Commission, but a summer (July–August) depression was noted between navigation mile 75 and 100 (Ager et al. 1983). Cox and Auth (1971) had similar findings; no explanation was offered in either instance. All water quality parameters examined during the Game and Freshwater Fish study met State standards.

The only major point-source discharge to the Apalachicola River is the Gulf Power Scholz Electric Power Plant near Blountstown. This coal-burning plant uses once-through cooling water from the river. The FDER and EPA have permitted outfalls which include noncontact cooling water, ash pond water, low volume wastes, boiler blowdown, metal cleaning wastes, construction runoff, coal pile runoff, and sanitary waste. NPDES pH violations were noted in 1982 and illegal sanitary waste discharges were found in 1983 (FDER 1984a). A limited study of the plant's thermal discharge was performed in 1977 (Wieckowicz 1977) and also as a research project by the University of Florida. Winger et al. (1984) investigated river biota for residues of organochlorine insecticides, PCB's, and heavy metals. Elder and Mattraw (1984) looked at the accumulation of trace elements, pesticides, and polychlorinated biphenyls in river sediments and in the clam *Corbicula manilensis*.

This basin was sampled at four sites for biological indicators of water quality during 1973–78 (Ross and Jones 1979). The upper station was near the Bristol boat landing and, though only sampled a few times, it showed good macroinvertebrate diversity. This was also true of a station downstream, 2.5 km below the Chipola River cutoff (a connection above the confluence of the Chipola and Apalachicola Rivers where water from the Apalachicola flows into the Chipola; the Chipola below the cutoff consists primarily of Apalachicola water). The next station was in the Brothers River about 1.5 km above its confluence with the Apalachicola River. This area was basically undeveloped swamp, which was reflected in the good macroinvertebrate diversity. The next station, at Buoy No. 40 in the lower Apalachicola River, showed a marginal Biotic Index and generally high diversity. Occasional high coliform bacteria counts were attributed to runoff. The final station was at the mouth of Lake Wimico (the head of the Jackson River). Here the macroinvertebrate diversity was generally high and the introduction of estuarine forms into the lake from the Intracoastal Waterway to the west was noted.

The watershed south of Lake Seminole (i.e., the portion of the basin in Florida) is relatively pristine, and water quality in the river recovers during its transit. However, heavy-metal bearing sediments are being deposited in Apalachicola Bay from the Apalachicola and Chipola Rivers (FDER 1986c). Fishery studies suggest that, despite the alterations, the Apalachicola River is relatively productive (Bass 1983).

Leitman et al. (1983) examined shallow ground-water movement in parts of the basin. They found that ground-water flow at Sweetwater, approximately 7 km north of Blountstown, was generally toward the river at low river stages and away from the river at high stages, but that ground-water flow from the uplands east of the floodplain showed constant flow to the floodplain. At Brickyard, near Sumatra, ground-water flow was away from the river at low and medium river stages, but the ground-water level was essentially equal to that of the river at high river stages. They felt that ground-water flow at Brickyard was possibly toward the river at extremely low stages, but could not document this since these conditions did not occur during the study.

Apalachicola Bay is a highly productive estuary, providing most of Florida's oysters and a nursery area supporting a substantial shrimp, crab, and finfish fishery. The bay is nevertheless suffering from developmental pressures and from the lack of cohesive plans to handle area wastes. These problems are being addressed by State and local governments through establishing the river and bay as an Area of Critical State Concern. This designation allows the local governments to enlist the aid of State planning experts in developing methods to deal with area problems and requires them to follow a State management plan. The Area of Critical State Concern designation remains in effect until the State is satisfied that the local government has established programs capable of dealing with the problems. The Apalachicola River is believed to be the dominant factor controlling the seasonal changes of nutrient levels and salinity, which drive the estuary and keep the fisheries potential of the estuary extremely high (Florida Rivers Study Committee 1985).

The U.S. Army Corps of Engineers studied the Apalachicola River basin's water resources and discussed ground-water supplies (USACE 1981). Apalachicola Bay is not further discussed here since it has been thoroughly covered in a recent profile by Livingston (1984). In addition, further information may be found through Banks et al. (1983), a thorough (as of the date of its publication) bibliography of literature concerning the Apalachicola River basin.

### 4.7.4 Chipola River Basin (Figure 53)

The Chipola River, a major tributary of the Apalachicola, drains a 3,200 km$^2$ area into the lower Apalachicola River. Eighty-two percent of this basin (2,640 km$^2$) lies in Florida, with the remaining 18% (560 km$^2$) lying in Alabama. The Chipola emerges from subterranean streams in southeast Alabama, flows generally south, then goes underground for a short distance north of Marianna, Florida. It reappears and flows south another 65 km to its confluence with the Apalachicola River near Wewahitchka. The Dead Lake area is formed where the natural levees of the Apalachicola River impound the Chipola above their confluence and produce a usually-flooded area. A low dam was constructed to enlarge the lake, stabilize the lake level, and enhance fishing access. Dead Lake, along with Lake McKenzie, Mirror Lake, Turkey Pen Pond, and Merrits Mill Pond farther north in this basin, is among the 50 lakes in the State listed in Myers and Edmiston (1983) as most in need of preservation and protection. At the Chipola Cutoff above the confluence, approximately 25% of the Apalachicola River flow diverts to the Chipola River (Ager et al. 1983), where it constitutes the bulk of the Chipola River water below that point (Leitman et al. 1983). The largest spring in the basin is Blue Spring, located about 10 km northeast of Marianna. Blue Springs Creek flows from the spring into the Chipola River.

The Chipola generally has good water quality (Hand and Jackman 1984) but was, in recent years, receiving indirect discharges via Dry Creek from a battery reclamation plant, Sapp Battery Company. Extensive damage has occurred to the wetlands near the Sapp plant site because of runoff contaminated with battery acid (sulfuric acid) and heavy metals. In 1970 Sapp employed five people to crack used automotive batteries and recover lead. By 1978, 85 people were employed, cracking 50,000 batteries per week (Watts 1984). Acid from the batteries was dumped outside the plant building where it drained into a cypress swamp on company property. Water from this swamp drained south into a shallow lake named Steele City Bay, then through a series of cypress swamps into Little Dry Creek about a mile from the factory. Little Dry Creek is a tributary of the Chipola River via Dry Creek. By 1977 the acid had started to kill the cypress trees in Steele City Bay and beyond and, upon receiving complaints, the FDER became involved. After taking some unsuccessful steps to alleviate the off-site discharge and coming under legal action by FDER, Sapp abruptly closed down in 1980 (Watts 1984). In 1982 FDER began investigating the contamination under the U.S. EPA Superfund program. Contamination included lead, manganese, aluminum, and sulfuric acid. Approximately 17,500 m$^3$ of battery casings were buried on site to a depth of over 1.5 m with another 2,600 m³ piled on the surface.

High levels of lead were found in most of the upper soils, the concentration generally decreasing with depth. At certain sites, which proved to be sinkholes, concentrations increased with depth to approximately 30 m. Sampling wells drilled in the bottom of one sink proved to be the most contaminated of any taken on the site, with extremely high levels of lead, manganese, aluminum, and sulfate, and somewhat lower levels of cadmium and nickel. It was concluded that water from these sinks was seeping into the Floridan Aquifer, and that concentrations of lead, cadmium and aluminum in samples taken from this aquifer under the Sapp site represented maximum theoretical solubilities for the metals (Watts 1984). It was further concluded that the shallow aquifer was most likely to suffer widespread contamination; subsequent testing identified moderate to high levels of lead and aluminum contamination of this aquifer in a zone east of the site.

Surface waters were also sampled for contamination. The on-site pond and cypress swamp proved to be heavily contaminated with lead, manganese, and aluminum, with concentrations decreasing irregularly downstream until levels were indistinguishable from background concentrations at the most distant stations on Little Dry Creek. Concentrations measured in this study during 1983 proved to be significantly less than those obtained in an U.S. EPA study three years earlier (Watts 1984). This contamination is now being cleaned up using State and Federal funds.

The U.S. Fish and Wildlife Service (USFWS) examined the fish, clams, and sediment in the Chipola River in 1982 for possible effects from the Sapp site contamination (Winger et al. in press). They found that while the levels of trace elements in samples of biota and sediments demonstrated no serious contamination in the Chipola River, metal concentrations generally increased downstream from the two stations located above the rivers confluence with Dry Creek. This increase was particularly noticeable for arsenic, cadmium, chromium, lead, and zinc in clam and sediment samples, though the arsenic and cadmium levels in the downstream biota were similar to those found in the biota of the Apalachicola River in a 1978 study (Winger et al. 1984). The levels of lead in clams were, however, greater than those found in Apalachicola River clams. They speculate that Dead Lake may be serving as a sink for contaminants flowing down the Chipola, as the metal concentrations in sediments from the lower part of the lake were higher than those downstream of the Dead Lake dam near the Chipola's confluence with the Apalachicola River. Additionally, the only organochlorine pesticides found in the sediment samples were from those taken at Dead Lake.

Simultaneously with the FDER study of the Sapp site, Little Dry Creek and Dry Creek were investigated as part of an EPA sponsored study attempting to define similarities and differences between laboratory and field toxicity data (Livingston 1986a). The ecological effects of the gradient of contamination found downstream from the Sapp site provided a comparison to effects projected from similar toxicity gradients used in normal laboratory bioassay testing. At the same time the information concerning the effects of the Sapp contamination on the ecosystems of the creeks was documented.

The Florida Department of Health and Rehabilitative Services (HRS) in 1983 reported levels of lead in the introduced clam *Corbicula* above FDA levels for removal of food from the market place (Ager et al. 1983). Investigation of mercury contamination in the Chipola is addressed by the FDER (1984b). A study in 1982 showed that the Chipola below the Dead Lakes Dam had moderately hard, very clear, and slightly acid water, but that the DO indicated an unusually high BOD upstream (Ager et al. 1983). The constant water level provided by the dam is killing trees and is allowing the growth of excessive aquatic plants. The dam is presently scheduled for removal (Banks 1983, Cason et al. 1984). There has been concern expressed about the potential for the release of substantial concentrations of heavy metals from the sediments trapped behind the Dead Lakes Dam when the structure is removed as planned (Bob Patton, FDER, Tallahassee; pers. comm.). This potential release would be the result of the anaerobic reaction of sulfur and iron.

Four stations within the Chipola Basin were sampled for biological indications of water quality during 1973–78 (Ross and Jones 1979). The uppermost station was downstream from Waddell's Mill Creek in Jackson County. Macroinvertebrate diversities were fairly high, but lower than expected; numbers of species collected were somewhat low, and the Biotic Index was marginal. These results were attributed to heavy silt loads and subsequent degraded water quality from farming along the stream banks. The next station in the Chipola River at SR 274, east of Chason and upstream of Tenmile Creek, had high macroinvertebrate diversities and Biotic Index values and showed a significant improvement during the study period. Occasionally, Class III (i.e., suitable for recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife) bacteria standards were exceeded. This was possibly caused by the Marianna sewage treatment plant, though it was felt that it might be too far upstream to be the source of the fecal coliform bacteria. A third station was in Juniper Creek near Frink. This station showed high macroinvertebrate diversity and high Biotic Index values during the three times it was sampled. High bacteria counts were attributed to runoff. The last station was just downstream of the dam which forms Dead Lake. It was sampled only twice but had high macroinvertebrate diversities both times.

### 4.7.5 St. Andrew Bay and Coastal Area (Figure 54)

The St. Andrew Bay drainage basin encompasses approximately 3,500 km² and includes St. Andrew, West, North, and East Bays, St. Andrew Sound, and, to the east, St. Joseph Bay. There are no large rivers within the watershed; the largest inflow to the St. Andrew Bay system comes from Econfina Creek, which most of the year is composed predominantly of ground water from springs fed by the Floridan Aquifer (Musgrove et al. 1964). Much of the terrain is very porous sands, which allow quick infiltration of rainfall. Stream baseflow within much of the area is maintained from the shallow sandy aquifer. The Deadening Lakes area (not to be confused with Dead Lake at the confluence of the Chipola and Apalachicola Rivers) at the northern end of the basin contains numerous sinkhole lakes formed by the collapse of solution holes in underlying limestone. Most of the lakes in this area have no surface outlets (Musgrove et al. 1964) and have subterranean connections.

Econfina Creek flows into Deer Point Lake, formed by the construction in 1961 of a dam across North Bay (USACE 1980a). This dam maintains the lake level approximately 1.5 m above sea level and provides the primary water source for Panama City.

The water in the streams and lakes within the basin is low in dissolved solids because they are generally fed from surface runoff or from the shallow sand aquifer. This aquifer has little buffering effect, and as a result the surface waters have about the same mineral concentration as rainwater; this concentration changes little between periods of high and low flow (Musgrove et al. 1964). Color and pH change with stream and lake stage as the proportion of water having contacted decayed organic materials increases. The pH normally ranges from 6.0 to 7.0 but falls below 6.0 during high flow. The exception to these generalities occurs in an area along Econfina Creek downstream of a point east of Porter Lake, where springs from the Floridan Aquifer flow to the Econfina and increase dissolved solids concentrations in proportion to the concentration of spring water (Musgrove et al. 1964).

The St. Andrew Bay system was studied in 1974 in order to calculate a waste load allocation (i.e., the amount and quality of waste that can be discharged to the system based upon its calculated ability to assimilate that waste without damage to its ecosystem) (Johnson et al. 1974). During this study St. Andrew Bay had the poorest water quality of the four bays in this drainage. Some locations, particularly Watson Bayou and the International Paper Company outfall, did not meet DO, turbidity, or bacterial standards for Class III waters (i.e., recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife) . The other bays generally met Class II standards (i.e., shellfish propagation or harvesting). The model produced in this study showed Watson Bayou to be quite sensitive to storm-water runoff, resulting in significant DO reductions.

Ten years later, Hand and Jackman (1984) reported that of 400 km² of estuary in this basin, all but 14 km² has good water quality. The major urban development in the area centers around Panama City. Major point sources of pollution include two large paper-pulp processing plants: the International

Figure 54. East-central Panhandle drainage basins—(E) St. Andrew Bay and (F) Choctawhatchee River (after Conover and Leach 1975).

Paper Company, discharging to St. Andrew Bay after treatment at the Bay County Regional sewage treatment plant, and the St. Joe Paper Company, discharging directly to St. Joseph Bay. Historically, problem areas include Watson Bayou, Martin Bayou, the area which used to receive the International Paper Co. discharge, and Deer Point Lake at the head of North Bay. Hand and Jackman (1984) report no data since 1981. Watson Bayou had DO, bacteria, and nutrient problems. The bayou received discharge from the Millville Sewage Treatment Plant, which has since been diverted to the regional treatment plant. Martin Bayou had pH, nutrient, and aesthetic problems caused, in part, by a limited assimilative capacity, discharge from two small sewage package plants, and urban runoff. The area around the International Paper Co. discharge into St. Andrew Bay had low DO, high bacteria, and aesthetic problems; these discharges are now diverted to the regional plant. Deer Point Lake had low DO but is now, along with Crystal Lake and Gap Pond in Washington County, among the 50 lakes in the State listed in Myers and Edmiston (1983) as most in need of preservation and protection.

Biological sampling of water quality during 1973–78 was performed at six stations within this basin (Ross and Jones 1979). A station in fast flowing Econfina Creek near the town of Econfina showed the stream supporting an excellent macroinvertebrate community with high diversity and very high Biotic Index values. Occasional high bacteria counts were attributed to runoff. Stations in East Bay east of the mouth of Burnt Mill Creek and in West Bay on the gulf side south of Calloway exhibited good diversity and no trends were evident. Bacteria counts in West Bay exceeded Class II (i.e., shellfish propagation or harvesting) water quality standards. This was attributed to the greater development surrounding West Bay than is found around East Bay. A station in St. Andrew Bay near the entrance to West Bay and two stations in St. Joseph Bay, one off the T.H. Stone State Park on Cape San Blas and one off Port St. Joe, all had very high macroinvertebrate diversities and only occasional high bacteria counts. None of these three stations appeared to have been degraded by pollution during this study period.

Ground water in this basin, particularly near Panama City, lies in an area of the Floridan Aquifer of relatively low transmissibility. By 1963 groundwater levels had been lowered 61 m by pumping since the first deep well was drilled in 1908 (Musgrove et al. 1964). In 1964 pumping from one well field of 21 wells was stopped and water levels rose 50 m within 51 days.

The aquifer east of East Bay was tested in order to estimate pumping drawdown and determine consequences of increased use as a source of irrigation water (Barr and Pratt 1981). This investigation dealt with the multilayered nature of the aquifer in order to provide a more realistic estimate than that given by the simpler conventional methods. They found that the aquifer could be considered to be a low permeability layer about 90 m thick and a high permeability layer about 40 m thick. They concluded that heavy pumping from an irrigation well would be felt for several miles and that multiple wells would lead to substantial general water table decline. The NWFWMD also performed a reconnaissance of ground-water resources in southwestern Bay County (Barr and Wagner 1981).

Area water resources and their potential for fulfilling future demands, flooding problems, and area navigation problems are addressed in a U.S. Army Corps of Engineers study (USACE 1980a).

### 4.7.6 Choctawhatchee River Basin (Figure 54)

The Choctawhatchee River drains 12,030 km², of which 31% (3,700 km²) lies in Florida and 69% (8,330 km²) lies in Alabama. It is one of the four largest rivers in terms of flow in Florida and is second only to the Apalachicola River in floodplain area. In Florida the river is vigorous, slightly meandering, and heavily loaded with sediment. The Floridan Aquifer provides a major source of inflow to the river system (Hand and Jackman 1984). It travels 143 km from the Alabama border through an extremely swampy floodplain to Choctawhatchee Bay. At the mouth the flood plain is over 5 km wide and the river flows into the bay over shoals. The major Florida tributary is Holmes Creek, which flows approximately 80 km from southeastern Alabama to its Choctawhatchee confluence near the town of Ebro. The river has been designated an Outstanding Florida Water (OFW), in part because its forested floodplain is virtually undeveloped and its basin is the least developed major river corridor in Florida. Numerous streams, springs, and lakes characterize this basin. Two lakes, Lake Victor in Holmes County and Smith Lake in Washington County, are listed by Myers and Edmiston (1983) as among the 50 lakes in the State most in need of preservation and protection.

The Choctawhatchee River is presently undergoing a State-funded baseline study under the direction of Dr. Robert Livingston of Florida State University.

The Federal government authorized a navigable channel from the mouth of the Choctawhatchee River to Geneva, Alabama, just north of the Florida-Alabama border. However, commercial navigation was abandoned by the mid-1930's and Corps of Engineers maintenance ceased in 1942 (Florida Rivers Study Committee 1985). The strategic plan for regulating development within the basin was developed by the Florida Rivers Study Committee (1985).

Six cities with populations greater than 5,000 are located in this basin, five in Alabama and one (Chipley) in Florida. The largest Florida cities are Chipley, Bonifay, and Defuniak Springs. Some development in the river flood plain is beginning near Freeport and Caryville, primarily in the form of second homes.

Caryville is the major community along the Choctawhatchee River in Florida experiencing flooding problems. The town was almost totally inundated in 1975 after 45 cm of rain fell in 21 hours in the upper Pea River basin 1 month after a storm dropped 23 cm in 24 hours (U.S. Dept. of Agriculture 1975). This storm caused severe erosion damage to cropland as well. The severity of flooding was blamed on sediment deposition (Florida Rivers Study Committee 1985). To date the Corps of Engineers has concluded that the costs of flood control measures for the river would far outweigh the reduction in flood damage and the increased navigability. The NWFWMD also performed a study of sedimentation in the river (Musgrove 1983) and a flood reconnaissance (NWFWMD 1978a).

Forestry and agriculture constitute the major land use in this largely undeveloped basin. Large timber companies own most of the land along the river. The Choctawhatchee is a moderately fertile, alluvial river and is the richest in nitrogen and phosphorus of the Panhandle rivers, a result of the high clay content of basin soils and the runoff-promoting relief, as well as from anthropogenic nutrient inputs. The majority of sedimentation originates in the agricultural land of Alabama along the Choctawhatchee and Pea Rivers (Florida Rivers Study Committee 1985).

The water quality of the river in Florida is generally good except for its high sediment load. The river is probably the only economical source of potable water for the massive coastal development predicted for southern Walton County (Florida Rivers Study Committee 1985). Twenty-four sewage treatment plants discharge into the Alabama portion of the drainage basin, eight into the major tributary Pea River and sixteen into the Choctawhatchee and its smaller tributaries. In addition, nine industrial sites discharge into the Alabama portion, four into the Pea River and five into the Choctawhatchee and its tributaries. Nonpoint sources throughout the basin, particularly in Alabama, include extensive agriculture, including dairy and hog farms. Florida discharges causing water quality problems include sewage treatment plants in Chipley discharging to Alligator Creek, in Graceville discharging to Holmes Creek via Little Creek, and in Bonifay discharging to Holmes Creek via Camp Branch. These plants have caused bacteria, DO, and nutrient problems in the Florida portion of the basin (Hand and Jackman 1982, 1984); however, Graceville and Bonifay are upgrading their plants which should improve the water quality in this area. Additional water quality problems are caused by the Defuniak Spring sewage treatment plant discharging to Sandy Creek and a chicken processing plant discharging to Bruce Creek via Carpenter Creek (Hand and Jackman 1984).

Improper logging methods in Washington County, primarily clearcutting near surface streams and rivers, are increasing the sediment problems in the river. Because timber is the dominant industry in the area, any regulation to curb the practice is expected to be slow to occur (Florida Rivers Study Committee 1985). Holmes County is aware of sedimentation originating in the county and is working with the Soil Conservation Service to construct watershed projects to reduce it.

Biological sampling was performed at stations within the basin during 1973–78 for indications of water quality (Ross and Jones 1979). Stations in the Choctawhatchee River at SR 2 near the Alabama border and at SR 20 near Ebro had high Biotic Indices from qualitative macroinvertebrate sampling. Quantitative macroinvertebrate sampling showed high diversity at the SR 20 station. Both stations characterized the river as clean and fast flowing. Both stations also had rather high bacteria counts, especially the one at SR 2. Stations in Holmes Creek, at SR 2 near Graceville and at SR 79 near Vernon, both had moderately high macro-invertebrate diversities and occasional problems with bacteria. Showell Farms, an industrial point source, has been identified by the FDER district office as a significant polluter of Bruce Creek, a Choctawhatchee tributary. Fish communities in the Florida portion of the basin are considered healthy (Bass 1983).

Leaking gasoline from a small service station in northwestern Holmes County has contaminated the Floridan and Claiborne aquifers underlying the site (Busen et al. 1984). Corrective actions have been taken by FDER.

Flooding problems, area navigation problems, and area water resources and their potential for fulfilling future demands are addressed in a U.S. Army Corps of Engineers study (USACE 1980a).

### 4.7.7 Choctawhatchee Bay and Coastal Area (Figure 55)

This 1,190 km² coastal basin is drained by Lafayette, Magnolia, Alaqua, Rocky, Turkey, and Juniper Creeks. The largest stream is Alaqua Creek which drains 324 km². These streams have a high base flow (i.e., minimum flow) which is attributed to seepage from the Sand and Gravel Aquifer (USACE 1980a). In 1978–79 baseflow constituted 92%–98% of the total runoff from Turtle, Juniper, and Turkey Creeks in southern Okaloosa County (Barr et al. 1985). Choctawhatchee Bay, 40 km long by 5 km wide, averages 3 m in depth at the eastern end where the highly alluvial Choctawhatchee River flows into the bay (Musgrove 1983), and 9 m in the remainder of the bay. It receives flow from a watershed which includes the Choctawhatchee River and which totals approximately 13,830 km². The bay is characterized by its minimal connection with the Gulf of Mexico. East Pass, a narrow channel west of Destin and east of Santa Rosa Island, is the only connector and is often shoaled to a depth of 2 m (Collard 1976) requiring maintenance dredging to keep a 4 m channel open (USACE 1975). Fort Walton Beach, Destin, and Valparaiso are the largest cities in the basin, and the area around these cities along the gulf coast is undergoing rapid urban development.

A State-funded, in depth ecological baseline study of Choctawhatchee Bay during 1985–86 was recently completed (Livingston 1986b). Forty eight stations were monitored to provide information for preserving the bay in the face of expected massive development of surrounding lands. This study was prompted by plans to construct a bridge over the middle of the bay between White Point and Piney Point. Similar bridges were constructed in other bays without proper understanding of the factors controlling the estuary ecosystem, causing marked damage to the fisheries in parts of those estuaries (e.g., the St. George Island bridge in Apalachicola Bay). This study concluded that the proposed bridge can be constructed with minimal environmental damage if (1) observed seagrass beds in the vicinity of White Point and Piney Point were protected during the varous stages of bridge construction and operation, (2) storm-water runoff from the completed structure was processed adequately to prevent water quality deterioration in the bay, and (3) causeway construction was kept to a minimum to avoid direct habitat destruction and possible changes in the flushing rates of the areas at depth in western sections of the bay.

According to long-term area residents, during heavy flooding in the late 1920's, East Pass formed due to a "blow-out" of bay water (Livingston 1986b). Resulting higher salinity levels within the bay were associated with losses of the well-developed emergent and submergent vegetation, and a reduced fishery. Vertical salinity stratification was found in the deeper portions of the bay. These areas (especially in the central and western bay) also had vertical stratification of DO and were hypoxic at depth during various times of the year.

Figure 55. West-central Panhandle drainage basins—(G) Choctawhatchee Bay and (H) Yellow River (after Conover and Leach 1975).

Oyster Lake and Lake Stanley, located on the coastal spit south of Choctawhatchee Bay, are listed by Myers and Edmiston (1983) as among the 50 lakes in the State most needing preservation and protection. Surface waters within the basin had a pH varying from 4.2 to 7.4 and averaged 5.5 during 1978–79 (Barr et al. 1985). Water quality is good but would be corrosive to water distribution systems.

The low range of tides (averaging 0.2 m within the bay and 0.4 m in the adjacent gulf) produces minimal tidal flushing. This, combined with the fact that the salt water input is at the opposite end of the major source of freshwater input, results in poor mixing of bay waters. Bay salinity gradients followed river flow fluctuations; lowest salinities were found from December through April at the bay surface and highest salinities were found during summer-fall. As a result of these factors, the deeper water of Choctawhatchee Bay is some of the most stratified in the Panhandle, with the western two-thirds being sharply stratified and the eastern third weakly stratified (Collard 1976, Livingston 1986b). These conditions tend to produce a situation where the underlying high salinity water stagnates. Collard (1976) found that in summer the bottom of the bay was "biologically barren." Livingston (1986b) found that low DO levels associated with the salinity gradients in the deeper portions of the bay were life-limiting to various estuarine forms during certain months of the year. Low DO was most evident during summer months and by August the entire bay was hypoxic to anoxic at depth.

The baseline study also found that nitrogen levels were highest in the western sections of the bay (Cinco, Garnier, lower Rocky , and Boggy Bayous). Phosporus levels were also highest in the western end (Old Pass Lagoon, lower Rocky and Boggy Bayous). This was attributed to storm-water runoff from the Destin peninsula and adjacent developed areas. Pesticide and heavy-metal analyses were not performed in the study, but it is suggested that improved management of the Choctawhatchee River basin (e.g., regulation of pesticide use, municipal waster disposal, etc.) might improve the relatively low productivity found in the eastern portions of the bay.

A tabulation of past data and an excellent bibliography on the Choctawhatchee Bay system was compiled by the Northwest Florida Water Management District as it began development of an area management program (Northwest Florida Water Management District 1980b). This report cites a 1978 study of the bay (Taylor Biological Co. 1978) as being one of the most useful as a guide for policy and decision making.

The NWFWMD has compiled all their studies of the bay into one report (NWFWMD 1986). Included in the compilation is an investigation of the extremely high temperatures found below the halocline during 1984 sampling (Maristany and Cason 1984). The cause of this has not been resolved.

A waste-load allocation study was performed on the bay using a water-quality model from the University of South Florida (Johnson et al. 1974). This model examined the salinity, DO, N, and P concentrations, and the 5-day BOD. Water quality was found to be generally good with the exceptions of the Cinco, LaGrange, Boggy, and Alaqua Bayous, and nutrient levels in most of the bay indicated no eutrophication processes in existence. Their model indicated that conditions in Cinco and LaGrange Bayous could be improved by requiring secondary treatment for all discharges to the bay. They also expressed concern for the effects of urban runoff from future land development along the shores.

Stations in the basin were sampled for biological indications of water quality during 1973–78 (Ross and Jones 1979). A station a few kilometers up Lafayette Creek showed consistently high Biotic Index values from qualitative macroinvertebrate samples. Nutrient-enriched runoff from a large nearby farm contributed to the lush growth of aquatic plants. At a station in Choctawhatchee Bay near Fort Walton Beach macroinvertebrate diversities suggested a fairly healthy community. A station in the bay near Piney Point showed a significant decline in macroinvertebrate diversity during the sampling period. Both the bay stations were being influenced by the rapid development in the west end of the bay. Occasional occurrences of bacteria levels in excess of Class II (i.e., shellfish propagation or harvesting) water quality standards were noted at the Piney Point station, though counts were generally low.

According to Hand and Jackman (1984) the Choctawhatchee Bay basin has historically had good water quality in all areas and at present Old Pass Lagoon, which drains the coastal area of Destin, is the only area exhibiting poor water quality. This small lagoon is in the process of becoming a landlocked salt lake due to the natural shifting of coastal sand, and a channel is maintained by dredging. The lagoon has poor circulation and receives nutrients from surrounding housing developments and possibly from the drainage of nutrient-enriched shallow ground water from a nearby sewage treatment plant spray field (Donald Esry, Northwest Florida Water Management District; pers. comm.). The circulation problems are aggravated by the presence of numerous dredge-and-fill constructed finger canals. As a result Old Pass Lagoon suffers from low DO levels and frequent fish kills. The Northwest Florida Water Management District is planning to install a large pump to transfer water from the Gulf of Mexico into the lagoon to enhance the circulation and ease the water quality problems.

The NWFWMD examined the ground water conditions around Choctawhatchee Bay (Barr 1983). Additionally, they investigated the ground water near the wastewater percolation ponds in Destin for increased nutrients (Barr and Bowman 1985).

Area water resources and their potential for fulfilling future demands, flooding problems, and area navigation problems are addressed in a USACE study (USACE 1980a). The USACE also prepared a report concerning coastal storm flooding in the Destin area (USACE 1970). The highest flood tide reported occurred in 1926 and was 3–3.5 m above mean sea level on the beach. The most severe storm tide expected, given area conditions, was predicted to be 4.25 m above sea level. These calculations did not take into consideration the predicted, relatively rapid rise in world-wide sea level (Hoffman et al. 1983) (see section 4.8.1).

### 4.7.8 Yellow River Basin (Figure 55)

The Yellow River drains 3,540 km$^2$, of which 63% (2,220 km$^2$) is in Florida and 37% (1,320 km$^2$) is in Alabama, and drains into Blackwater Bay. This river, along with its only major tributary, the Shoal River, and the neighboring Blackwater River are considered classic sand-bottom streams (Beck 1965). The waters are clear and of relatively low primary productivity. In this basin, Lake Jackson, Juniper Lake, and Oyster Lake are listed by Myers and Edmiston (1983) as among the 50 lakes in the State most needing preservation and protection.

Forestry is the predominant land use with agriculture second. Milligan and Crestview are the largest towns in the basin. The main sources of pollution in the area include agricultural and urban runoff and domestic sewage discharge (Hand and Jackman 1984). The only problem area in the basin is Trammel Creek, which receives treated sewage from the Crestview sewage treatment plant. This discharge caused nutrient and bacterial problems in the creek, but assimilation is complete and water quality good by the time the creek reaches the Yellow River. Crestview is in the process of upgrading their plant. A 1979 train derailment spilled anhydrous ammonia into the Yellow River just below its confluence with Trammel Creek. Hand and Jackman (1984) reported that the river benthos in the area of the spill still showed reduced diversity.

The Yellow River exhibits only fair to good water quality in Alabama because of DO, nutrient, and bacterial violations associated with sewage treatment plant discharges. The Yellow River has not been extensively sampled, though indications are that the river in Florida is relatively unspoiled (FDER 1986c). Sampling at a station in the Shoal and in the Yellow Rivers during 1973–78 showed healthy macroinvertebrate communities and no signs of DO deficiencies (Ross and Jones 1979). Occasionally high total coliform bacteria counts from the Shoal River station east of Crestview were attributed to agricultural runoff. Higher fecal coliform counts from the Yellow River station south of Holt were attributed to the Crestview sewage treatment plant.

### 4.7.9 Blackwater River Basin (Figure 56)

The Blackwater River drains 2,230 km$^2$ of which 81% (1,810 km$^2$) is in Florida and 19% (420 km$^2$) is in Alabama. The river originates north of Bradley, Alabama and flows south to Blackwater Bay. Groundwater seepage from the Sand and Gravel Aquifer provides much of the riverflow (USACE 1980b, Hand and Jackman 1984). Most of the watershed is contained within two State forests, the Conecuh in Alabama and the Blackwater in Florida. Thus forestry is the predominant land use, with agriculture of secondary importance. The river's major tributaries include Panther, Big Juniper, Big Coldwater, and Pond Creeks. The Blackwater River, a clear, sand-bottomed stream, has been designated an OFW (i.e., no significant degradation allowed) and receives heavy recreational use. Within the basin, Hurricane Lake, Lake Karick, and Bear Lake are listed by Myers and Edmiston (1983) as

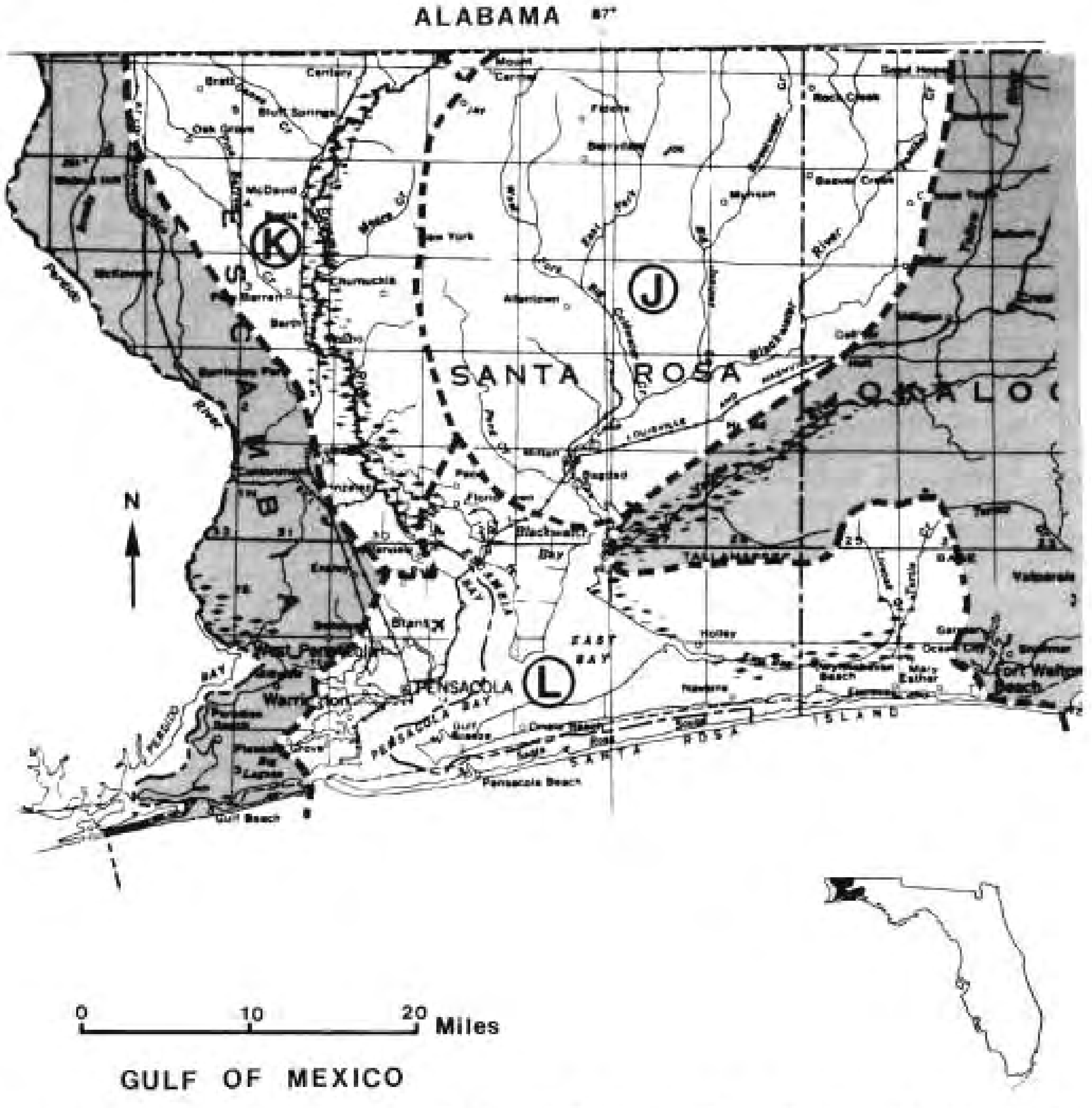

Figure 56. West Panhandle drainage basins–(J) Blackwater River, (K) Escambia River and (L) Escambia Bay (after Conover and Leach 1975).

among the 50 lakes in the State most needing preservation and protection.

This river basin is sparsely developed and populated; most of the population is located near Milton. Water quality problems in the Blackwater River are limited to the stretch at the mouth of the river below Milton. Here, chronically high bacteria and nutrient levels have been recorded because of the discharges from the Milton sewage treatment plant