SOUTH CAROLINA'S WATER RESOURCES

THE WATER CYCLE

The earth's water is in constant motion above, on, and under its surface. Energy from the sun causes water to evaporate from the surface and drives soil and plants to transpire water into the atmosphere. This atmospheric water concentrates into cloud formations, and, under proper meteorological conditions, precipitates to earth. Once on the earth's surface, water flows into streams, lakes, and oceans; infiltrates into the subsurface and enters ground-water storage; or evaporates and transpires into the atmosphere. This continuous change in the geographical position and physical state of water is known as the hydrologic cycle, or water cycle. The cycle is a worldwide process modified by local geographical and meteorological factors. Regional variation in the water cycle affects vegetation, topography, and climate and results in landscapes ranging from deserts to rain forests. Precipitation, evapotranspiration, ground-water infiltration, and surface runoff compose the four basic processes of the hydrologic cycle (Figure 3-1).

Precipitation

The air contains varying amounts of water vapor. Warm air can hold greater concentrations of water molecules than cool air. Winds, temperature variations, and physical and meteorological obstructions (hills, mountains, colder or slower-moving air masses) cause air and water vapor to rise higher into the atmosphere. As the air rises, atmospheric pressure decreases and the air expands, cools, and loses its moisture-holding ability. When this cooling air reaches its saturation point, the gaseous water molecules condense to the liquid state. Clouds are the visible manifestation of moisture-laden air reaching saturation. Water droplets are extremely small and are kept aloft by air currents initially. Where these droplets coalesce around ice and dust particles, larger drops may form and fall to earth. Depending on the surrounding air temperatures and atmospheric conditions, these drops may fall as liquid or solid precipitation or may even evaporate before reaching the earth.

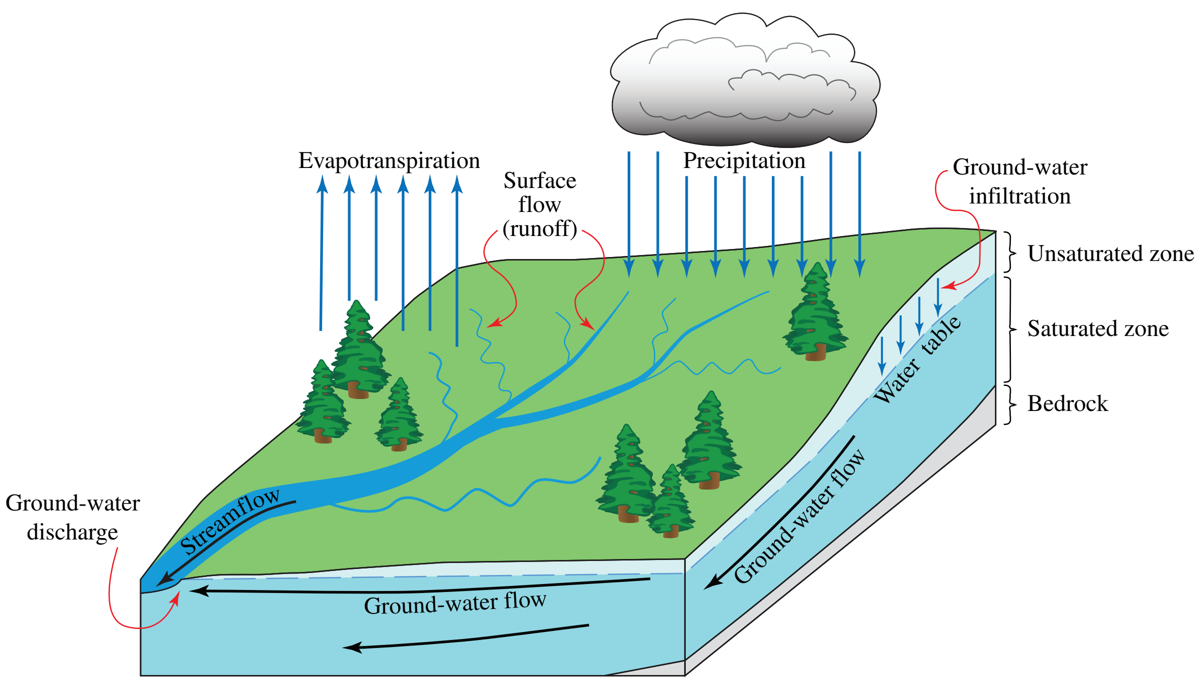

Figure 3-1. The water cycle.

Evapotranspiration

Most precipitation is returned directly to the atmosphere through the combined processes of evaporation and transpiration, termed evapotranspiration or ET. Evaporation is the process by which water changes from the liquid state to the vapor or gaseous state. Temperature, humidity, and wind are the principal environmental factors affecting evaporation rates. Energy from the sun drives the hydrologic cycle and is especially important to the process of evaporation. Solar radiation increases air and water temperatures at different rates; water molecules on the surface of soil, water, and plants heat faster than air molecules. This temperature difference causes higher vapor pressure in the water than in the air, and, to equalize the pressure, liquid water vaporizes and moves into the atmosphere. In general, increasing the vapor-pressure differential between water and air increases the rate of evaporation.

Evaporation rates also are affected by the relative humidity, a measure of the moisture content of air. The relative humidity is simply the ratio of water vapor in the air to the amount of water needed to saturate the air at a particular temperature, expressed as a percentage. As water molecules gradually saturate the air near the site of evaporation, relative humidity adjacent to the site increases, and the rate of evaporation decreases. When the relative humidity reaches 100 percent, evaporation stops.

The mixing influence of the wind can greatly accelerate evaporation. Where the saturated layer of air above an evaporating water body is disturbed by wind and is replaced with drier air, evaporation will continue.

Water also is lost to the atmosphere by transpiration from plants. Plants require large quantities of water for the transport of nutrients and food (sugars), formation of plant cells, photosynthesis, and gas exchange. Water enters plants through the root system, moves through the plant to the leaves, and is then transpired into the atmosphere through stomata, tiny openings on the underside of leaves.

Transpiration is more variable than evaporation because the water molecules pass through living organisms before entering the atmosphere. These water molecules are subject to the same physical factors as in evaporation (temperature, wind, and humidity) and, additionally, are subject to the numerous chemical and biological processes within the plant. Transpiration rates depend on the plant species, time of day, season, and on the availability of water in the root zone.

Ground-Water Infiltration

Precipitation that does not evaporate, transpire, or fall directly on surface-water bodies may infiltrate the earth's crust and contribute to soil moisture and ground-water storage. The rate of ground-water infiltration depends on the soil characteristics and moisture, the type and extent of vegetative cover, and the topography of the terrain. Some water that enters the soil moves downward to recharge underlying ground-water reserves, but much of the water is retained as droplets and films attached to soil particles near the surface. This soil moisture is easily driven into the atmosphere by evaporation and plant transpiration, and soil moisture must be replaced regularly to sustain vegetation. Soil moisture also affects the rate and quantity of infiltration to underlying water-table aquifers. Soil particles accumulate water on their surfaces by molecular attraction until the force of gravity acting on the water exceeds the forces of attraction in the soil; the saturation of soils and storage of ground water occur only after the volume and weight of percolating water exceed the soil's capacity to retain water by molecular attraction. The ground water discharges to the surface where aquifers are incised by stream channels, and that ground water represents the base flow to streams and rivers.

Surface Runoff

Precipitation that does not return to the atmosphere through evaporation and transpiration and cannot infiltrate the earth because the soil is saturated or the precipitation rate exceeds the soil's infiltration capacity becomes surface runoff. This excess water pools on the surface and is diverted to surface streams. The amount of runoff available to streamflow depends on rainfall intensity and duration, type and extent of vegetative cover, soil-moisture state, and the slope and area of the stream-drainage basin. Surface runoff, or overland flow, is a brief and typically small component of total streamflow but can be a major contributor to flooding as stream-basin soils become saturated.

SURFACE-WATER RESOURCES

Historically, the State's numerous rivers served as transportation routes, fishing-and-hunting grounds, and drinking water for Native Americans and Europeans settling along their shores. Later these streams were used to irrigate rice plantations, power grist and textile mills, and transport people and goods. More recent water development includes hydroelectric- and thermoelectric-power plants, flood-control projects, and increased withdrawals for established uses such as public supply, industry, and irrigation. Presently, surface water is used to meet most of the water demand in the State.

River Systems

On the basis of hydrologic drainage characteristics, the State contains all or parts of four major basins: the Pee Dee, Santee, Ashley-Combahee-Edisto (ACE), and Savannah (Figure 3-2). The U.S. Water Resources Council, in cooperation with the U.S. Geological Survey, has subdivided these major basins into several hydrologic units (U.S. Geological Survey, 1974). The 15 subbasins discussed in this report were derived from these hydrologic units, and are listed below under their respective major drainage basins.

- **Pee Dee River basin**
  Pee Dee River subbasin
  Lynches River subbasin
  Little Pee Dee River subbasin
  Black River subbasin
  Waccamaw River subbasin

- **Santee River basin**
  Broad River subbasin
  Saluda River subbasin
  Catawba-Wateree River subbasin
  Congaree River subbasin
  Santee River subbasin

- **Ashley-Combahee-Edisto (ACE) River basin**
  Ashley-Cooper River subbasin
  Edisto River subbasin
  Combahee-Coosawhatchie River subbasin

- **Savannah River basin**
  Upper Savannah River subbasin
  Lower Savannah River subbasin

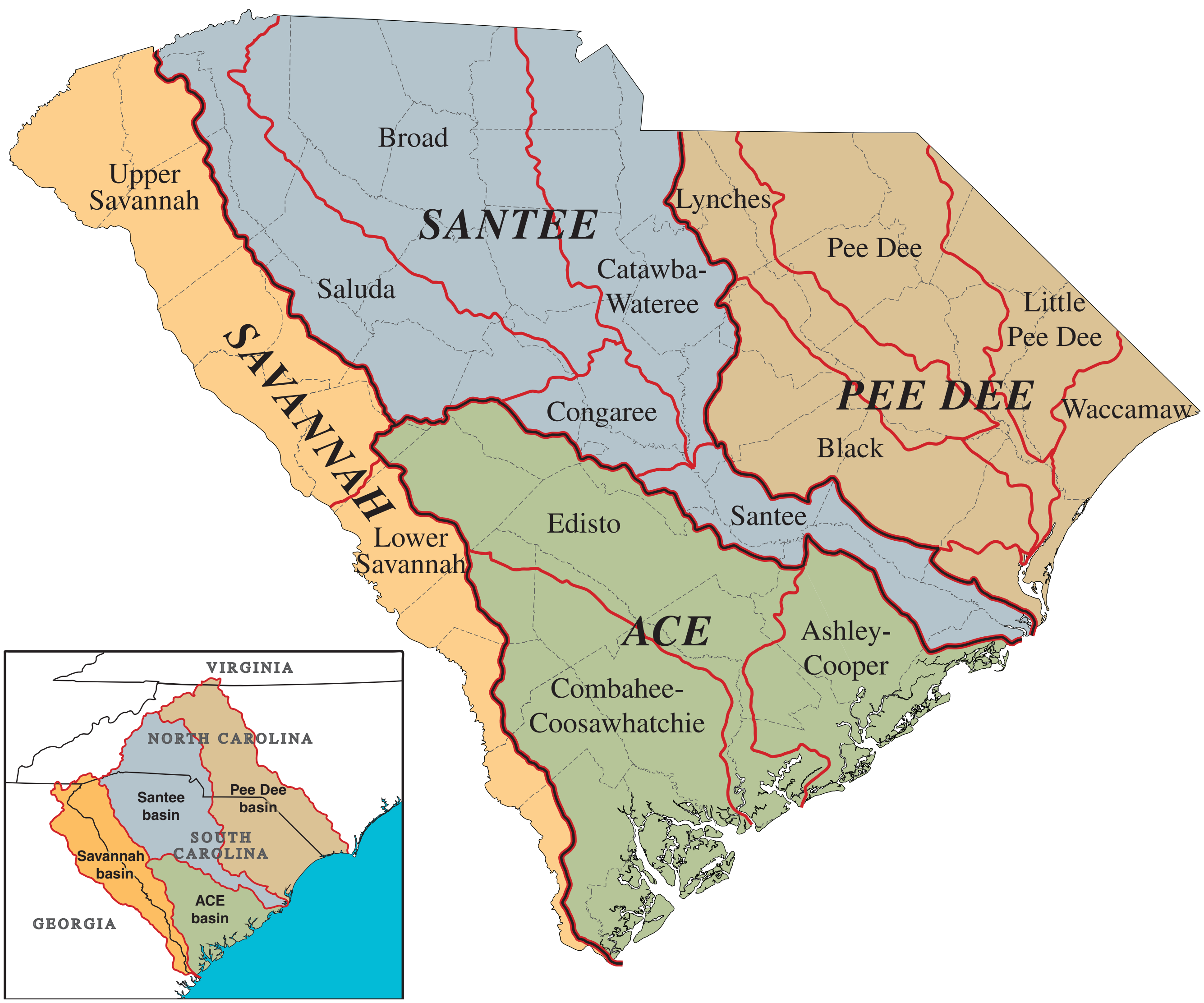

Figure 3-2. Major stream basins and subbasins of South Carolina.

Streamflow Monitoring

The U.S. Geological Survey (USGS) conducts most of the streamflow monitoring in South Carolina, with the South Carolina Department of Natural Resources (DNR), South Carolina Department of Health and Environmental Control (DHEC), and other agencies providing matching funds for most hourly-measured gaging stations. The monitoring network consists of streamflow gages, stage-only gages, and crest-stage gages (Figures 3-3, 3-4, and 3-5). Streamflow gages measure stages hourly, and their data are combined with stream-bottom profiles and periodic flow-velocity profiles to calculate flow volumes. Stage-only stations record lake and stream levels but are not used to calculate flows; crest gages record peak levels during flood events.

The USGS identifies each streamflow gaging station with an eight-digit number. The number reflects the downstream-order position of the station in relation to the main stream and other gaging stations. The complete eight-digit number, such as 02175000, includes the two-digit hydrologic part number (02) plus a six-digit downstream order number (175000) (U.S. Geological Survey, 1980). The gaging-station numbers used in this report are an accepted abbreviated version of the complete eight-digit number. In general, the first two digits (02) referring to South Atlantic Slope basins were deleted, and the last two digits were deleted if equal to zero but follow a decimal point if greater than zero (02172020 becomes 1720.2).

About 100 cooperatively and federally funded continuous-recording stations monitor streamflow. DHEC

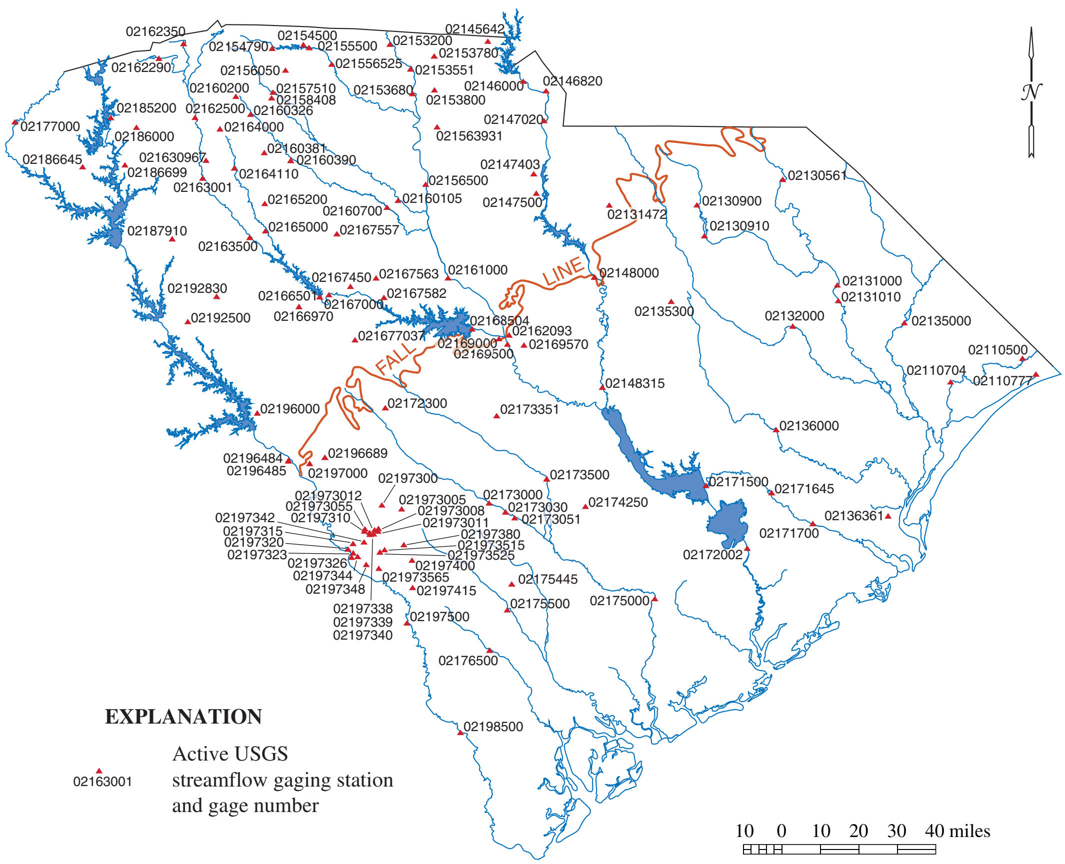

Figure 3-3. USGS streamflow gaging stations.

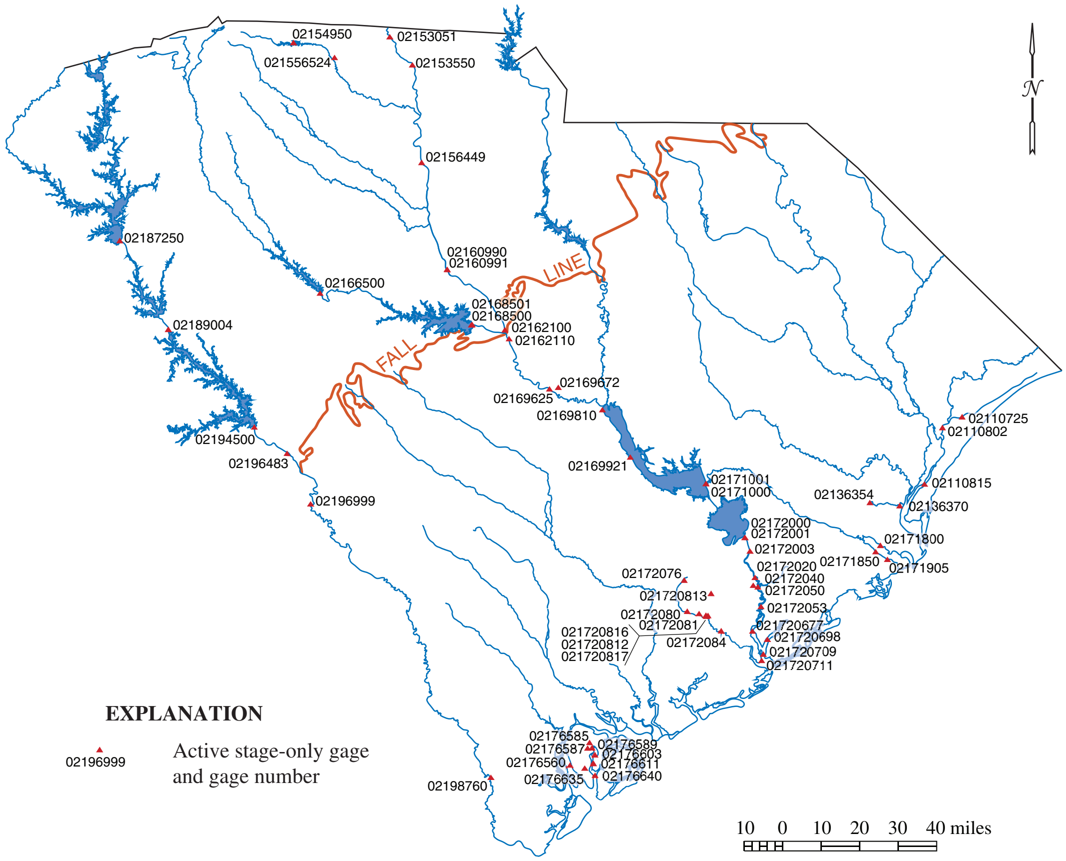

Figure 3-4. USGS stage-only gaging stations.

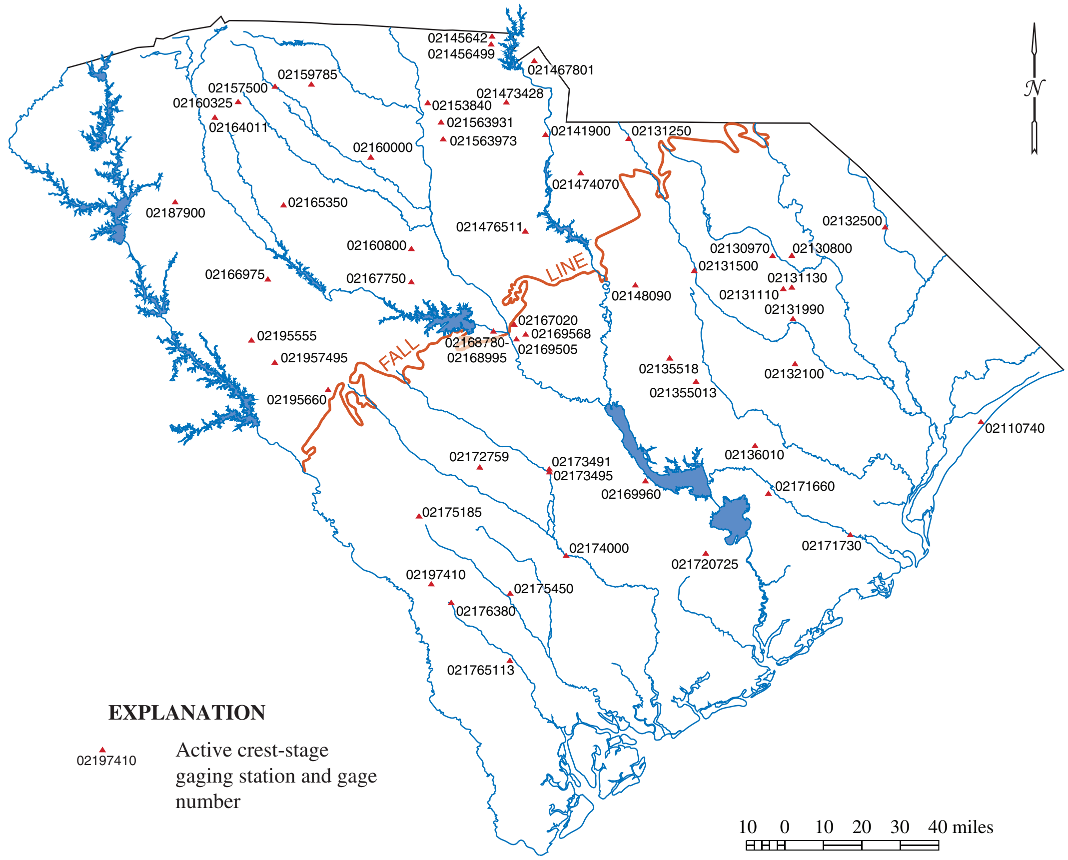

Figure 3-5. USGS crest-gage stations.

periodically measures streamflow at 314 primary water-quality sampling stations and uses those data to calculate waste-load allocation for streams. DNR operates temporary stage-only stations for saltwater-intrusion studies and salt-marsh restoration projects.

Effective monitoring and interpretation of stage data depend on adequate and consistent funding, because the number, distribution, and duration of gage-station records affect the timeliness and quality of streamflow predictions. In particular, statistically meaningful flow histories and accurate trend predictions require record durations of more than 20 years. Multiple gage sites and real-time access to recorded data likewise affect the quality and utility of flow predictions. The need for more and better data increases as the State's population grows, but the number of stations has diminished owing to funding reductions during recent years.

SURFACE WATER OVERVIEW

Average streamflow in South Carolina is about 33 billion gallons per day. The Santee River in its original state had the highest average streamflow in South Carolina with 18,700 cfs (cubic feet per second). This discharge was the third largest on the East Coast, with only the Susquehanna (37,190 cfs) and Hudson (19,500 cfs) Rivers discharging more water to the Atlantic Ocean. Before the completion of the Cooper River rediversion project, most of the Santee River flow, about 15,000 cfs, was diverted to the Cooper River. Since completion of the project, flow of 5,500 to 7,500 cfs is rediverted to the Santee River, and the Cooper River flow is about 4,500 cfs. Other major rivers in the State are the Great Pee Dee River, with an average discharge of 15,600 cfs, and the Savannah River, which discharges about 12,100 cfs.

Throughout the State, streamflow is generally highest

SUPPLEMENTAL INFORMATION BOX 3-1

Surface-Water Analyses

In this report, analyses of surface-water hydrology for the State's streams (except the Ashley-Cooper subbasin) consist of streamflow-characteristics tables and flow-duration hydrographs. The records used to construct these tables and hydrographs are from USGS gaging stations. Gaging-station records and status are available from the U.S. Geological Survey.

Each streamflow-characteristics table consists of the gaging-station number, name, and location; drainage area; average daily flow; 90th percentile flow; minimum daily flow and year of occurrence; maximum daily flow and year of occurrence; and highest peak flow and year of occurrence.

Hydrographs are plots of streamflow against time or date. Duration hydrographs are plots of selected flow percentiles versus date, and help resource managers to statistically quantify the variability of streamflow at a gaging station. Each duration hydrograph contains bands that show the low-, normal-, and high-streamflow conditions for each day of the year. Daily average flows are used to construct these bands for nonregulated streams, and 7-day average flows are used to construct these bands for regulated streams. Duration hydrographs are constructed only for gages with at least 30 years of record.

Surface-Water Terminology

7-day average flow: the flow of a stream averaged over a 7-day period. Hydrographs made using 7-day running averages (rather than daily averages) are often used for regulated streams in order to smooth out highly variable flows caused by widely fluctuating reservoir releases.

Continuous-discharge station: a site at which (a) stage or streamflow is recorded on a continuous basis or (b) water-quality, sediment, or other hydrologic measurements are recorded at least daily.

Crest gage: measures the peak state of a rising stream or impoundment. A crest gage commonly consists of a wooden stick and powdered cork inside a vertical, perforated pipe. The cork adheres to the stick at the highest point of a flood stage, and the cork level is compared with a known elevation datum to calculate peak stage.

Cubic foot per second (cfs): the discharge rate representing 1 cubic foot passing a given point in 1 second—about 7.5 gallons per second, 450 gallons per minute, or 646,000 gallons per day.

Cubic foot per second per square mile (cfsm): the discharge in cubic feet per second divided by the drainage area in square miles.

Discharge: flow, as the volume of water that passes a given point in a given period—commonly stated as cubic feet per second.

Flow percentile: the percentage of time for which a flow is not exceeded at a particular gaging station. For example, the 90th percentile flow is equal to or greater than 90 percent of the discharge values recorded at that gage. In general, a percentile greater than 75 is considered above normal (high), a percentile between 25 and 75 is considered normal, and a percentile less than 25 is considered below normal (low).

Stage-only gaging station: a continuous gaging station used only for determination of stream and lake levels.

Streamflow gaging station: site at which the stream-elevation records, stream-bottom profile, and periodic stream-velocity measurements are used to calculate flow.

during late winter and early spring and lowest during late summer and fall. Minimum flows generally occur only during the summer and fall, but maximum flows may occur at any time during the year.

Streams in the Blue Ridge and upper Coastal Plain provinces generally exhibit greater flow per square mile of drainage area and well-sustained base flow. High average rainfall with little variation year round and substantial ground-water reserves ensure reliable flows in the Blue Ridge streams. Reliable streamflows in the upper Coastal Plain are attributed primarily to discharge from ground-water storage. Lower Piedmont and lower Coastal Plain streams exhibit highly variable flows, small flow per square mile of drainage area, and poorly sustained low flow. Seasonal streamflow variation in these streams is substantial owing to their dependence on rainfall and runoff. Dry conditions during late summer and fall result in minimum-flow conditions with some streams periodically experiencing no-flow conditions.

FACTORS AFFECTING STREAMFLOW

South Carolina's abundant surface-water resource is not geographically and temporally uniform. Streamflow is influenced by natural and man-induced conditions. Physiographic characteristics of the watershed, which affect the seasonal, yearly, and geographical variation in precipitation and evaporation, greatly affect flow. Modification of watercourses for hydroelectric-power generation, navigation, flood control, and water withdrawal also impacts streamflow.

Physiography

Characteristics of the land surface greatly affect local and regional hydrology. Streams in each of the State's provinces —Blue Ridge, Piedmont, and Coastal Plain—exhibit flow characteristic of the province. The following sections describe general surface-water characteristics in each of these provinces.

Blue Ridge. This mountainous region of the State has steep terrain with some stream gradients greater than 250 feet per mile (Bloxham, 1979). The geology of this region significantly affects surface-water flow. Surface fractures in crystalline rock provide channels for runoff. Because of this, stream channels are often angular and local drainage patterns are often rectangular (Acker and Hatcher, 1970). These fractures also provide avenues for ground-water flow and storage. As the deeply incised streams of this region intercept the crystalline-rock aquifers, relatively large quantities of ground water contribute to the streamflow. Overlying the crystalline rock is a layer of weathered bedrock termed saprolite. This layer of semipermeable material stores ground water for release later to crystalline-rock aquifers and to streams. Although some rainfall infiltrates the saprolite layer, the steep terrain and semipermeable soils cause much of the rainfall to run off rapidly into stream channels. Blue Ridge province streams, therefore, typically exhibit rapidly fluctuating flows dependent on rainfall and ensuing runoff but have well-sustained base flow due to substantial ground-water discharge.

Piedmont. The rolling hills of the Piedmont range in elevation from 1,000 feet near the mountains to 400 feet at the Fall Line. Stream gradients range from 60 feet per mile in the mountain foothills to about 5 feet per mile near the Fall Line (Bloxham, 1981). Bedrock in this province is jointed and fractured similarly to that in the Blue Ridge province, but ground-water storage and base flow generally decrease downslope across the Piedmont for two reasons: (1) saprolite permeability decreases from the upper Piedmont to the lower Piedmont, retarding rainwater infiltration and causing more surface-water runoff; and (2) stream channels are less deeply incised than in the Blue Ridge province, which decreases the number of intercepted fracture zones available to support base flow. Piedmont streamflow is, therefore, highly dependent on rainfall and runoff with little ground-water support. No-flow conditions during summer and fall months are common for smaller streams, especially in the lower Piedmont region, and even basins of several hundred square miles may experience no flow under extreme conditions.

Upper Coastal Plain. The upper Coastal Plain extends southeastward from the Fall Line to the Citronelle Escarpment (Cooke, 1936) and is characterized by moderately sloped, irregularly shaped, and rounded terrain. Stream gradients range from 5 to 20 feet per mile (Bloxham, 1979). This region includes outcrops of the Middendorf, Barnwell, and McBean Formations that are composed of loosely consolidated sediments overlain by coarse sand to sandy loam soils. Streams deeply incise these porous materials, resulting in shallow ground-water aquifers above stream level. These aquifers discharge into streambeds to support flow, especially during periods of low rainfall. In addition, these shallow aquifers absorb large quantities of rainfall, thus reducing peak runoff to streams. Upper Coastal Plain streamflows are, therefore, supported primarily by discharge from ground-water storage and typically exhibit less variable flow year round with well-sustained base flow.

Middle and Lower Coastal Plain. The middle and lower Coastal Plain extends from the Citronelle Escarpment to the coast, an area approximately 80 miles wide. This region has moderate to low relief, shallow stream incisement, stream gradients of about 3.5 feet per mile (Bloxham, 1979), and extensive swamplands associated with large segments of the river systems. Middle and lower Coastal Plain streams depend more on rainfall and runoff than on ground-water discharge to support flow. The highly permeable soils in this region are similar to those of the upper Coastal Plain, which readily absorb rainfall and retard runoff to streams. Streamflows, therefore, rise and fall gradually. The low relief and shallow stream incisement of the region allows little ground-water storage area above stream channels. Therefore, ground water provides less support than in the upper Coastal Plain, and these streams typically have poorly sustained base flows. No-flow conditions in the middle and lower Coastal Plain are common during dry periods.

Precipitation and Evapotranspiration

Average annual rainfall is greatest in the Blue Ridge province (up to 80 inches), decreases to about 45 inches over most of the Piedmont and Coastal Plain regions, and increases to about 52 inches near the coast (Figure 3-6). Rainfall amounts vary seasonally, with peaks generally occurring in the winter and summer and minimums in the fall.

The potential evapotranspiration (PET) rate increases from north to south across South Carolina, and the average annual ET rates range from 29.6 inches near Spartanburg to 46.6 inches at Savannah, Ga. (Figure 3-7). Evapotranspiration mainly is controlled by air temperature but is modified by relative humidity and wind speed. Marked seasonal variation occurs, with the highest monthly rates occurring during the summer (3.5–4.9 inches per month) and the lowest rates occurring during the winter (0.35–1.0 inches per month).

The amount of runoff and ground-water base flow contributing to streamflow equals total rainfall minus the amount contributed to evapotranspiration, and combined runoff and base flow ranges from approximately 10 to 35 inches per year (Figure 3-8). Where ground-water infiltration is negligible, as in the Piedmont and lower Coastal Plain, the interaction of rainfall and evapotranspiration are major factors affecting streamflow. Flow characteristics in Piedmont and lower Coastal Plain streams primarily depend on rainfall and runoff, and flows reflect seasonal variations in precipitation and evapotranspiration (Figure 3-9).

Where ground-water base flow is significant, as in the upper Coastal Plain and Blue Ridge provinces, flows are more regular throughout the year. The interaction of rainfall and evapotranspiration and the resulting runoff are greatly impacted by porous soil and substratum in the two provinces. Average annual streamflow may vary considerably, as Figure 3-10 illustrates, but the variation primarily is caused by differences in yearly precipitation.

SURFACE-WATER DEVELOPMENT

Alteration of the State's streams dates to early colonialism. Canals were built; streams were cleared and dredged to improve navigation; and numerous watersheds were modified to drain agricultural land and minimize flooding. Many of these developments also provided stillwater habitat for fish and wildlife and provided areas for recreational activities.

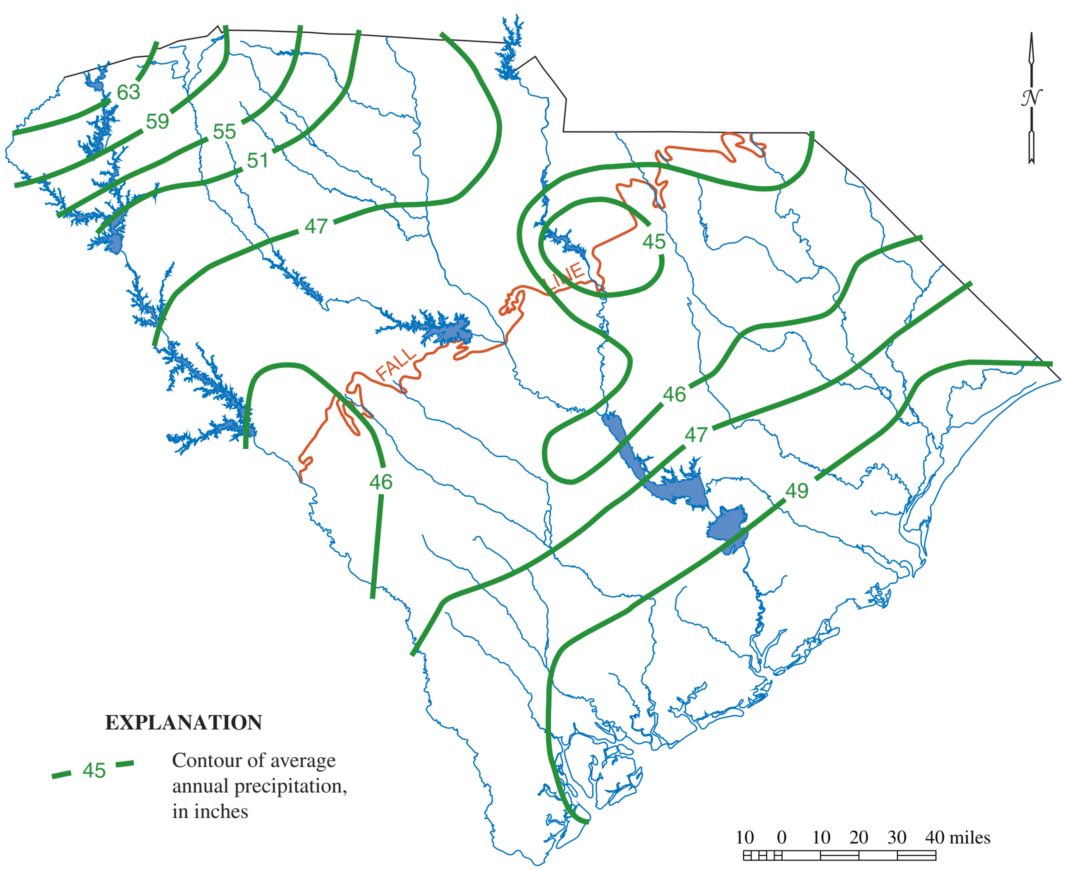

Figure 3-6. Distribution of average annual precipitation in South Carolina, 1948–1990 (Badr and others, 2004).

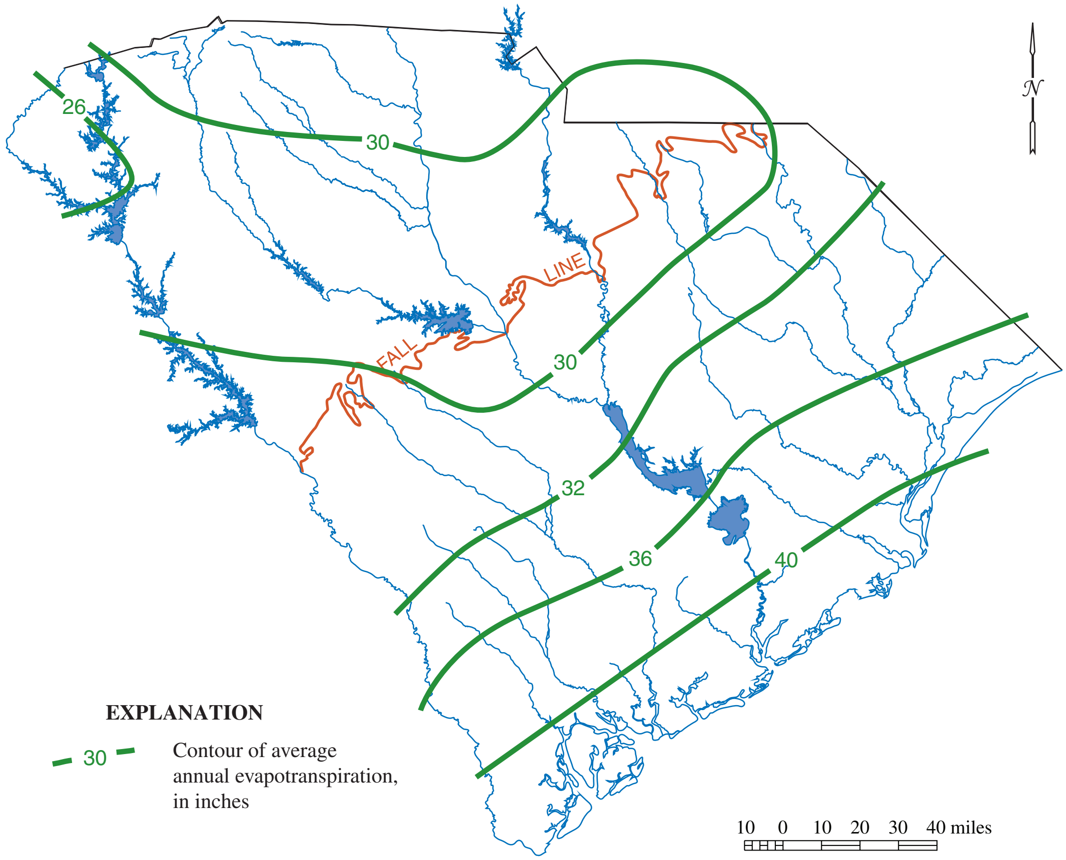

Figure 3-7. Distribution of average annual evapotranspiration in South Carolina, 1948–1990 (Badr and others, 2004).

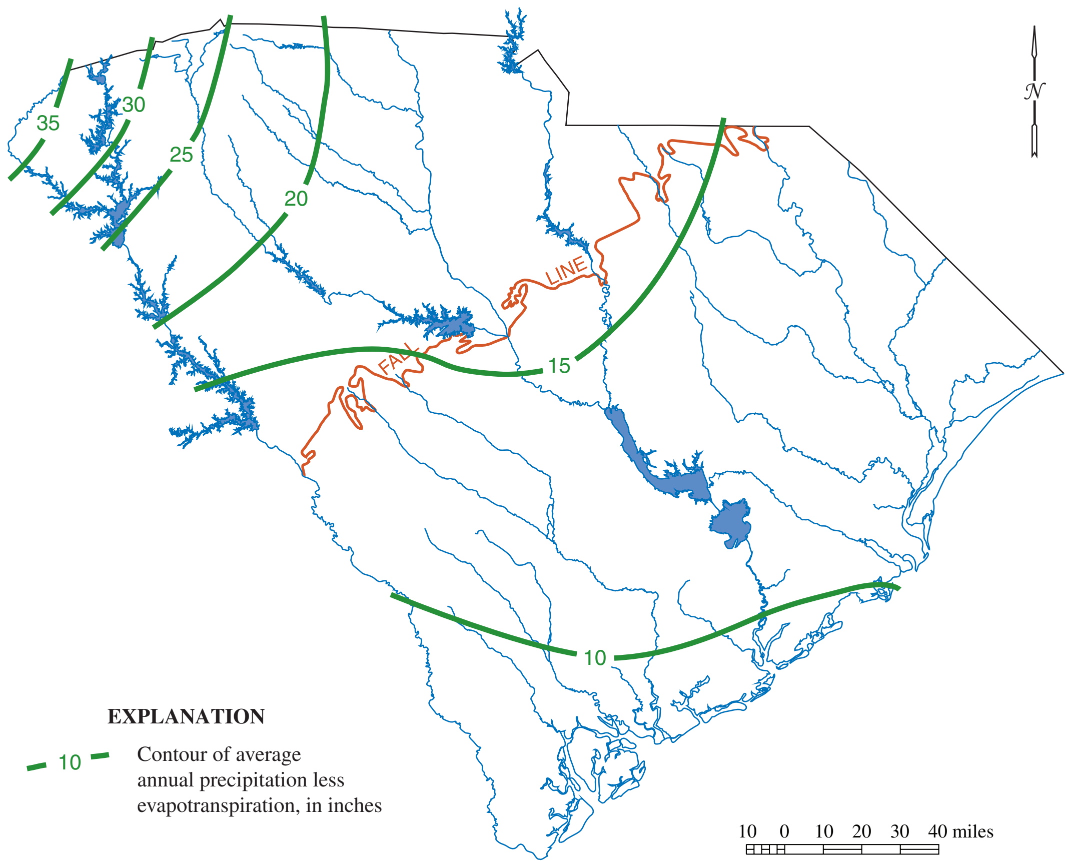

Figure 3-8. Distribution of average annual runoff and base flow in South Carolina, 1948–1990 (Badr and others, 2004).

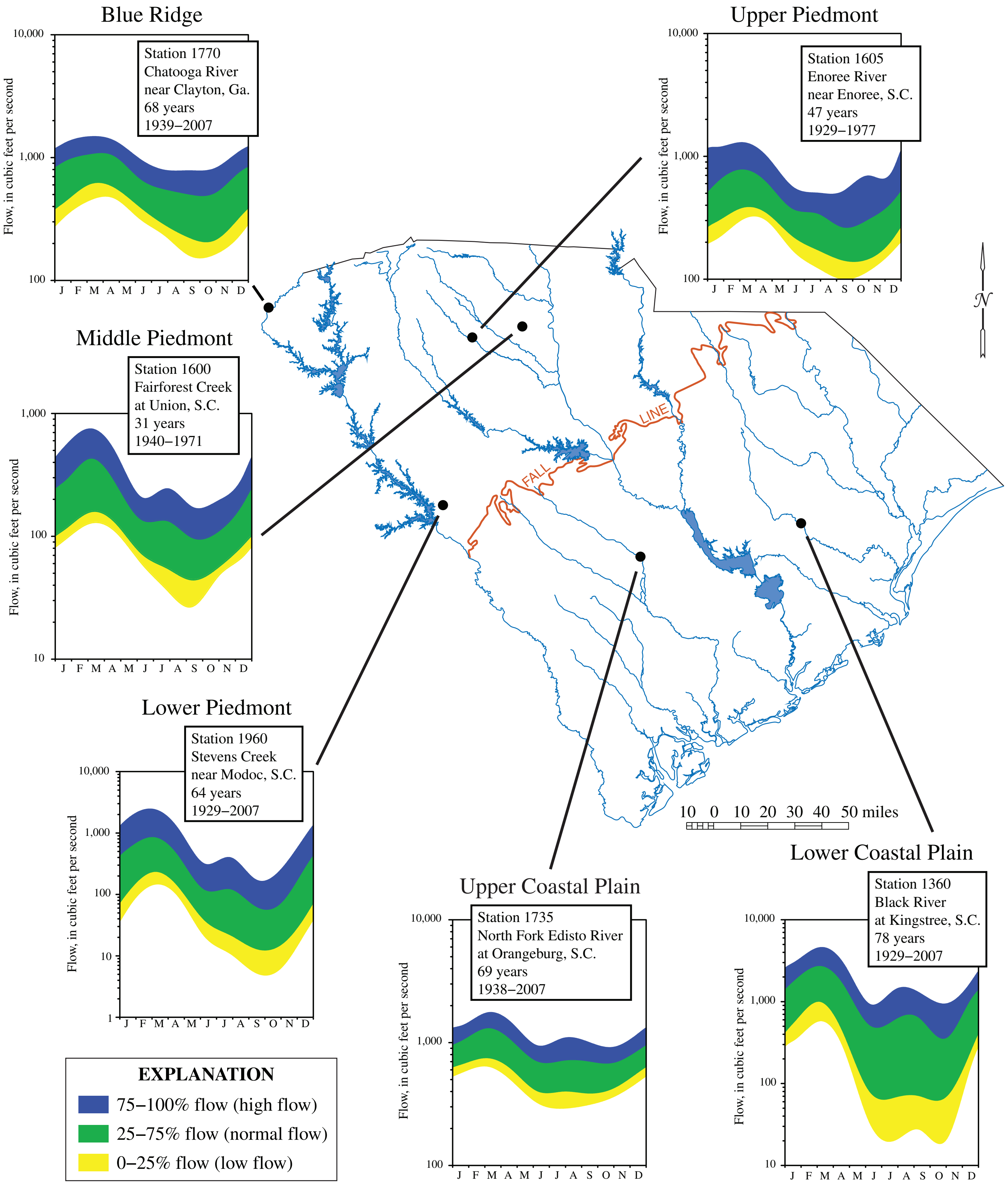

Figure 3-9. Typical flow-duration hydrographs for the physiographic provinces of South Carolina.

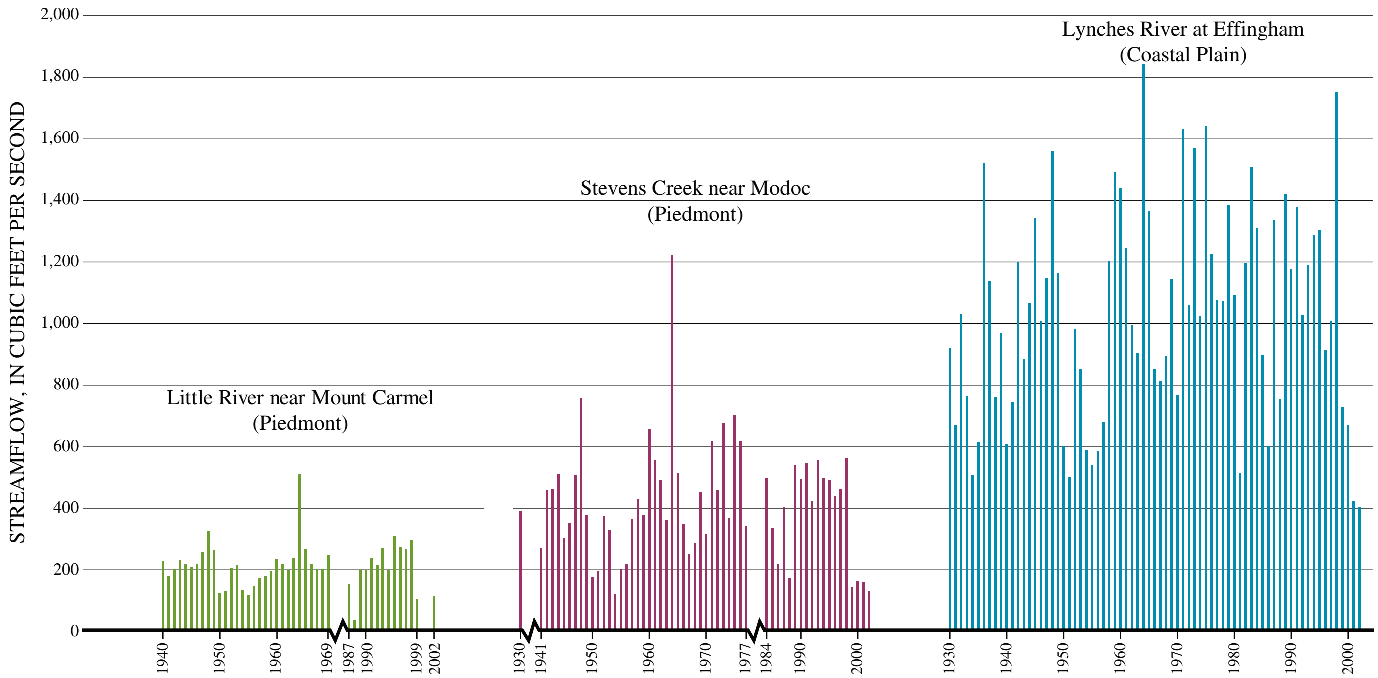

Figure 3-10. Average yearly streamflow of typical streams in the Piedmont and Coastal Plain of South Carolina.

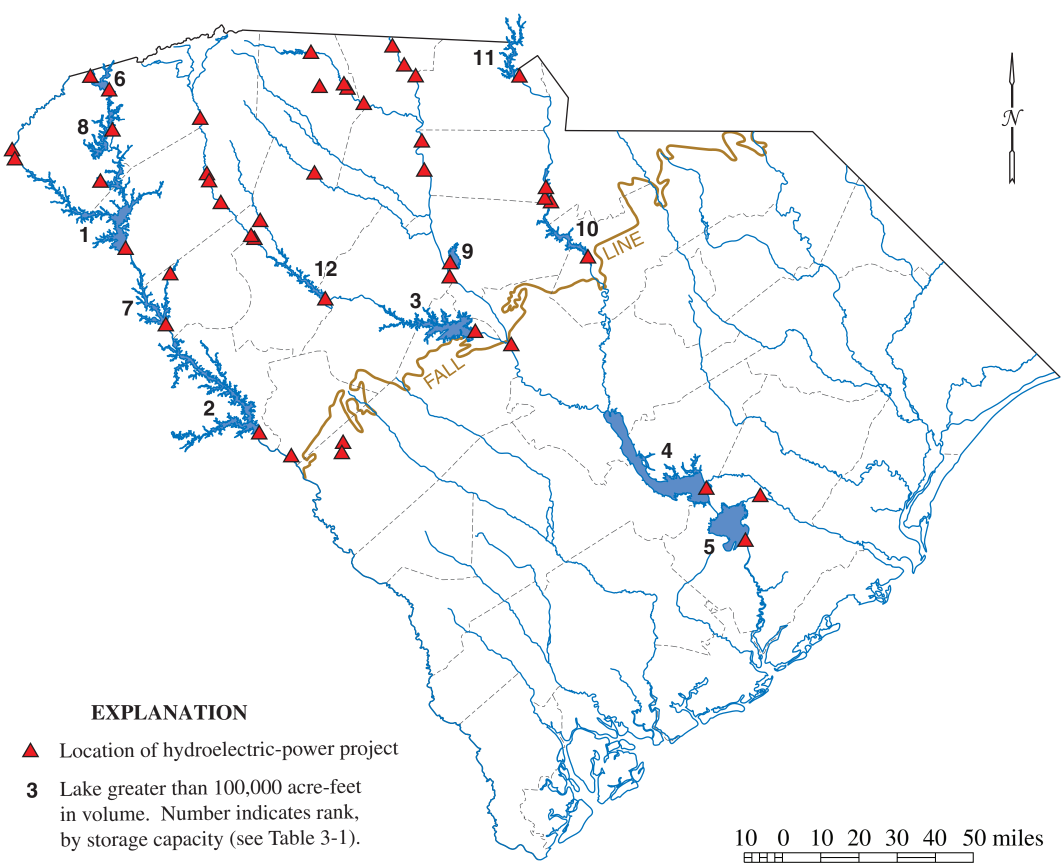

Figure 3-11. Location of hydroelectric-power projects and major lakes in South Carolina.

Forty-six hydroelectric-power projects of varying generating capacity and reservoir size are located in South Carolina (Figure 3-11). Eighty-seven percent of these projects and most potential hydroelectric power sites are in the Piedmont, where high relief and steep stream gradients are naturally suited for reservoir development. Few reservoirs are located in the Coastal Plain region, and impoundments in the region typically are broad and shallow. The 12 largest reservoirs in the State are listed in Table 3-1 by storage capacity. No major reservoirs have been constructed since the completion of the Russell Dam in 1984.

Table 3-1. Largest lakes in South Carolina, by storage capacity

Rank (by capacity)	Name	Surface area (acres)	Storage capacity (acre-feet)	Use*
1	Lake Hartwell	56,000	2,549,000	P R W
2	Lake Thurmond	70,000	2,510,000	P R W F
3	Lake Murray	51,000	2,114,000	P R W
4	Lake Marion	110,600	1,400,000	P R W
5	Lake Moultrie	60,400	1,211,000	P R W
6	Lake Jocassee	7,560	1,186,000	P R
7	Lake Russell	26,650	1,026,000	P F R
8	Lake Keowee	18,370	1,000,000	P R W
9	Lake Monticello	6,800	431,000	P R
10	Lake Wateree	13,700	310,000	P R W
11	Lake Wylie	12,460	281,900	P R W
12	Lake Greenwood	11,400	270,000	P R W

*P, power; R, recreation; F, flood control; W, public water supply.

Controlled releases from hydroelectric dams above the licensed minimum releases depend on electric-power demand and may be highly variable. Generally, extreme maximum and minimum flows are modified by these facilities; however, in some instances (Wateree River, Santee River, Saluda River, Broad River) low-flow conditions may be aggravated due to insufficient discharge while reservoir supplies are replenished or power demand is low.

Approximately 2,000 miles of river channel have been cleared and dredged for navigation, but maintenance on most of these channel miles has been discontinued for various reasons. Currently, fewer than 500 miles of navigation channel are maintained by the U.S. Army Corps of Engineers. Most of these navigation projects are in the lower Coastal Plain region of the State and include the Intracoastal Waterway (ICW), Charleston Harbor, Winyah Bay, and the Savannah River between Savannah and Augusta, Ga. Dredging of the ICW has diminished owing to declining commercial shipping and consequent reductions in Congressional funding.

Modification of watersheds for flood control may entail diking, straightening, clearing, dredging, and damming of stream channels. Flood-control projects in the Piedmont province are made necessary by relatively impermeable soils that cause rapid runoff and subsequent flooding during heavy rainfall. Flood-control projects in the middle and lower Coastal Plain provinces mainly are related by low elevations and relief and the resultant poor drainage and pooling.

SURFACE-WATER QUALITY

The chemical, physical, and biological integrity of surface water greatly affects man's use of this important resource. While water of high quality is suitable for all activities, including swimming, fishing, and drinking (after treatment), less pure water might safely serve only industrial and agricultural needs. The maintenance of a healthy community of aquatic organisms requires a suitable chemical and physical environment. The introduction of toxic substances or the presence of essential constituents outside acceptable ranges can adversely alter aquatic populations and, in turn, adversely impact human water-use activities.

Factors Affecting Water Quality

Pollution occurs where chemical, physical, or biological constituents are present at levels detrimental to human use or to aquatic life. These contaminants can be of natural origin and enter surface water by precipitation or runoff. The impact of this non-point source pollution depends upon the amount of precipitation, watershed characteristics, pollutant type, and assimilative capacity of the water body. Man's modification of watersheds for agriculture, silviculture, mining, waste disposal, and other activities is the main cause of non-point source pollution. Typical non-point source pollutants include sediment, organic material, nutrients, metals, pesticides, oil and grease, and acids. In the Coastal Plain watersheds, tannins from naturally decomposing swamp vegetation stain the water of many streams: the dark brown color is a natural characteristic of the State's blackwater streams and is not a water-quality problem.

Pollutants also originate from industrial, municipal, and domestic wastewater discharges. The impact of these point-source pollutants depends upon the volume and composition of the discharged effluent and the assimilative capacity of the water body. The uncontrolled release of a wide variety of toxic and non-toxic chemical substances, nutrients, oxygen-demanding substances, and waste heat from point-source discharges can severely impact the State's surface water.

Water-Quality Management

The Federal Clean Water Act states: "it is the national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water shall be achieved by July 1, 1983."

The State of South Carolina has promulgated S.C. Regulation 61-68, Water Classifications and Standards and S.C. Regulation 61-69, Classified Water, which designates classified uses for each water body and establishes standards and rules to protect and maintain these uses. It is the intent and purpose of the regulations that water that meets standards shall be maintained and water that does not meet standards shall be improved. The agency primarily responsible for protecting and maintaining the quality of South Carolina's water resources is the South Carolina Department of Health and Environmental Control (DHEC). In pursuit of the national goals and in accordance with state and federal regulations, DHEC established a water classification and standards system, a statewide water-quality monitoring network, and several water-quality control programs. Other local, state, and federal agencies that have interests and programs involving water-quality protection include the South Carolina Department of Natural Resources (DNR), U.S. Environmental Protection Agency (EPA), U.S. Army Corps of Engineers (USACE), U.S. Geological Survey, the regional planning councils, and local governments.

Classification and Standards

The surface-water bodies of the State have been classified in regulation based on the desired uses of each water body. State standards for various parameters have been established to protect all uses within each classification. The water-use classifications that apply to surface water in South Carolina are as follows:

1. Class ORW (outstanding resource water): freshwater or saltwater that constitutes an outstanding recreational or ecological resource, or freshwater suitable as a source for drinking water supply purposes, with treatment levels specified by DHEC.
2. Class FW (freshwater): freshwater that is suitable for primary and secondary contact recreation and as a source for drinking-water supply after conventional treatment, in accordance with the requirements of DHEC. These water bodies are suitable for fishing and for the survival and propagation of a balanced indigenous aquatic community of fauna and flora. This class also is suitable for industrial and agricultural use.
3. Class SFH (shellfish harvesting) water: tidal saltwater protected for shellfish harvesting and also suitable for the uses intended for Classes SA and SB water.
4. Class SA (tidal saltwater): suitable for primary and secondary contact recreation and for crabbing and fishing. Class SA water must maintain daily DO (dissolved oxygen) averages not less than 5.0 mg/L, with a minimum DO of 4.0 mg/L. These water bodies are not protected for harvesting of clams, mussels, or oysters for market purposes or human consumption. The water is suitable for the survival and propagation of a balanced indigenous aquatic community of marine fauna and flora.
5. Class SB (tidal saltwater): suitable for the same uses intended for SA water, but with DO levels not less than 4.0 g/L.
6. Class TN (trout natural) water: freshwater suitable for supporting reproducing trout populations and a cold-water, balanced, indigenous, aquatic community of fauna and flora.
7. Class TPGT (trout put, grow, and take) water: freshwater suitable for supporting the growth of stocked trout populations and a balanced, indigenous aquatic community of fauna and flora.
8. Class TPT (trout put and take) water: freshwater protected by the standards of Class FW.

All water in South Carolina falls within one of the preceding classes and must meet associated quality standards. Some classified water bodies are identified by name, while all other water bodies assume the classification of the water body into which they flow.

Numeric standards are used as instream water-quality goals to maintain or improve water quality. They are used to determine permit limits for treated wastewater discharges and other activities that might impact water quality. All discharges to the waters of the State are required to have a National Pollutant Discharge Elimination System (NPDES) permit and must abide by those limits, under penalty of law.

Classifications are based on desired uses and are a legal means to obtain the necessary treatment of discharged wastewater to protect the designated uses. Actual water quality may not have a bearing on a water body's classification. A water body may be reclassified if existing public uses justify the reclassification and if the water quality necessary to protect those uses is attainable. A classification change requires an amendment to State regulation and requires public participation, DHEC Board approval, and General Assembly approval.

Natural conditions may prevent water from meeting the water-quality goals set forth in the standards. The fact that a water body does not meet the standards for a particular classification does not mean the water body is polluted or of poor quality. Certain types of water bodies (e.g., some swamps, lakes, and tidal creeks) naturally have water quality lower than the numeric standards. A water body can have water-quality conditions below standards due to natural causes and yet meet its use classification.

Monitoring Programs

The South Carolina Department of Health and Environmental Control (DHEC) routinely assesses and reports on the quality of the State's waterways in eight basins (Figure 3-12). Water-quality monitoring data are important in determining current conditions and identifying long-term trends and in determining that water-quality standards and use classifications are being met. Toward this end, DHEC has established the Ambient Surface Water Quality Monitoring Network to provide physical, chemical, and biological data about the State's streams, reservoirs, and estuaries.

The network is composed of five sampling categories. Integrator sites are 320 permanent fixed-location monitoring sites (Figure 3-13). The sites are sampled monthly to provide uniform baseline data. Special-purpose sites (33) are semipermanent stations for areas of special interest (e.g., ground-water remediation sites) and for supplementing integrator-site data. A few special-purpose sites are sampled monthly in summer only, but most are sampled monthly year round. Watershed water-quality management sites are sampled monthly for 1 year once every 5 years and supplement integrator sites. Probability-based monitoring sites augment the integrator baseline sites and are small sample sets used to estimate conditions for large areas: each year about 90 sites are randomly selected and are sampled monthly for 12 consecutive months. Sediment samples are collected once per year at 87 permanent sampling sites and at all probability-based monitoring sites.

Point-Source Management

Point-source wastewater discharge to the State's surface-water bodies is controlled through several DHEC programs. These programs manage the impact of agricultural, industrial, municipal, and domestic wastewater discharges by planning, permitting, enforcement, and pollution-response and -investigation activities.

The National Pollutant Discharge Elimination System (NPDES) directly regulates point-source discharges. A NPDES permit limits the type and amount of materials that may be discharged and establishes monitoring requirements. Discharge limits are based on Federal guidelines and on the treatment needed to prevent contravention of State water-quality standards. NPDES permit requirements for oxygen-demanding substances, ammonia, and phosphorus are determined by evaluating the water quality and assimilative capacity of the receiving water in relation to State water-quality standards. Potential receiving water is designated "effluent limited" or "water-quality limited," depending on the level of wastewater treatment required to maintain standards for dissolved oxygen. The application of secondary-treatment technology is sufficient for effluent discharging into effluent-limited water, whereas discharges to water-quality limited water require more advanced treatment technology.

Non-Point Source Management

In South Carolina, non-point sources, rather than point sources, are most commonly responsible for failures to achieve classified uses. The control of surface-water contamination by runoff from large areas is typically more difficult than for well-defined discharge sites, and control primarily depends on effective land-use practices. DHEC, in conjunction with other State agencies and entities, developed strategies to abate non-point source pollution from several types of land uses, including agriculture, silviculture, mining, and hydrologic modifications. There are nine categories of non-point source pollution: agriculture, forestry, urban areas, marinas and recreational boating, mining, hydrologic modification, wetlands disturbance, land disposal/ground-water impacts, and atmospheric deposition. Technology-based management measures are employed to address these impacts. The NPS (Non-Point Source) Program describes specific management measures and implementation schedules for each category. South Carolina has the legal authority to implement all of the necessary management measures. Solid-waste, hazardous-waste, and air-quality control programs in DHEC, in addition to local zoning and the water- and land-management programs of other local, State, and Federal agencies, help to control non-point source pollution. DHEC's South Carolina NPS

Management Program Update describes a framework for agency coordination and presents a strategy and management measures to control NPS pollution.

Surface-Water Quality Overview

Water-quality conditions are influenced by many natural and man-induced factors. Therefore, water quality can change yearly, seasonally, and even daily depending on the type and location of the water body, natural events and conditions, and human activity within the watershed. Water-quality conditions and problems identified here and in the individual subbasin assessments represent documented conditions at the writing of this report—but these conditions are not static. DHEC periodically publishes monitoring data, water-quality assessments, and the results of special studies.

The quality of surface water in South Carolina is generally adequate for most water-use needs. DHEC estimates that 79 percent of the State's major river miles fully support aquatic-life uses: the predominant cause of partial or non-support is low dissolved-oxygen levels. Eighty-three percent of the State's lakes fully support aquatic-life uses: the predominant cause for partial or non-support is high nutrient levels. Eighty-one percent of the State's estuaries fully support aquatic-life uses, with low dissolved oxygen being the predominant cause of non-support. Recreational use is fully supported in 58 percent of the rivers, 99 percent of the lakes, and 93 percent of the estuaries. High fecal-coliform bacteria levels are the predominant cause for the water bodies to be classified as partially or not supportive.

The most widespread water-quality problem is fecal-coliform bacteria contamination. The bacteria primarily impair shellfish harvest and recreational water-use activities, and the bacteria typically are associated with municipal wastewater discharges and non-point source runoff from urban and agricultural areas.

Physiography and climate also influence water quality. Widespread contravention of standards occurs in Coastal Plain wetlands during the summer months. Decomposition of large quantities of organic matter in swamps, coupled with little or no streamflow and high water temperatures, often results in water with low dissolved oxygen concentrations, low pH, and high nutrient levels. Low dissolved oxygen

Figure 3-12. South Carolina Department of Health and Environmental Control water-quality management basins.

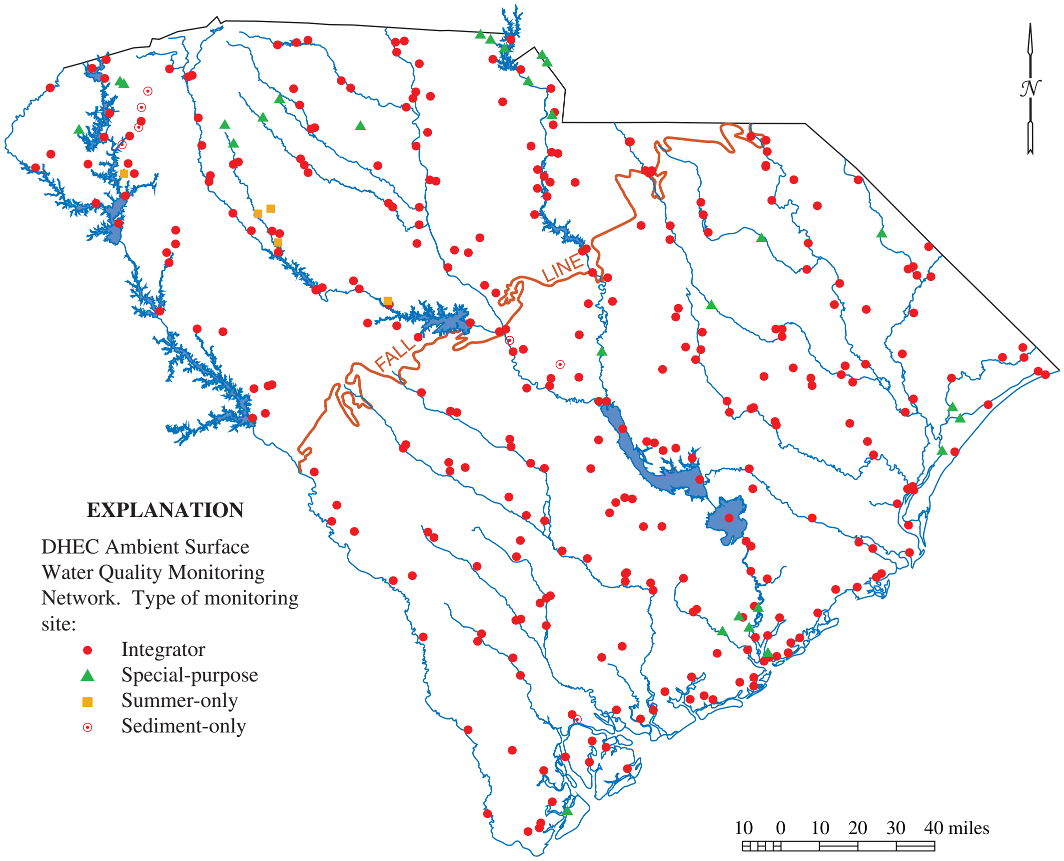

Figure 3-13. DHEC ambient surface-water quality monitoring network (DHEC, 2003b).

levels occur in all impaired waters of the Pee Dee and ACE basins. Fish-consumption advisories have been issued for many of the major rivers and lakes in the Coastal Plain because of high mercury concentrations: the source of mercury contamination is believed to be general aerial deposition.

Piedmont water bodies exhibit somewhat different naturally occurring water-quality problems. The province's high topographic relief and impermeable soil contribute to rapid runoff and cause high levels of suspended solids, turbidity, and fecal coliform bacteria.

Although natural conditions affect water quality statewide, it is generally man's activities that adversely impact surface water to the point of impaired use. Elevated fecal coliform bacteria, nutrients, biochemical oxygen demand, and metals all have been attributed to industrial and municipal wastewater discharges. These same problems, in addition to increased sedimentation, poor macroinvertebrate structure, and dissolved oxygen levels, have been attributed to non-point sources of pollution commonly caused by man's alteration of the watershed.

In the Santee basin, an average of 71 percent of water from all subbasins fully supports aquatic-life uses, but only 67 percent supports recreational uses. Impaired water exhibits poor macroinvertebrate populations, elevated metals, and high fecal coliform levels. The highly developed Saluda subbasin exhibits the State's poorest water quality, with only 58 percent of water supporting aquatic-life uses and 57 percent supporting recreational uses. The Saluda watershed and adjacent Catawba watershed are two of five basins designated as high priority for water-quality restoration.

The Pee Dee and Waccamaw watersheds also are among the five basins in need of restoration because of poor water quality (South Carolina Department of Health and Environmental Control and U.S. Department of Agriculture, 1998). Approximately 70 percent of waterways in the Pee Dee basin meet aquatic-life standards while more than 75 percent support recreational uses; however, many water bodies in this Coastal Plain basin suffer from naturally occurring low dissolved-oxygen levels and high fecal coliform counts. High mercury levels in some game fish have prompted fish-consumption advisories for many lakes and rivers. A nationwide analysis of vulnerable fish and mussel species found the Waccamaw subbasin to be a “Watershed Hot Spot” because ten or more freshwater fish and mussel species were considered at risk (South Carolina Department of Health and Environmental Control and U.S. Department of Agriculture, 1998).

Most water bodies in the ACE basin support aquatic-life and recreational uses, but the basin exhibits the poorest quality in the State owing to exceptionally low compliance in the Ashley-Cooper subbasin (61 percent). As in other Coastal Plain basins, naturally occurring low dissolved-oxygen levels and high fecal coliform levels impair full compliance. Fish-consumption advisories and shellfish advisories have been issued for major waterways throughout this basin.

The Savannah basin has the best water quality overall, with an average of 80 percent of lakes and streams fully supporting aquatic-life uses and 75 percent supporting recreational uses. Impaired water in the Savannah basin tends to have low pH, poor macroinvertebrate communities, and high fecal coliform levels. Fish-consumption advisories have been issued for part of the Savannah River due to high mercury levels and for Lake Hartwell due to high PCB levels. The Seneca-Keowee watershed, in the upper Savannah basin, is one of the State’s five basins most in need of restoration (South Carolina Department of Health and Environmental Control and U.S. Department of Agriculture, 1998).

GROUND-WATER RESOURCES

South Carolina’s ground water occurs in fractured crystalline rocks of Paleozoic age that are exposed in the Piedmont region and in sand and limestone aquifers in the Cretaceous, Tertiary, and Quaternary formations of the Coastal Plain. Three distinct aquifer types are present: (1) cracks in the crystalline rock of the Piedmont and the Coastal Plain basement, (2) sand beds in several formations of the Coastal Plain, and (3) permeable limestone units of the southern coastal area. The principal geologic and hydrologic units of the Coastal Plain and their correlation with the terminology of the 1983 *State Water Assessment* are shown in Table 3-2. The hydrogeologic units discussed in this assessment are based on the delineations published by Aucott and others (1986) for the USGS Regional Aquifer Systems Analysis project. Schematic representations of the principle Coastal Plain aquifers are shown in Figure 3-14.

The number, size, and shape of openings in an aquifer determine its porosity, and the degree of interconnection of the openings determines the ground-water transmitting capacity. High porosity does not guarantee pore interconnection and high permeability; clay and limestone have porosities two to four times greater than most sand formations, but clay and most limestone store and confine water rather than yielding it to wells.

Table 3-2. Former, present, and proposed hydrostratigraphic systems used by the South Carolina Department of Natural Resources

Geologic system (1983 assessment)	Aquifer (1983 assessment)	Geologic system (2009 assessment)	Aquifer (Aucott and others, 1986)	Aquifer delineation system (modified from Aadland and others, 1995)
Post Oligocene	Shallow	Middle Miocene to Recent	Shallow	Surficial aquifer Upper Floridan confining unit
Cooper Fm. Ocala Limestone Santee Limestone	Floridan	Ashley Formation Harleyville Formation Ocala Limestone Santee Limestone	Floridan	Upper Floridan aquifer Middle Floridan confining unit Middle Floridan aquifer
Orangeburg Group	Tertiary sand	Upland Unit Barnwell Group McBean Formation Green Clay Congaree Formation Williamsburg Formation Ellenton Formation	Tertiary sand	Steel Pond aquifer Upper Three Runs aquifer Gordon confining unit Gordon aquifer Crouch Branch confining unit
Black Mingo Fm.	Black Mingo			
Ellenton Fm.	Ellenton			
Peedee Fm.	Peedee	Peedee Formation	Black Creek	Crouch Branch confining unit Crouch Branch aquifer McQueen Branch confining unit
Black Creek Fm.	Black Creek	Donoho Creek Formation Bladen Formation Tar Heel Formation Cane Acre Formation Caddin Formation		
Middendorf Fm.	Middendorf	Shepherd Grove Formation Middendorf Formation	Middendorf	McQueen Branch aquifer
Cape Fear Fm.		Cape Fear Formation	Cape Fear	Unnamed confining unit

Fm, Formation

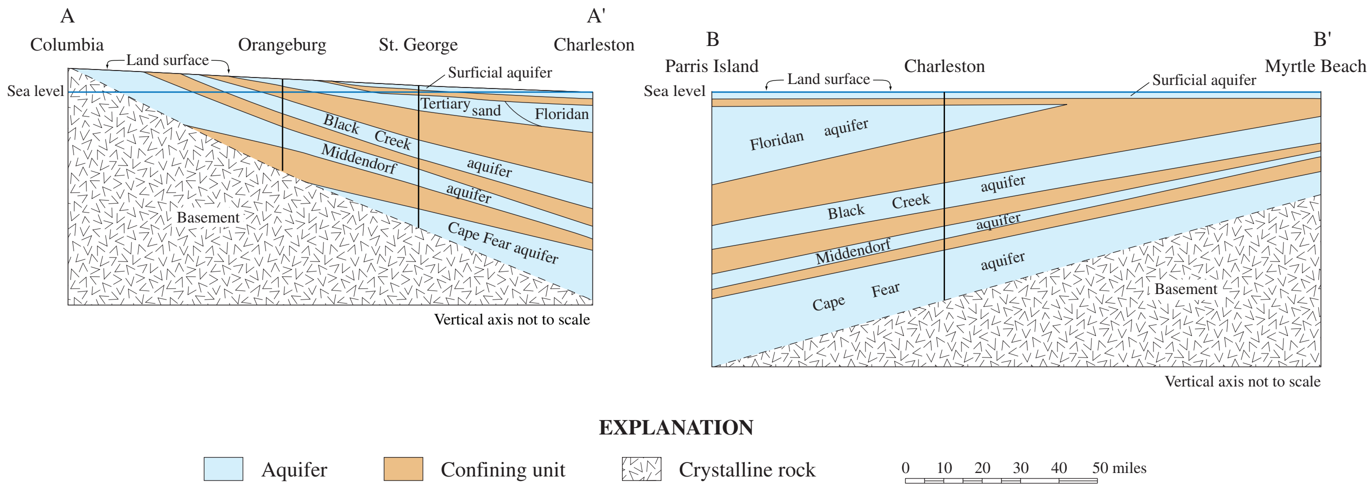

Figure 3-14. General hydrogeologic sections across the South Carolina Coastal Plain (after Aucott and others, 1986).

Ground water may occur under unconfined (water-table) or confined (artesian) conditions. Where unconfined conditions exist, the surface of the saturated zone is at atmospheric pressure and the water table is free to rise and fall in response to gravity. Water levels in wells penetrating unconfined aquifers define the water table. Unconfined aquifers are directly recharged by precipitation percolating downward through the soil column.

Confined conditions exist where aquifers are overlain and underlain by relatively impermeable confining beds. Ground water in such aquifers is under hydrostatic (artesian) pressure, and water levels in wells completed in a confined aquifer will rise above the top of the aquifer. These water levels define the potentiometric surface of the aquifer. Where the potentiometric surface is above ground level, the wells will flow. Confined aquifers receive recharge from precipitation on their outcrop areas and from leakage through adjacent confining beds in their downdip regions.

Ground-water occurrence and availability are directly related to the geology of a region, and well yields differ significantly between the Blue Ridge and Piedmont and the Coastal Plain. Blue Ridge and Piedmont crystalline rocks have little or no permeability except where fractures occur and are enhanced by weathering. Well yields depend on intercepting fractures formed by joints, faults, and partings along bedding and cleavage planes, on the number and size of fracture zones, on saprolite thickness, and on topography. Valleys typically are areas of intense fracturing and exhibit higher ground-water yields than topographically high areas; hilltops and their upper slopes commonly are underlain by thin saprolite and harder, less-fractured rocks with lower permeability.

The saprolite, a 0- to 100-foot thick zone of clayey, weathered rock, overlies the igneous and metamorphic rock. Most of the saprolite is saturated and, although the water seeps only slowly into bedrock fractures, there is a significant transfer of water when considered on a regional scale. The saprolite also can yield water to dug and bored wells that depend on large well diameters for storage, but saprolite wells commonly capture less than 1 gpm (gallons per minute), are drought sensitive, and are less common owing to improved drilling technology and increased household water demands.

Aquifers in the Coastal Plain are basically sand or limestone. The sand aquifers, some with significant amounts of shell or gravel, represent the shallow, Tertiary sand, and Cretaceous aquifers. Ground water in these unconsolidated aquifers is stored in and moves through the pore spaces among sand and gravel. Ground water in limestone aquifers is stored in and moves through diffuse networks of small fractures and poorly consolidated fossil shell or through local networks of pipe-like solution channels. Most limestone aquifers in the State are confined, and the ground water is under pressure. The Floridan aquifer, a sequence of limestone formations that extends from the Santee River to south Florida, is the most productive aquifer system in the United States. There is substantial pumping from the Floridan in southern South Carolina and coastal Georgia.

Near ground surface, ground water commonly occurs under water-table conditions. Water levels in these shallow aquifers fluctuate seasonally, and their well yields are modest because of the small available drawdown. Most Coastal Plain ground water, however, occurs in confined aquifers under artesian pressure. Water levels in these aquifers remain fairly constant, except where influenced by pumping.

An aquifer's capacity to transmit ground water and to yield water to wells is related to rock permeability, termed hydraulic conductivity (K), thickness (m), and storage coefficient (s). Hydraulic conductivity in the aquifers of South Carolina ranges from about 100 gpd/ft^2 (gallons per day per square foot) in fine, poorly sorted sand, to more than 3,000 gpd/ft^2 in some limestone aquifers. Hydraulic conductivity is greatest in and just downdip of aquifer outcrop areas but generally diminishes and falls within a fairly narrow range coastward of outcrop areas. Thickness, however, ranges widely, typically increasing as formations thicken toward the coast and thinning near the Fall Line where eroded in the geologic past, with increasing proportions of fine-grained sediment, and along lateral transitions in rock type.

Transmissivity defines the total capacity of an aquifer and is determined by hydraulic conductivity and aquifer thickness (K x m). It tends to be high in the upper Coastal Plain where there are great thicknesses of coarse sand and gravel; low to moderate across the middle Coastal Plain where medium- to fine-grained sand predominates; and high in the southern Coastal Plain where the stratigraphic column is 2,000 to 4,000 feet in thickness. Ground-water definitions and formulae used to describe and quantify ground-water availability are given in Supplemental Information Box 3-2.

GROUND-WATER PROGRAMS

Monitoring Programs

Ground-water levels and ground-water quality are routinely monitored statewide. Continuous ground-water level monitoring provides both long-term and short-term benefits. Hourly measurements track water-level and water-quality trends daily, yearly, and across decades. Many observation sites, particularly in the middle and lower Coastal Plain, show that artesian levels have declined as the State's population has grown and has concentrated near the coast. Regular measurements are used to predict drawdown and well interference caused by future ground-water use, to estimate changes in ground-water storage, and to observe how particular hydrogeologic settings affect artesian levels during drought. Hourly data can reflect local and regional well interference, the presence or absence of local recharge, daily and seasonal changes in evapotranspiration, and periods of peak ground-water use. Individual observations are made in about 600 wells in the Cretaceous- and Tertiary-age aquifers every 5 to 6 years and are used to construct potentiometric maps. These potentiometric maps reveal changes in the direction and rate of ground-water flow and identify new and expanding pumping centers. Such maps are essential for the calibration of predictive ground-water flow models. Water-quality monitoring includes ambient ground-water quality and water-quality changes caused by active saltwater intrusion.

Long-term ground-water monitoring is conducted by the USGS, DNR, and DHEC. The USGS has collected data since 1945, and it operated hourly water-level recorders on 19 wells during 2006. USGS sites typically have been monitored in cooperation with DNR and the former Water Resources Commission on a matching-funds basis. DNR expanded the statewide network after 1999 (Figure 3-15), and the DNR staff maintained 74 manually and hourly logged water-level sites during 2006. The base network operated by the USGS and DNR increased from 32 wells in 1980 to 109 wells in 2008.

About 150 well sites are monitored for water quality as part of regional or statewide programs. Twenty-seven permanent and temporary sites were monitored for ground-water levels and specific conductance by DHEC in Beaufort and Jasper Counties. The DHEC network is devoted to monitoring the impact of Floridan aquifer pumping at Savannah, Ga., and southern Beaufort County, S.C., a region of substantial water-level decline and widespread saltwater intrusion. DHEC also samples a network of wells open to the major aquifers of the Blue Ridge, Piedmont, and Coastal Plain: this ambient water-quality network began with 19 wells sampled in 1987 and expanded to 117 wells by 2002. The USGS operates a real-time (satellite transmission) specific-conductance station on northern Hilton Head Island for DNR and monitors saltwater intrusion there. DNR maintains a pair of specific-conductance stations near Edisto Beach to monitor saltwater upconing (Figure 3-16).

Management Programs

Water-Quality Management. DHEC has regulatory responsibility for protecting the quality of the State's ground-water resources. Its programs include the permitting of public water-supply systems and well construction, regulation of existing and potential ground-water contamination sites, and management of saltwater intrusion. These programs encompass:

- Reviews and permits for public-supply wells to insure proper design and construction;
- Delineation of well-head protection areas for public-supply wells;
- Regulation of the location, design, and construction of commercial-, domestic-, and irrigation-supply wells;
- Regulation and monitoring of underground storage tanks (UST Program);
- Regulation of pits, ponds, lagoons, and feedlots;
- Reviews and permits for the Underground Injection Control Program, including subsurface-storage wells and geothermal heat-pump return wells; and

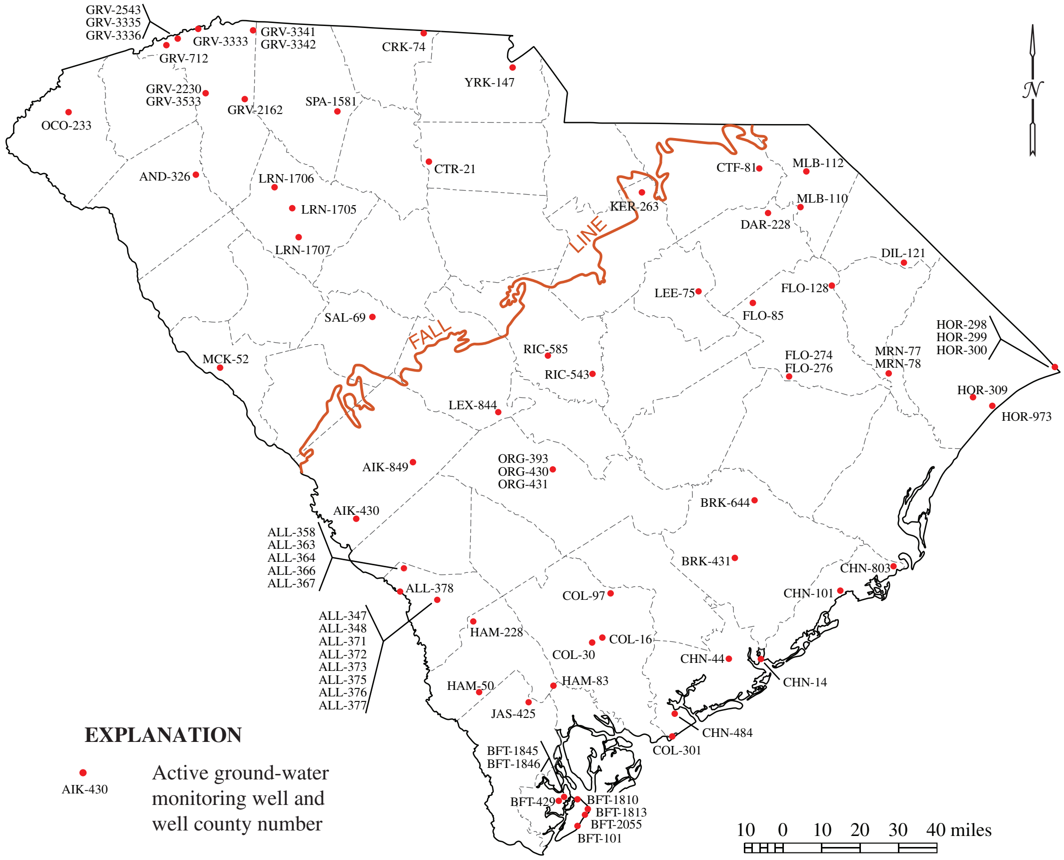

Figure 3-15. Distribution of permanent DNR and USGS–DNR cooperative ground-water level records.

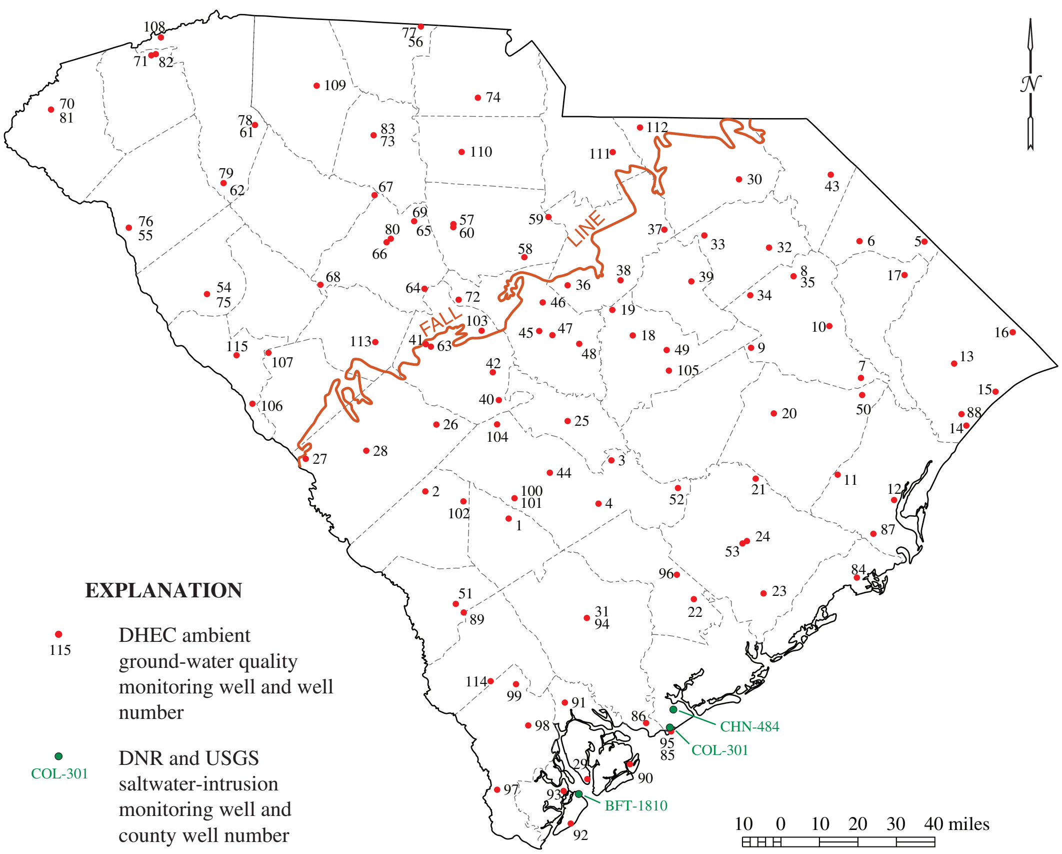

Figure 3-16. Distribution of permanent DNR, USGS, and DHEC ground-water quality monitoring sites.

- Mitigation of well interference and saltwater intrusion through the issuance of ground-water use permits.

Water-Quantity Management. Ground-water withdrawals are regulated in designated areas of the State under authority of the Ground-Water Use and Reporting Act (revised 2000). The former Water Resources Commission managed the State's first two Capacity Use Areas between 1978 and 1994. In 1994, DHEC assumed responsibility for Capacity Use Areas following State-government reorganization and has since designated two additional Capacity Use Areas. A Notice of Intent (NOI) to install a well that will withdraw more than 3 million gallons per month was required after 2000 for Coastal Plain counties outside of the Capacity Use Areas (Figure 3-17). The four Capacity Use Areas span the South Carolina coast and address multi-county ground-water problems:

- Waccamaw Capacity Use Area (Horry and Georgetown Counties)—declared in 1978 to address water-level declines greater than 100 feet in the Black Creek aquifers between North Carolina and Georgetown; to minimize public-supply well and irrigation-well interference; to prevent interconnection of brackish-water and freshwater aquifers within well bores; and to mitigate brackish-water intrusion from the Cape Fear Arch toward Myrtle Beach;
- Low Country Capacity Use Area (Beaufort, Jasper, Hampton, and Colleton Counties)—declared in 1982 to control saltwater intrusion in the Floridan aquifer at Edisto Island; around the Sea Islands of Beaufort County; and from Port Royal Sound toward Hilton Head Island;
- Trident Capacity Use Area (Charleston, Berkeley, and Dorchester Counties)—declared in 2003 to mitigate water-level declines greater than 200 feet and pumping-level interference among industrial and public-supply wells that rely on the Black Creek and Middendorf aquifers;
- Pee Dee Capacity Use Area (Marlboro, Darlington, Florence, Williamsburg, Dillon, and Marion Counties)—declared in 2004 to address water-level declines in the Middendorf and Black Creek aquifers.

Capacity Use permits are required for users who withdraw more than 3 million gallons per month in any month from any combination of wells. Applicants must plan water-conserving measures and consider water sources that are alternatives (e.g., treated effluent and ponds) to the principal aquifer in the Capacity Use Area. Certain uses of the area's principal aquifer, such as golf-course irrigation, might be limited with nonrenewable permits or can be prohibited. Total average-daily withdrawals from the area's principal aquifer may be capped.

SUPPLEMENTAL INFORMATION BOX 3-2

Ground-Water Terminology

Head (h): the height of a water column, or its water pressure, relative to a reference point.

Hydraulic conductivity (K): permeability. The rate at which ground water is transmitted through a unit-squared section of aquifer under a unit hydraulic gradient, expressed in gallons per day per square foot (gpd/ft^2) or in feet per day (ft/day) where cubic feet are used instead of gallons.

Potentiometric surface: the distribution of potentiometric water levels above or within an aquifer and commonly illustrated by contour maps showing potentiometric elevations relative to sea level.

Specific capacity of wells: the rate of discharge from a pumped well divided by the drawdown in water level after a specified period of time (usually 24 hours) and expressed in gallons per minute per foot (gpm/ft) of drawdown.

Specific yield (Sy): the volume of water an unconfined aquifer releases from storage by gravity drainage relative to the volume of the aquifer. The term is dimensionless, and values typically range from 0.01 to 0.1, e.g., 0.1 times one cubic foot (ft^3) of aquifer equals 0.1 ft^3, or 0.75 gallon per cubic foot of aquifer.

Storage coefficient (S): the volume of water a confined aquifer releases from storage per unit surface area per unit change in head. The term is dimensionless, and values for confined Coastal Plain aquifers typically are about 0.0002 (2×10^{-4}), e.g., 0.0002 times 100 ft of water-level decline equals 0.02 ft^3, or 0.15 gallon per square foot of aquifer.

Transmissivity (T): the rate at which ground water is transmitted through a unit width of aquifer under a unit hydraulic gradient, expressed in gallons per day per foot (gpd/ft) or in feet squared per day where cubic feet are used instead of gallons.

Water table: the surface of the saturated section in an unconfined aquifer.

Ground-Water Assistance

Technical assistance is provided to existing and potential ground-water users by DNR, DHEC, and the USGS. The assistance can be as simple as providing tabular data on well depths, yields, and chemistry near a potential well site, or it might be as involved as the inventory and testing of wells where well yield or water quality is unknown or problematic. DNR, DHEC, and the USGS also cooperate on regional studies requested by local governments.

Geologists and hydrologists with the three agencies make geologic interpretations, conduct aquifer testing and sampling, and provide recommendations for well

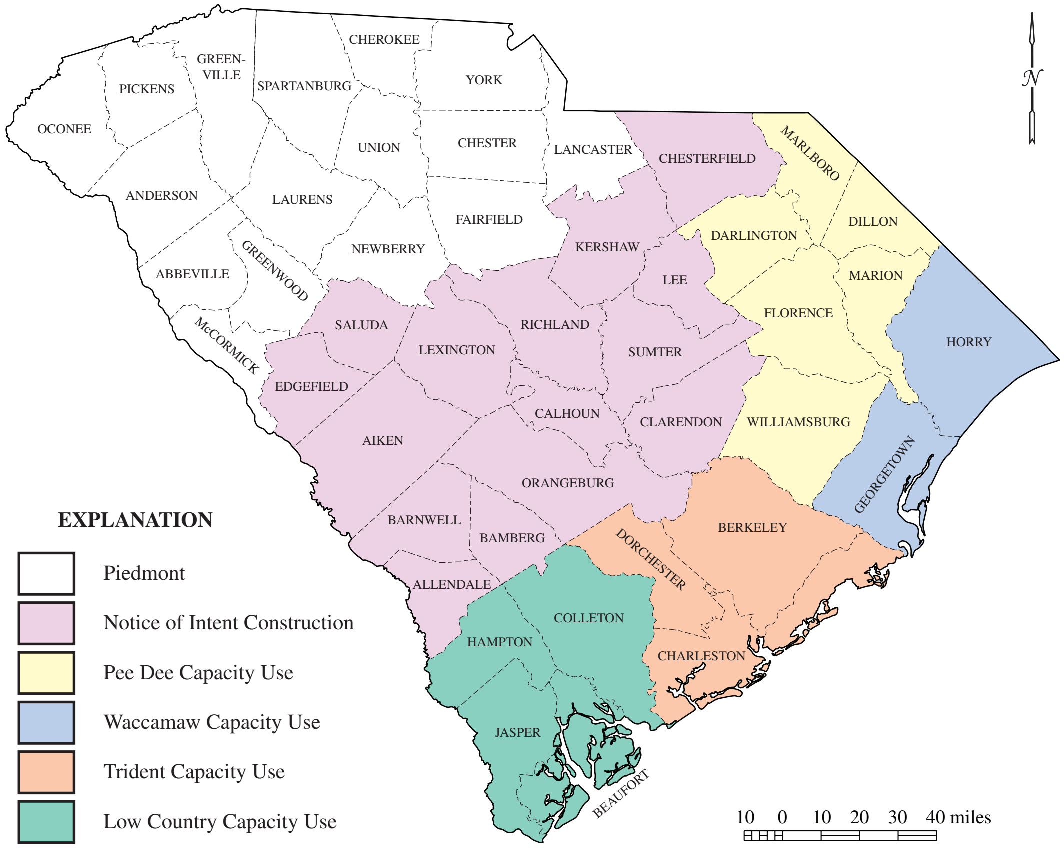

Figure 3-17. Capacity-Use and Notice-of-Intent areas in South Carolina.

design, well spacing, and pumping rates. DHEC, DNR, and the USGS each operate borehole geophysical loggers that measure the radiological, chemical, and geologic characteristics of subsurface formations: these measurements are used to identify rock types, select screen settings, and delineate aquifers. The agencies also operate water-quality laboratories to support their field research. DNR augments geologic and aerial mapping with VLF (very low frequency) technology to locate fracture zones in the crystalline-rock aquifers of the Piedmont and Blue Ridge provinces. VLF surveys greatly reduce the risk of drilling dry holes.

Ground-Water Research and Knowledge

Research. The research of DNR, DHEC, and USGS mainly focuses on projects that have immediate applicability, but it ranges from the utilitarian to the esoteric. Cooperative studies by the former SCWRC and USGS have provided the hydrogeologic and geochemical frameworks used to delineate and manage the State's four Capacity Use Areas. The congressionally-mandated RASA (Regional Aquifer Systems Analysis) projects require the USGS to quantify the nation's ground-water resources, and the USGS published aquifer-distribution maps, potentiometric maps, and flow models of the State's Coastal Plain aquifers during the 1980's—congressionally-funded updates of RASA began in 2004. DNR published ground-water summaries covering 18 counties between 1983 and 2008, completing at least basic coverage of 28 Fall Line and Coastal Plain counties. DHEC publishes a wide range of reports and atlases, particularly concerning water quality, and has extensive experience in mapping isotopes and age-dating rock and water. Research done locally, but having future and outside applications, also is done by Federal and State agencies and by State universities, particularly in the fields of subsurface microbiology, geochemistry, and ground-water remediation.

Knowledge. Judging the adequacy of ground-water knowledge largely depends on how the knowledge is to be used. Estimating the yield and quality of water beneath a potential well site typically requires little more than well-construction records and chemical analyses from nearby wells. Determining the radius of a well-head protection area requires data on geology, aquifer hydraulics, and potential contaminant sources, and calculation of the well's radius of capture. Predicting the impact of multiple wells on water levels or saltwater movement typically involves a computer model that depends on extensive knowledge of geology, transmissivity, water levels, and water use. The following criteria are used to categorize the level of ground-water knowledge in South Carolina's 46 counties (Figure 3-18):

File-data level—

- No systematic, countywide ground-water investigation has been published; or a published investigation is outdated owing to increased water demand, identification of water-supply problems and opportunities since publication, or otherwise limited data relative to the present need.
- Data exist mainly in the form of geophysical logs, pumping tests, water-chemistry analyses, and unverified water-well contractors' reports.
- Data generally are not suitable for planning well design as regards open intervals, drawdown, and specific requirements for well yield and chemical quality.

Planning level—

- Extensive file data are available from contractors' reports and field surveys, the geographic positions of significant well-data points are known, and systematic county or multicounty ground-water investigations have been published. One or more references:
  - o define a hydrogeologic framework; summarize geologic, hydraulic, and water-quality characteristics; and calculate water use.
  - o identify sources of additional water supply and impediments to ground-water development.

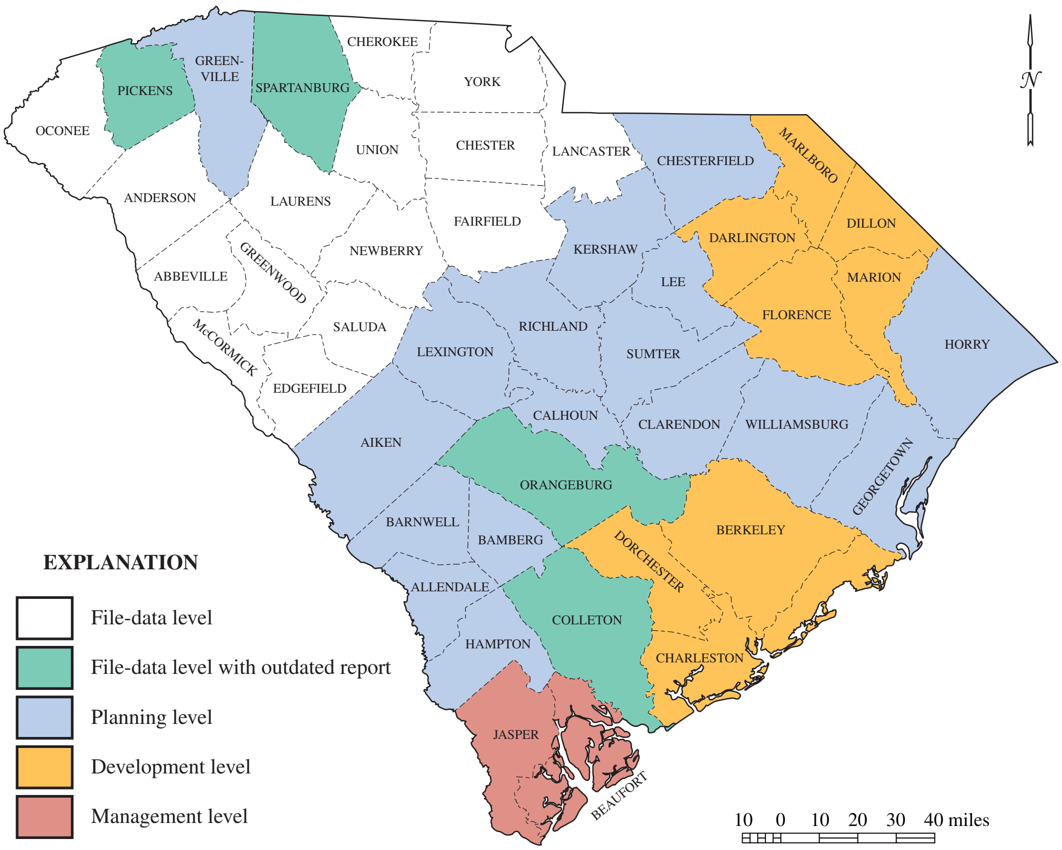

Figure 3-18. Levels of ground-water knowledge in South Carolina.

- Reports used in conjunction with file data can be used to plan approximate well-casing design, well-screen locations, and pump requirements, and to anticipate individual well yield, drawdown, and water quality for the most commonly used aquifer(s).

Development level—

- Summary reports define the hydrogeologic framework and describe significant physical conditions, water-supply problems and alternatives, and regulatory issues.
- The general hydrologic, hydraulic, and water-quality conditions in the principal aquifer(s) are well mapped and understood.
  - o Well design, maximum well yield, and water chemistry typically can be predicted with good confidence in most of the area.

- o Hydraulic and potentiometric data are adequate to identify recharge and discharge areas, to estimate regional flow rate and direction, and to calculate the drawdown and capture radius of individual wells and well fields.

- Information provides a framework for planning digital ground-water models. A digital model already may be available as a tool to identify knowledge gaps and plan future modeling efforts.

Management level—

- Ground-water conditions in one or more principal aquifers are described in digital models.
- The model may be used to predict ground-water conditions under various scenarios, and the model accuracy and the level of knowledge support water-supply management and regulatory decisions.
- Management plans are in progress or in place that encompass water-supply limitations and alternatives and address the nature, scope, and necessity of ground-water regulation.

GROUND-WATER OVERVIEW

Vast amounts of water are stored in the aquifers of South Carolina, and even greater quantities are stored in the thicker and more porous confining units. The availability and quality of this ground water depend on the geology and physiography and, in some places, on the activities of man. Permeable sand and limestone formations in the Coastal Plain contain large quantities of water (Figure 3-19) and readily yield water to wells. The crystalline rocks and saprolite of the Blue Ridge and Piedmont store large water quantities, but yield water reluctantly. Ground-water quality is good nearly everywhere, but local naturally occurring and manmade problems are found in most major aquifers.

Blue Ridge and Piedmont Provinces

Aquifers of the Blue Ridge and Piedmont provinces are weathered zones or fracture zones in the otherwise impermeable igneous and metamorphic rocks. Only limited quantities of ground water can be obtained in this region. The highest yields are from wells constructed in the fracture zones of the Piedmont's igneous and metamorphic rocks.

Until the mid-twentieth century, ground water in the Blue Ridge and Piedmont was developed predominantly from springs and from dug wells 2 or 3 feet in diameter. Water at these sources was obtained from the saprolite or from the top of the underlying hard-rock layer. Dug wells often went dry during droughts as the water table declined below the bottom of the well.

Ground-water supplies mainly are obtained from 4- to 8-inch diameter wells drilled into rock fractures.

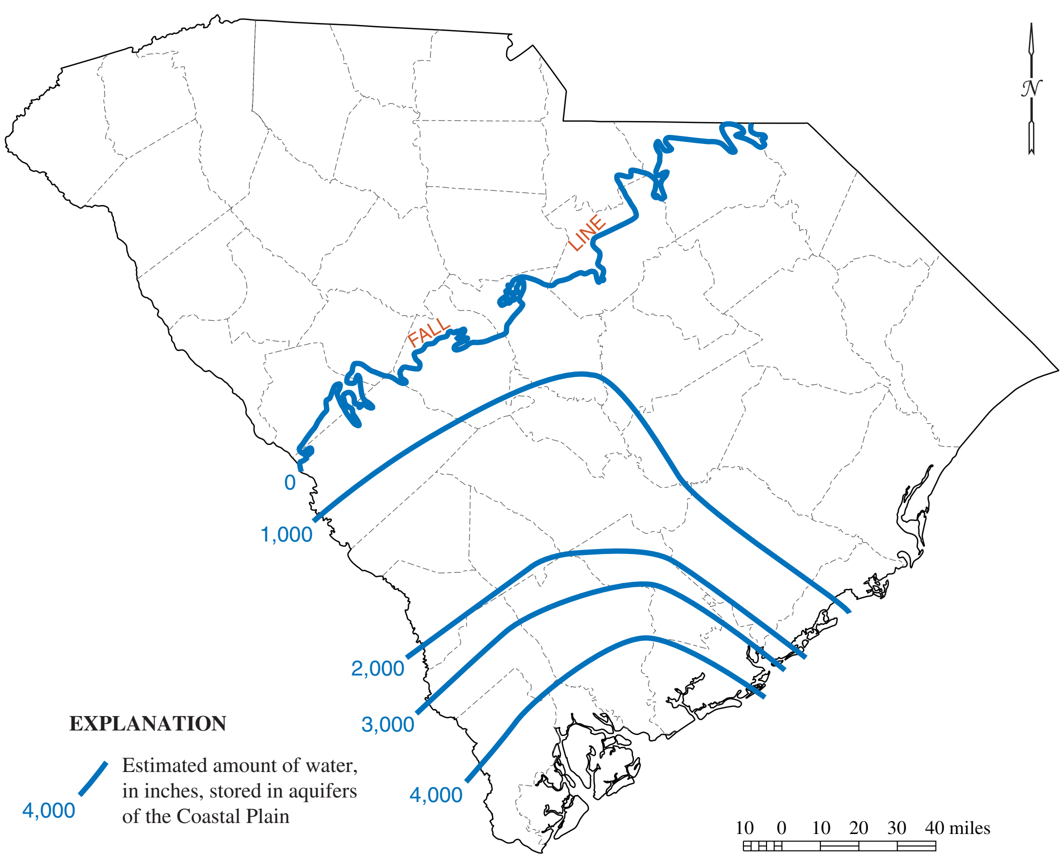

Figure 3-19. Estimated quantity of ground water in South Carolina Coastal Plain aquifers (Cherry and others, 2001).

Yields range from less than 1 gallon per minute to several hundred gallons per minute, and yields can vary greatly among wells located within several yards of one another. Recharge to the fractures that supply wells occurs directly from precipitation if the fracture extends to the land surface and indirectly from water stored in the saprolite. Well-water levels, therefore, usually rise during winter and spring when rainfall is greatest and ET is least, and levels decline during the summer and early fall months when rainfall is least and ET is greatest. Water-level changes in rock fractures can lag months behind drought and wet periods because saprolite clay stores large amounts of water but absorbs and releases it slowly.

Well-site selections and well designs typically are based on convenience and economy rather than hydrogeologic principles, and most domestic-supply wells do not penetrate the full thickness of potential aquifers. Consequently, specific aquifer and hydrogeologic units are not well delineated throughout the Blue Ridge and Piedmont: good databases are available for the more populated areas, such as Greenville and York Counties and, to a lesser extent, Abbeville, Anderson, Laurens, Newberry, Pickens, and Spartanburg Counties.

Ground-water quality in the Blue Ridge and Piedmont is of two general types. The first type includes water from the quartzose, micaceous, and light-colored silicate rocks—the water is generally soft and low in total dissolved solids. The second type includes water from gabbros, hornblende, and dark-colored calcic-magnesium rocks—the water is moderately-hard to hard and commonly has higher dissolved solids and iron concentrations than water in silicate rocks.

Water quality is generally good in crystalline-rock aquifers, but high concentrations of dissolved solids, iron, and hardness are prevalent in some areas. Hard ground water is common in Saluda County and parts of Edgefield and Union Counties; high dissolved-solids concentrations are common in parts of Union, York, Saluda, Newberry, and Greenwood Counties.

Naturally occurring radionuclides exceed recommended drinking water standards in isolated areas. Well samples containing uranium above the 30 μg/L (micrograms per liter) mcl (maximum contaminant level) are scattered through southeastern Greenville County and adjacent areas. The highest measured concentration exceeded 10,000 μg/L, and several others were above 1,000 μg/L. High concentrations of radium and radon also are present. The State Geological Survey and DHEC are working to determine the uranium source, and residents of the most-affected area now are served by municipal water systems.

Sodium, magnesium, and chloride concentrations, and alkalinity and hardness, are generally high in the geologic belts formed by low-grade metamorphism—the Carolina slate belt and, to a lesser extent, the Kings Mountain belt. Other water-quality constituents do not necessarily correlate with these belts. Ground-water quality in Piedmont and Blue Ridge aquifers typically is within drinking-water standards for most constituents (Moody and others, 1988). Concentrations of dissolved solids range from 22 to 1,100 mg/L but exceed the 500-mg/L secondary EPA Drinking Water standard only in limited areas. Ground-water data from the National Uranium Resource Evaluation program indicate a maximum of 1,260 mg/L for dissolved solids with an average in the Piedmont of 89 mg/L and a median value of 58 mg/L. The higher concentrations of dissolved solids are predominantly in the Carolina slate belt and in or near gabbroic plutons. The standard most often exceeded is the 50-μg/L limit for manganese (Patterson and Padgett, 1984), although the median concentration is only 17 μg/L. Manganese concentrations above 50 μg/L tend be located in the Carolina slate belt and near plutons, particularly gabbroic plutons. Water typically is soft in most Piedmont and Blue Ridge aquifers, although moderately-hard to very-hard water does occur locally (Moody and others, 1988). Alkalinity is generally low, ranging from 0.5 mg/L to 300 mg/L, with a median of 17 mg/L. Drinking-water standards for pH, chloride, fluoride, and nitrate are exceeded in some areas (Moody and others, 1988).

Coastal Plain Province

Cape Fear Aquifer. The Cape Fear aquifer consists principally of the Cape Fear Formation and is the basal aquifer of the South Carolina Coastal Plain. It consists of sand-and-gravel beds separated by thick sections of silt-and-clay. It is thought to occur mainly in the lower Coastal Plain and eastern part of the upper Coastal Plain. The type locality of the Cape Fear Formation is in North Carolina, and no part of the formation crops out in South Carolina. Structure contours on the top of the aquifer are shown in Figure 3-20.

Few wells penetrate the aquifer, hence hydraulic and water-quality data are scarce. In general, the aquifer is less permeable and productive than the overlying Middendorf aquifer, and the Cape Fear commonly contains more mineralized water. Those few wells completed exclusively in the Cape Fear exist mainly for test and observation purposes. DNR monitors Cape Fear observation wells near the Savannah River Site and at Calabash, N.C. Water-level observations show only small seasonal water-level fluctuations and little response to drought, mainly owing to its great depth and the small number of pumping wells. Cape Fear/Middendorf aquifer wells at Myrtle Beach and at Hilton Head Island have been constructed as tests for aquifer storage and recovery and for water-supply potential, respectively. The several wells that obtain water supply from the aquifer, at Mount Pleasant, Seabrook Island, and Hilton Head Island, also are screened in the Middendorf aquifer and obtain most of their water from that unit.

Water-quality data mainly are obtained from wells near the N.C.-S.C. border, where Cape Fear aquifers overlie the southwest flank of the Cape Fear Arch and are relatively shallow. Dissolved solids concentrations exceed 1,500 mg/L along the coast, increasing to more than 5,000 mg/L in northeastern Horry County, and generally reflect the trend seen in sodium and chloride concentrations. The distribution of the principal properties and constituents is shown in Figure 3-21.

Middendorf Aquifer. The Middendorf aquifer is composed mostly of Middendorf Formation sediment, but locally it includes parts of adjacent formations. In the updip areas, the aquifer is interbedded sand and clay lenses that were deposited in an upper delta-plain environment. Near the coast, the aquifer encompasses thin- to thick-bedded sand and clay deposited in marginal marine or lower delta-plain environments. In general, the Middendorf aquifer has coarser sand and less clay in the western part of the Coastal Plain than in the eastern part.

The Middendorf crops out along the Fall Line from Chesterfield County to Edgefield County, except for some areas of Aiken County where it not exposed (Figure 3-22). The aquifer dips southeastward near the Fall Line and southward along the coast. The top of the aquifer is at elevation 100, -700, and -1,700 feet msl (mean sea level) at Aiken, Little River, and Charleston, respectively. Thickness ranges from 0 feet at the Fall Line to more than 300 feet in Dorchester County.

Wells that tap the Middendorf can be found in nearly all of South Carolina's Coastal Plain counties, and it is the State's most widely used artesian aquifer. Well depths range from a few tens of feet in its subcrop area, where it locally is unconfined, to more than 2,700 feet in Beaufort County. Individual well yields that locally exceed 2,000 gpm and commonly exceed 500 gpm are reported. Transmissivities of up to 500,000 gpd/ft and specific capacities as great as 75 gpm/ft (gallons per minute per foot of drawdown) occur, but mainly in the upper Coastal Plain. Average hydraulic conductivities generally range between 200 and 500 gpd/ft^2, with the highest averages occurring in Aiken, Orangeburg, Chesterfield, and Marlboro Counties. Coarse sand-and-gravel formations occur in the aquifer in its subcrop area: where incised by stream erosion, these formations substantially contribute to the base flow of both upper Coastal Plain and through-flowing streams.

Pumping from the Middendorf has had a significant impact on potentiometric heads (water levels) near Charleston and in the region to the northeast. Figure 3-23 shows estimated water levels prior to ground-water development and in 2004. Declines of about 200 feet and 150 feet have occurred in Charleston and Florence Counties. Modern pumping, mainly in those two areas and in combination with modest aquifer transmissivity, has reversed ground-water flow from east to southwest.

Water from the Middendorf aquifer generally is of good quality, soft with low concentrations of dissolved solids, hardness, nitrate, and fluoride (Figure 3-24). Middendorf water becomes increasingly mineralized down gradient. Near the outcrop, the water is soft, acidic, and low in dissolved solids. Alkalinity (expressed as calcium carbonate), total dissolved solids, and sodium concentrations increase southeastward to more than 1,000, 2,500, and 1,000 mg/L, respectively. The pH increases from as low as 4.5 to more than 8.5. Dissolved-silica concentration exceeds 40 mg/L in eastern Florence, central Marion, and western Horry Counties. Ground water is highly mineralized or brackish beneath some areas near the coast and cannot be used for public supply without reverse-osmosis treatment.

Dissolved-iron concentrations commonly exceed 1 mg/L in a 25-mile wide band across Allendale, Bamberg, Orangeburg, Sumter, Florence, and Marion Counties. Southeast of this zone, dissolved iron decreases to less than 0.05 mg/L.

Middendorf water-quality variations reflect the geochemical and microbial reactions occurring in the aquifer. Water entering the aquifer is low in dissolved solids, and the sandy sediments of the upper Coastal Plain are less reactive than the clay and carbonate marine sediment near the coast. Mineral content therefore increases as groundwater flows coastward.

Major geochemical processes and trends that occur in the aquifer include:

- decomposition of organic matter;
- exchange of calcium from the dissolution of calcium carbonate minerals for sodium in sodium-rich marine clay minerals;
- the occurrence of dilute seawater near the coast.

Microbial processes also influence ground water chemistry. Dissolved oxygen decreases with increasing distance from recharge areas, iron-reducing bacteria generate soluble ferrous iron, and dissolved-iron concentrations increase. The ground water continues generally coastward, encountering sediment of increasingly marine origin and decreasing oxyhydroxide as the ground water approaches the coast, causing further sulfate reduction, formation of sulfide, and decreasing iron concentration as ferrous sulfide precipitates.

Black Creek Aquifer. The Black Creek aquifer is the youngest of the Cretaceous aquifers. It is composed mostly of permeable sediments of the Black Creek Formation but locally includes sediment of the overlying Peedee Formation. The aquifer encompasses thin- to thick-bedded sand and clay beds that were deposited in marginal-marine or delta-plain environments. The coarsest sand and least clay content are found in the western part of the Coastal Plain.

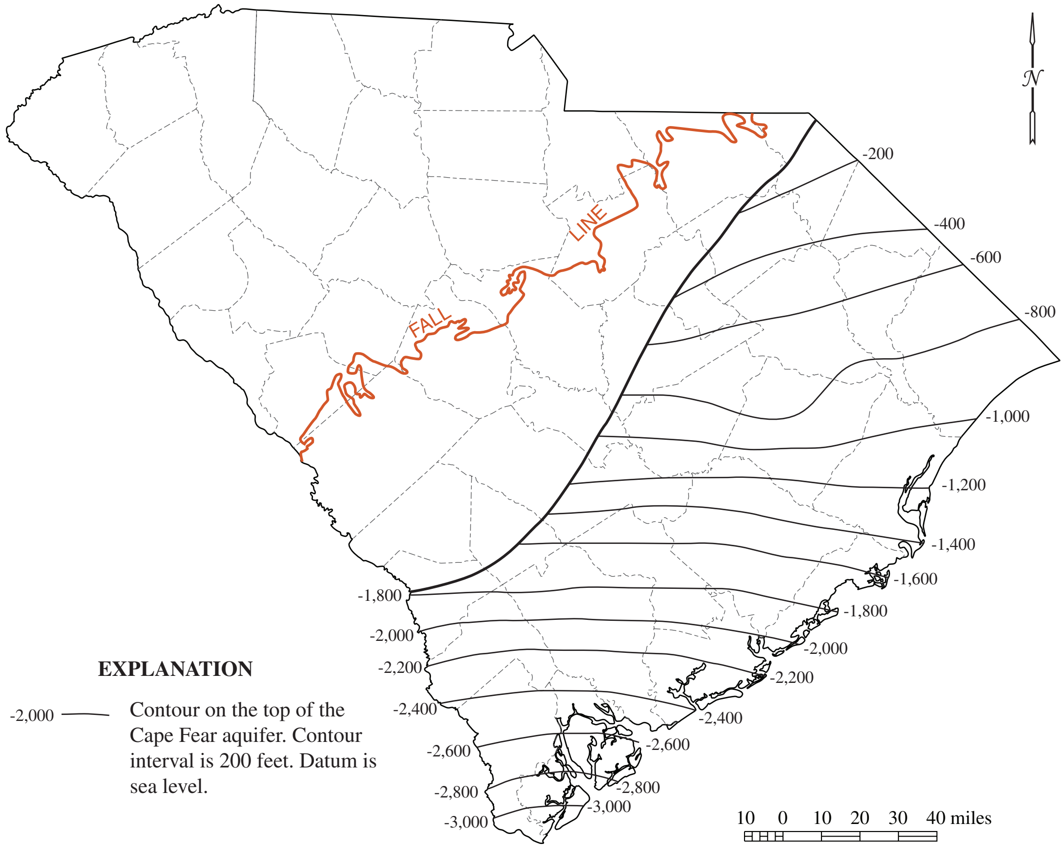

Figure 3-20. Structure contours on top of the Cape Fear aquifer (Aucott and others, 1986).

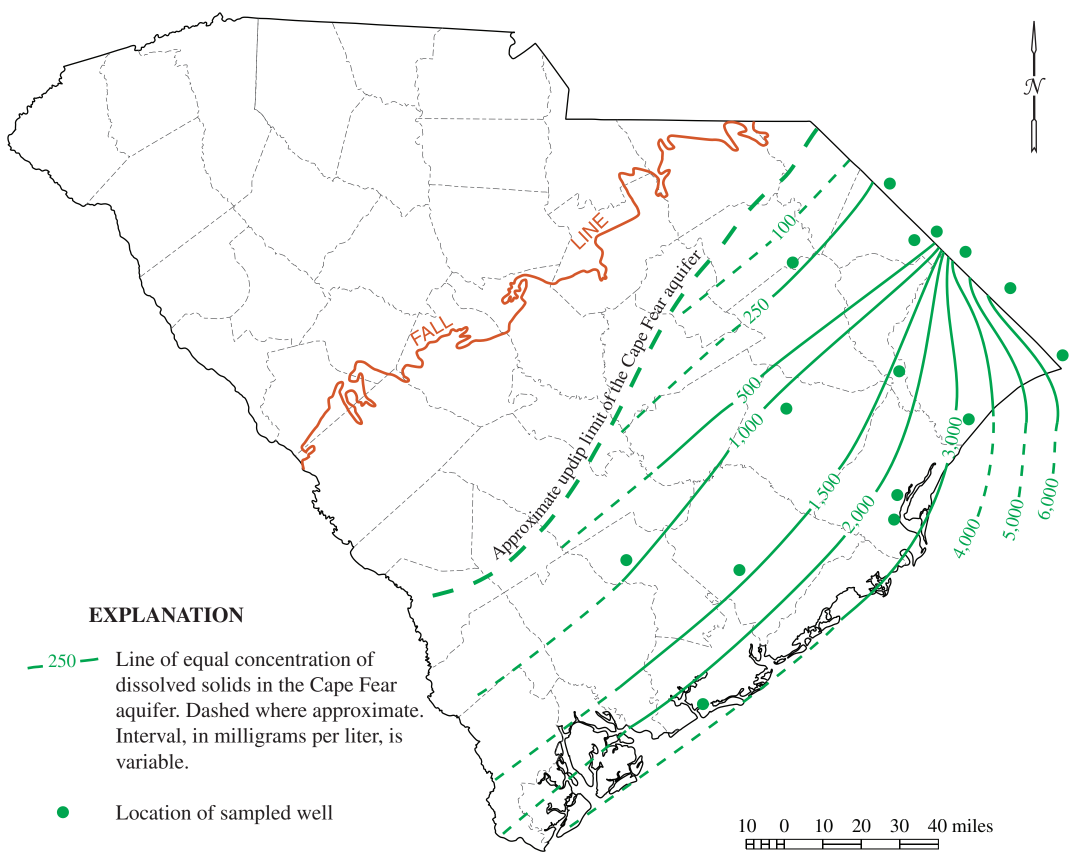

Figure 3-21. (a) Distribution of dissolved solids in the Cape Fear aquifer (Speiran and Aucott, 1994).

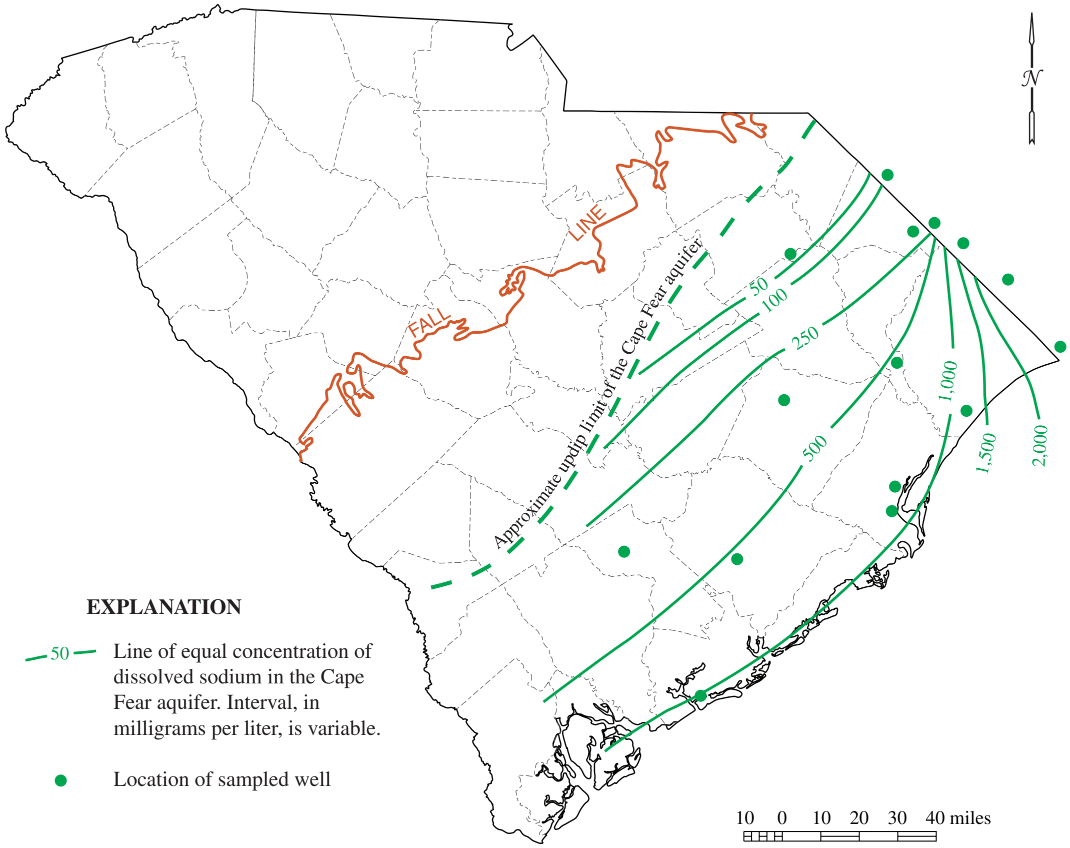

Figure 3-21. (b) Distribution of sodium in the Cape Fear aquifer (Speiran and Aucott, 1994).

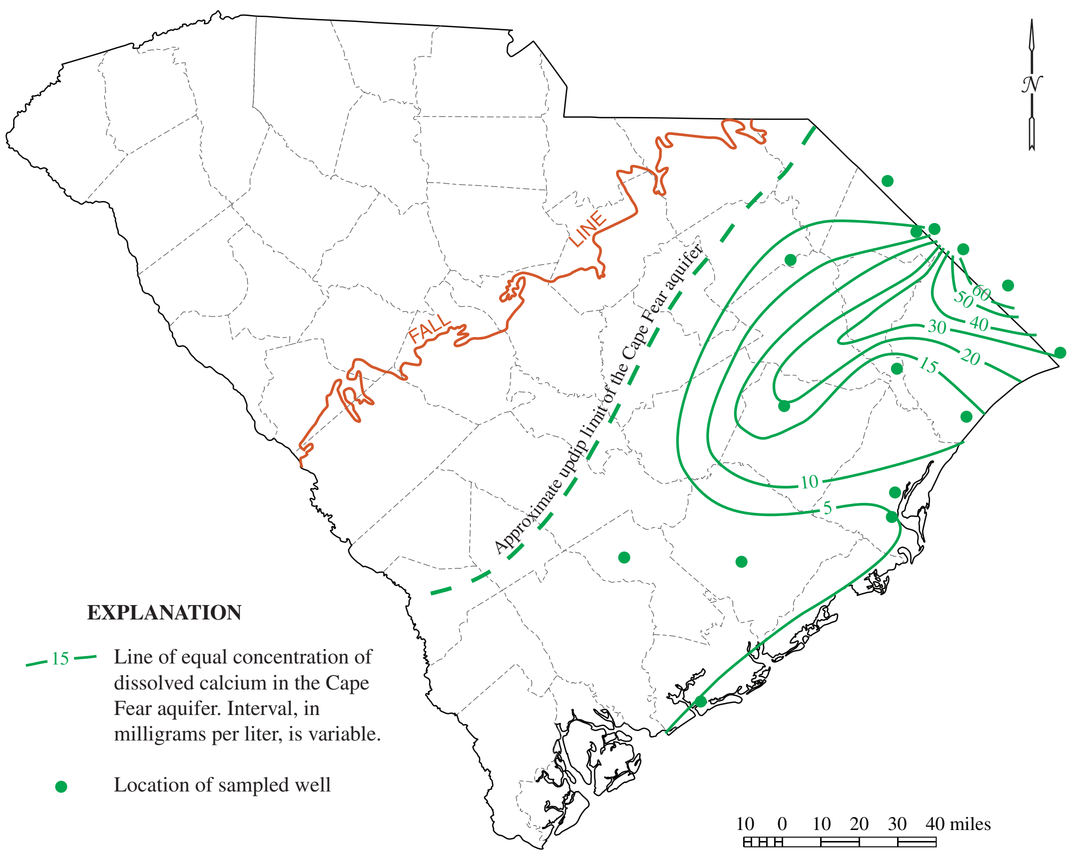

Figure 3-21. (c) Distribution of calcium in the Cape Fear aquifer (Speiran and Aucott, 1994).

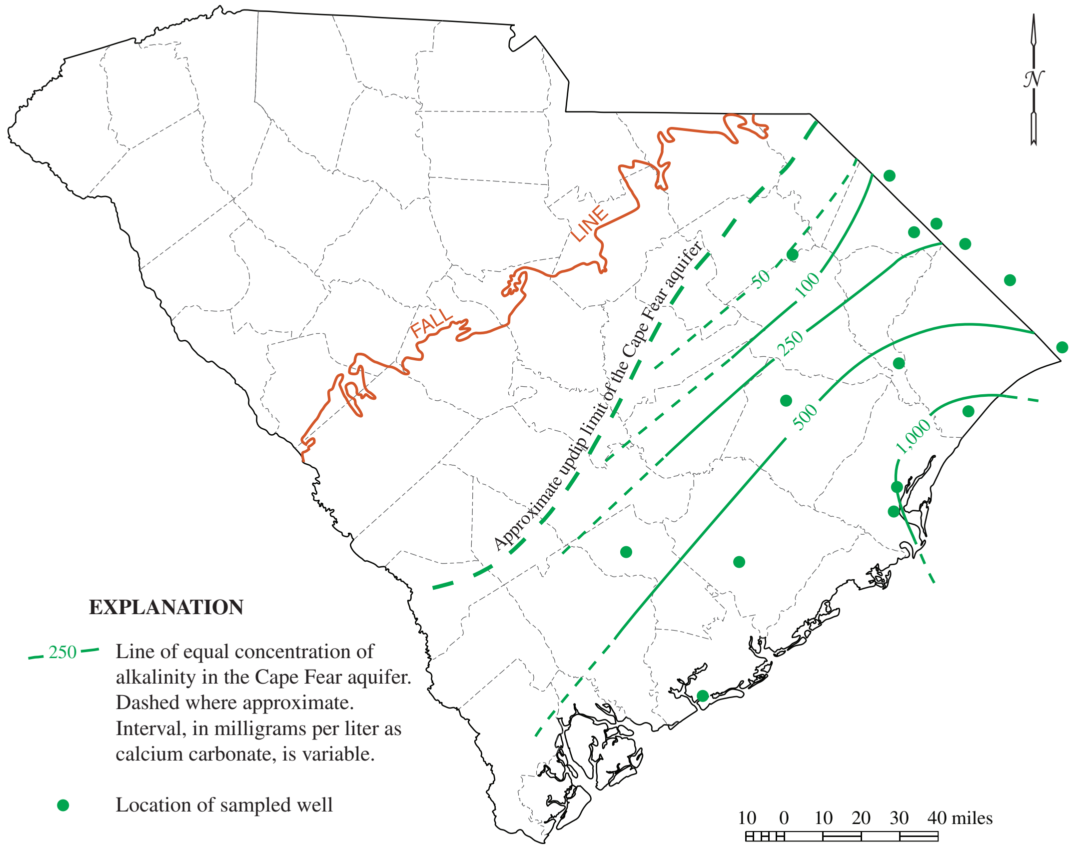

Figure 3-21. (d) Distribution of alkalinity in the Cape Fear aquifer (Speiran and Aucott, 1994).

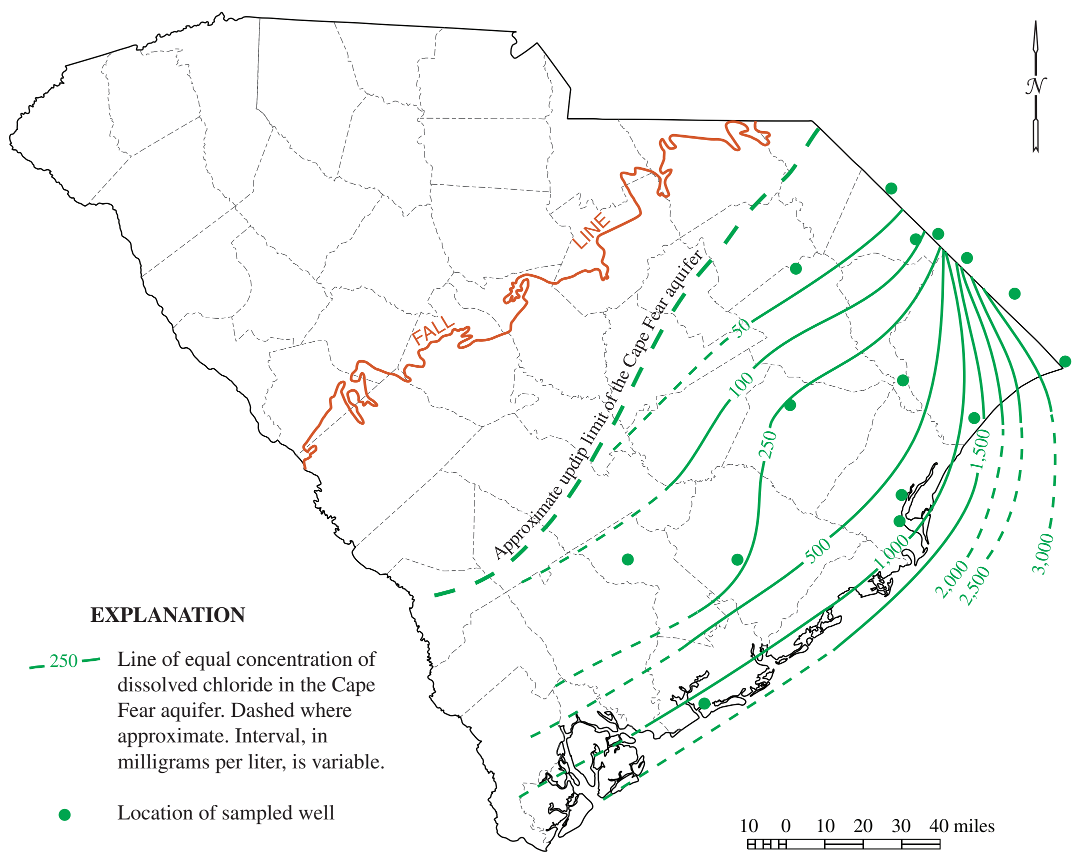

Figure 3-21. (e) Distribution of chloride in the Cape Fear aquifer (Speiran and Aucott, 1994).

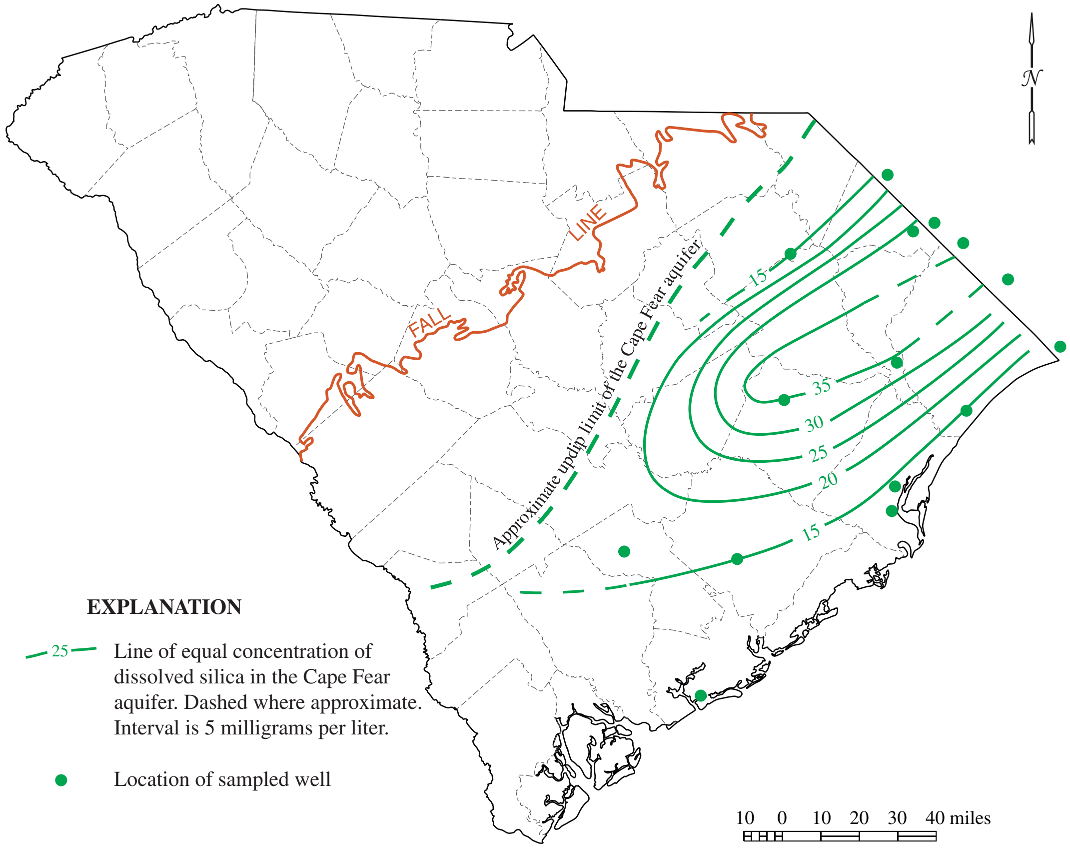

Figure 3-21. (f) Distribution of silica in the Cape Fear aquifer (Speiran and Aucott, 1994).

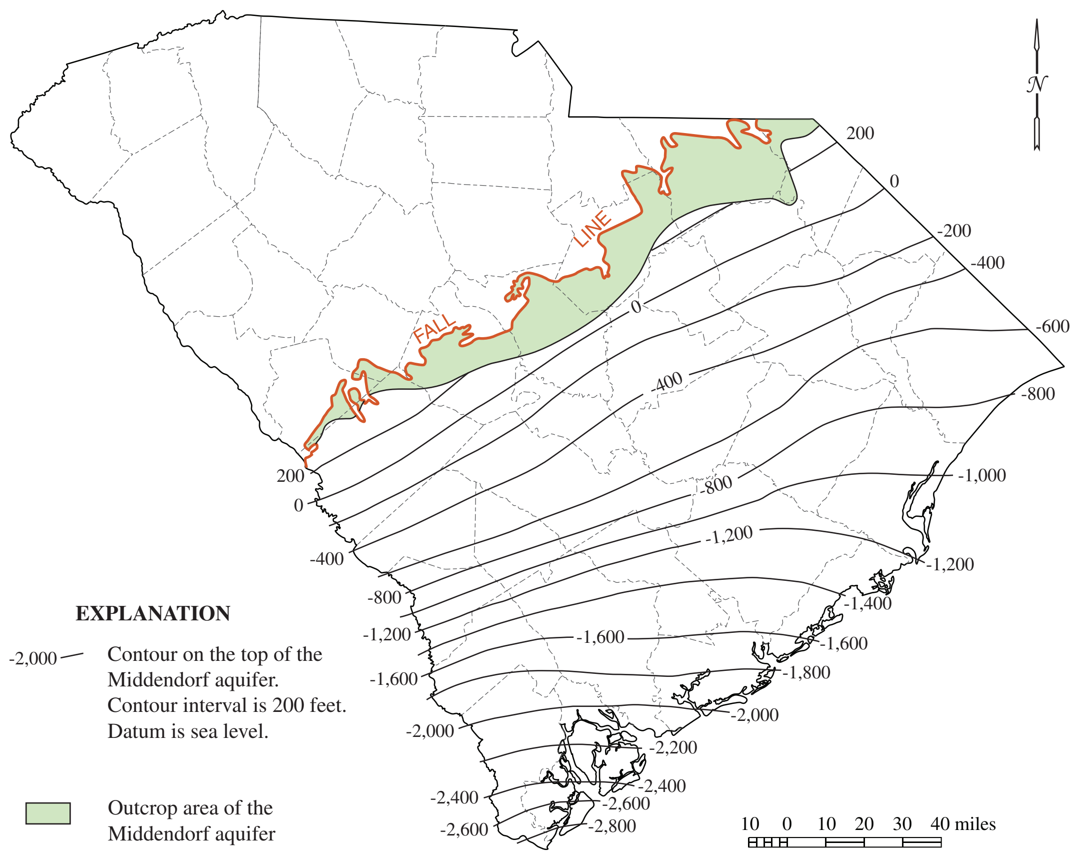

Figure 3-22. Structure contours on top of the Middendorf aquifer (Aucott and others, 1986).

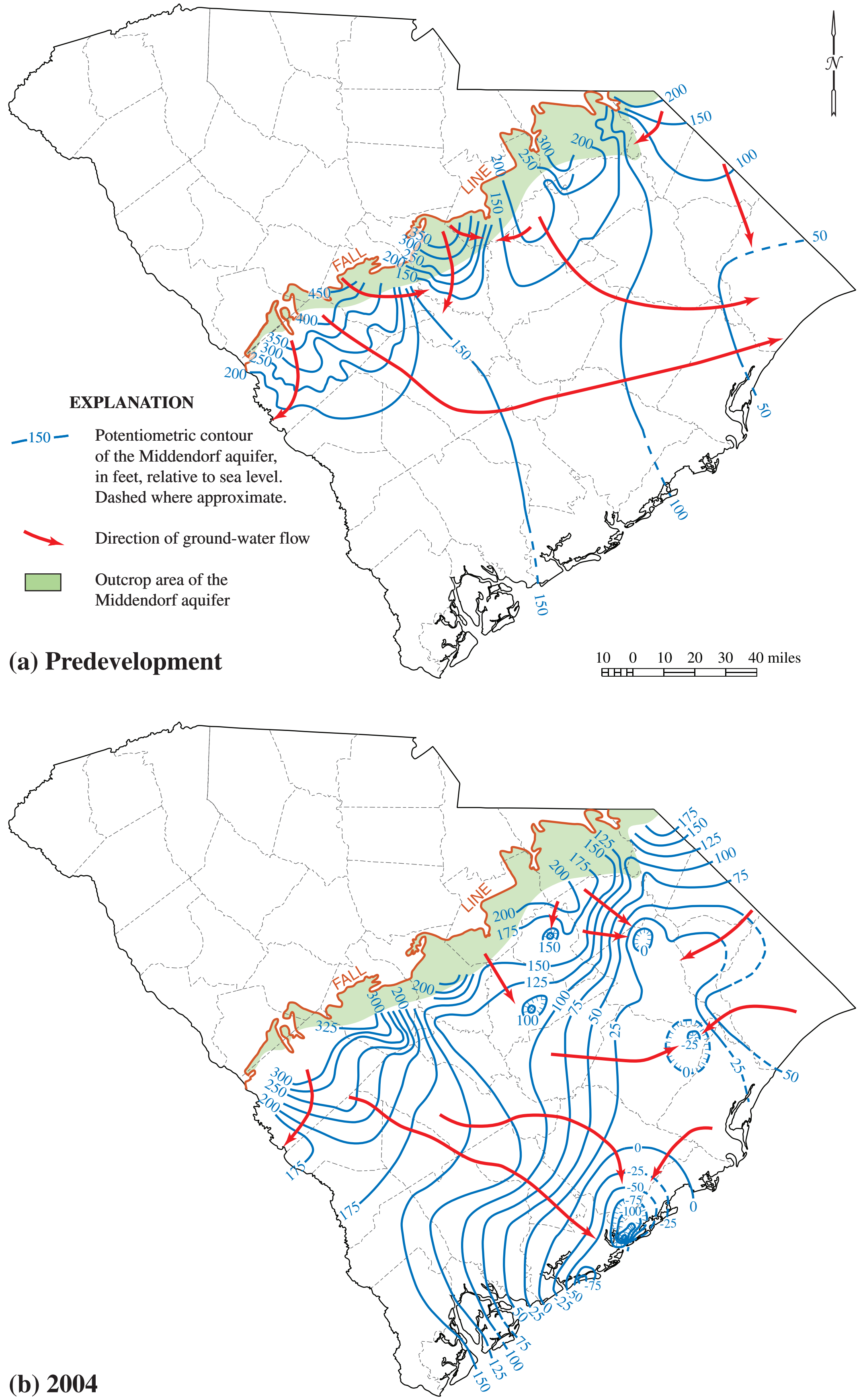

Figure 3-23. Predevelopment (a) and 2004 (b) water levels in the Middendorf aquifer. (Aucott and Speiran, 1985; Hockensmith, 2008a)

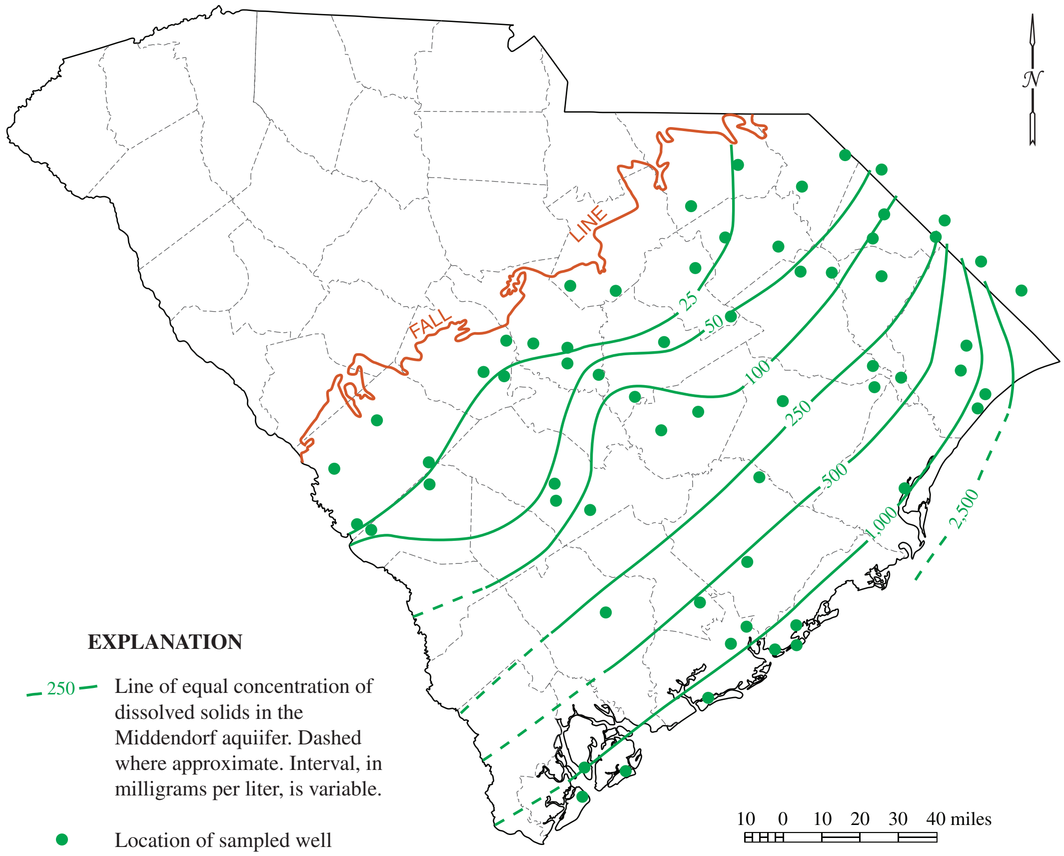

Figure 3-24. (a) Distribution of dissolved solids in the Middendorf aquifer (Speiran and Aucott, 1994).

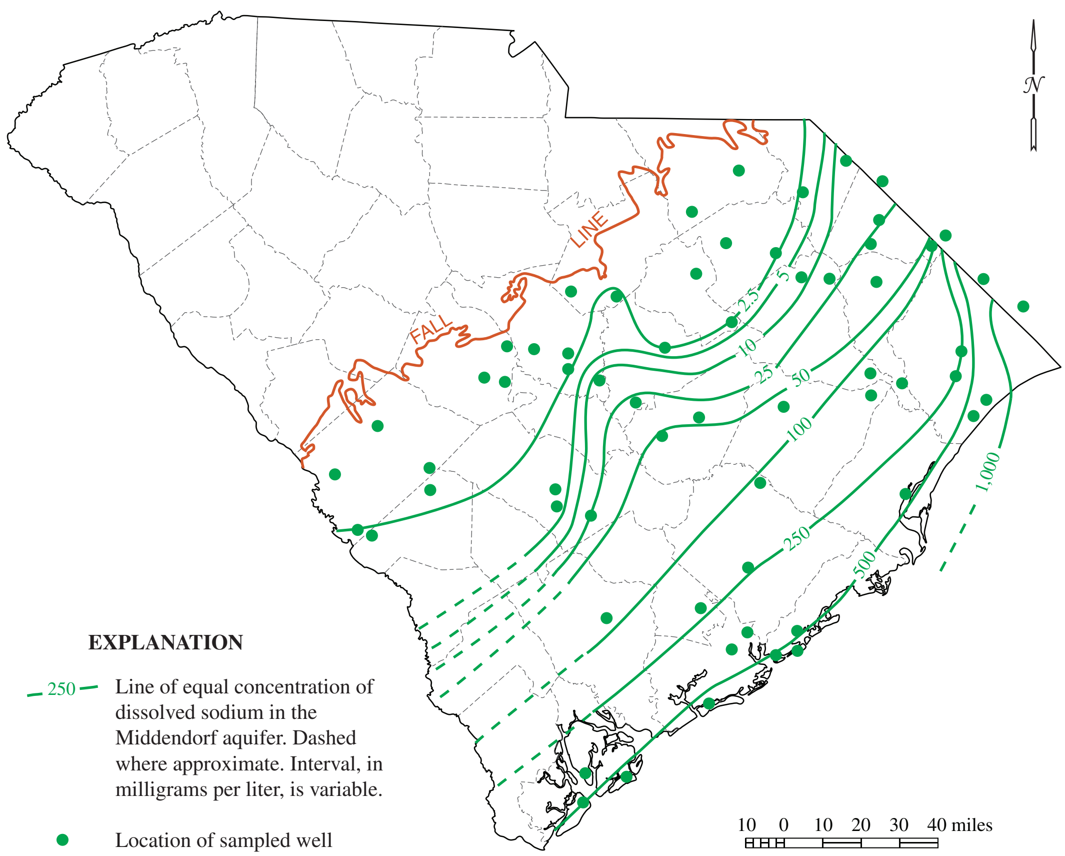

Figure 3-24. (b) Distribution of sodium in the Middendorf aquifer (Speiran and Aucott, 1994).

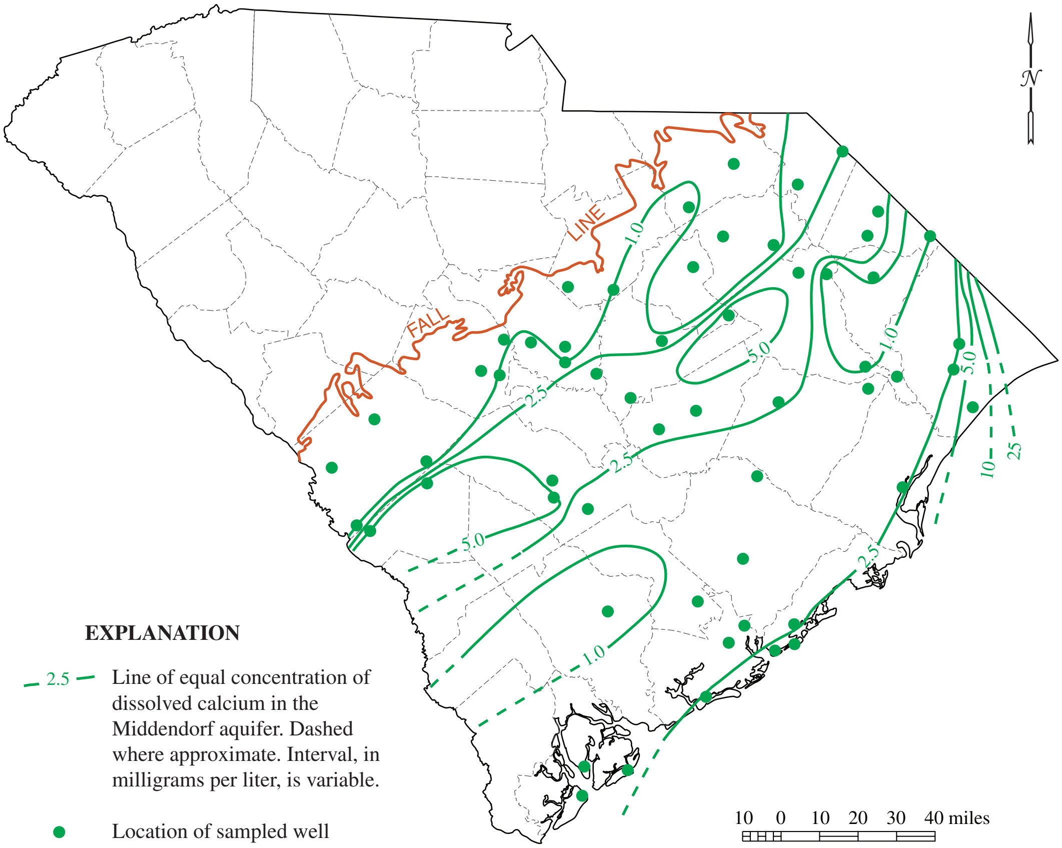

Figure 3-24. (c) Distribution of calcium in the Middendorf aquifer (Speiran and Aucott, 1994).

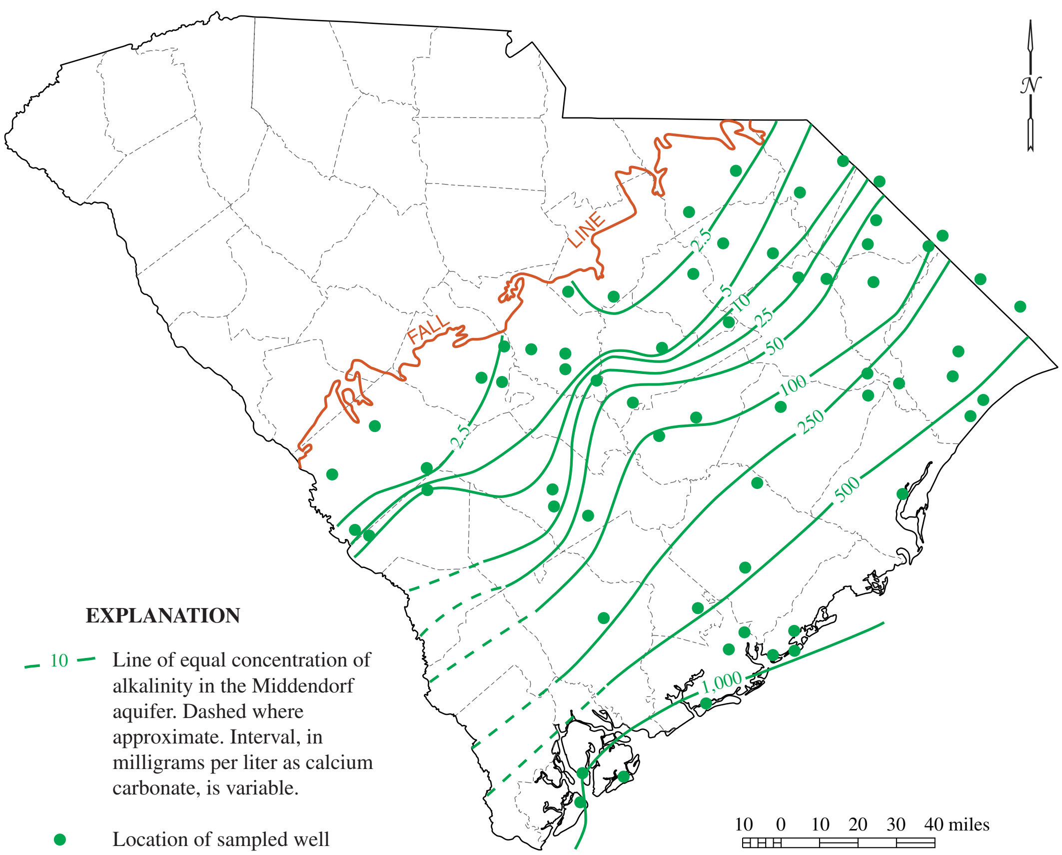

Figure 3-24. (d) Distribution of alkalinity in the Middendorf aquifer (Speiran and Aucott, 1994).

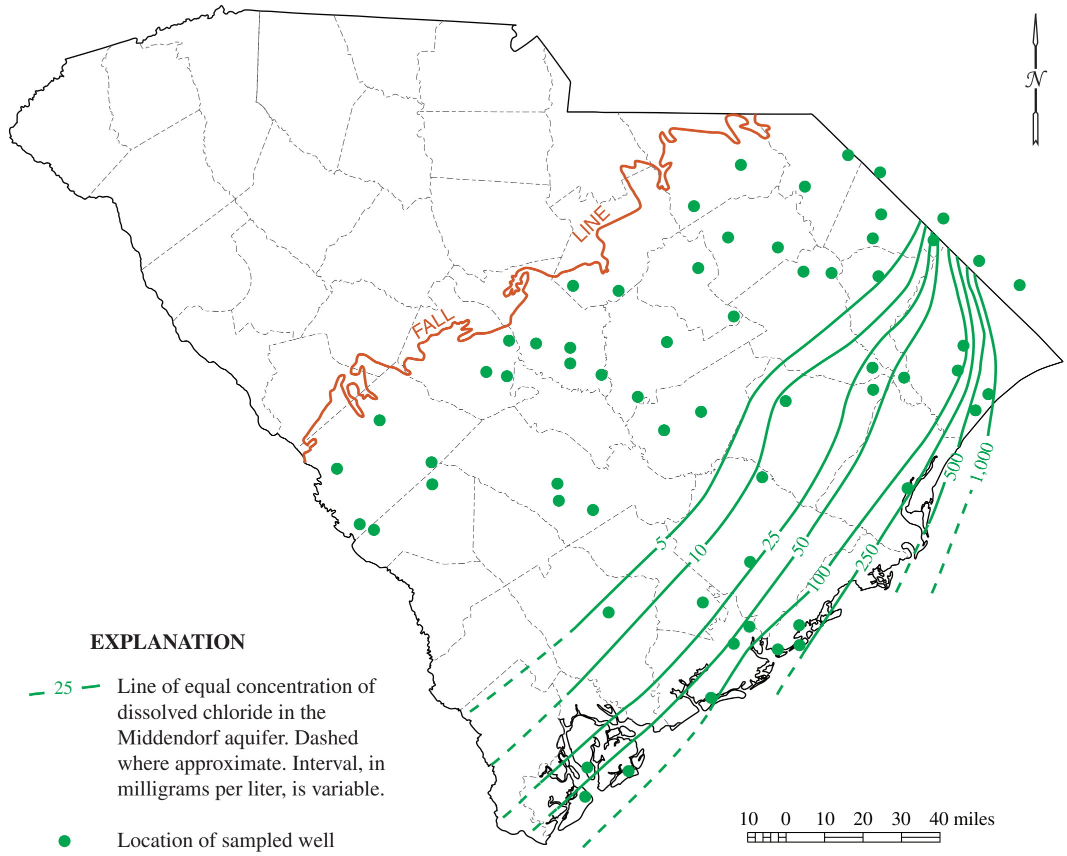

Figure 3-24. (e) Distribution of chloride in the Middendorf aquifer (Speiran and Aucott, 1994).

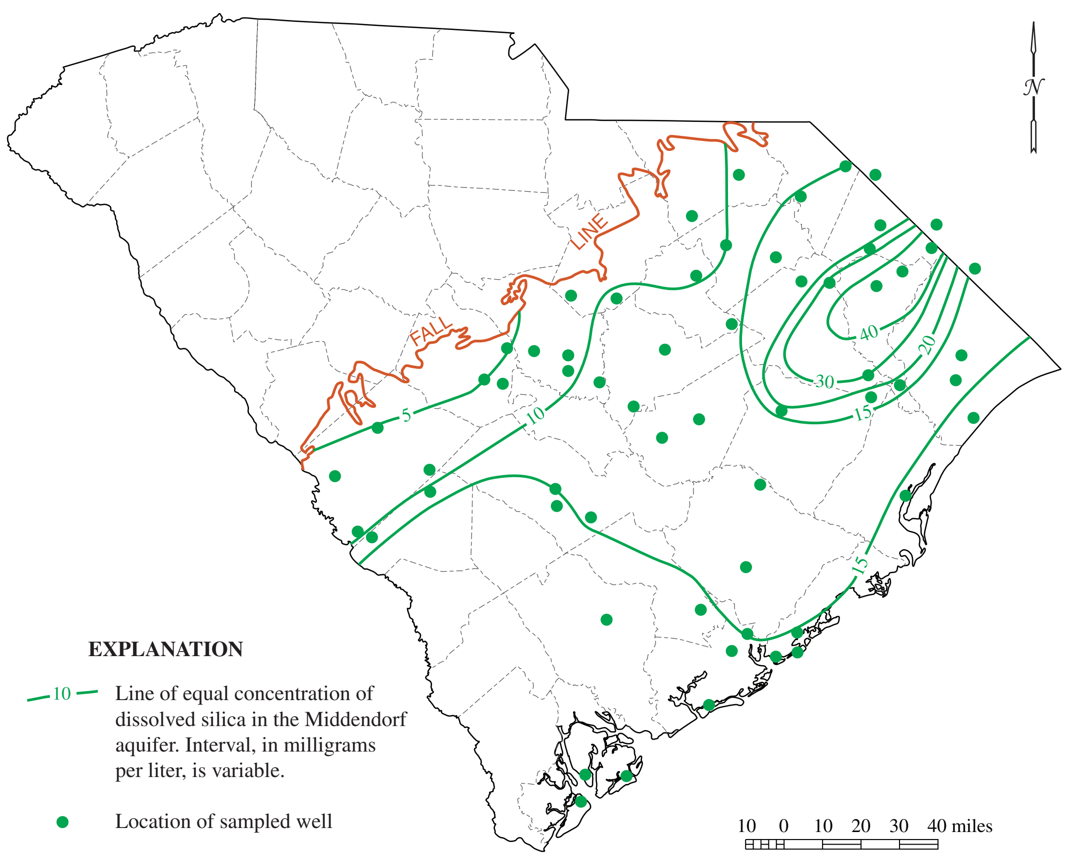

Figure 3-24. (f) Distribution of silica in the Middendorf aquifer (Speiran and Aucott, 1994).

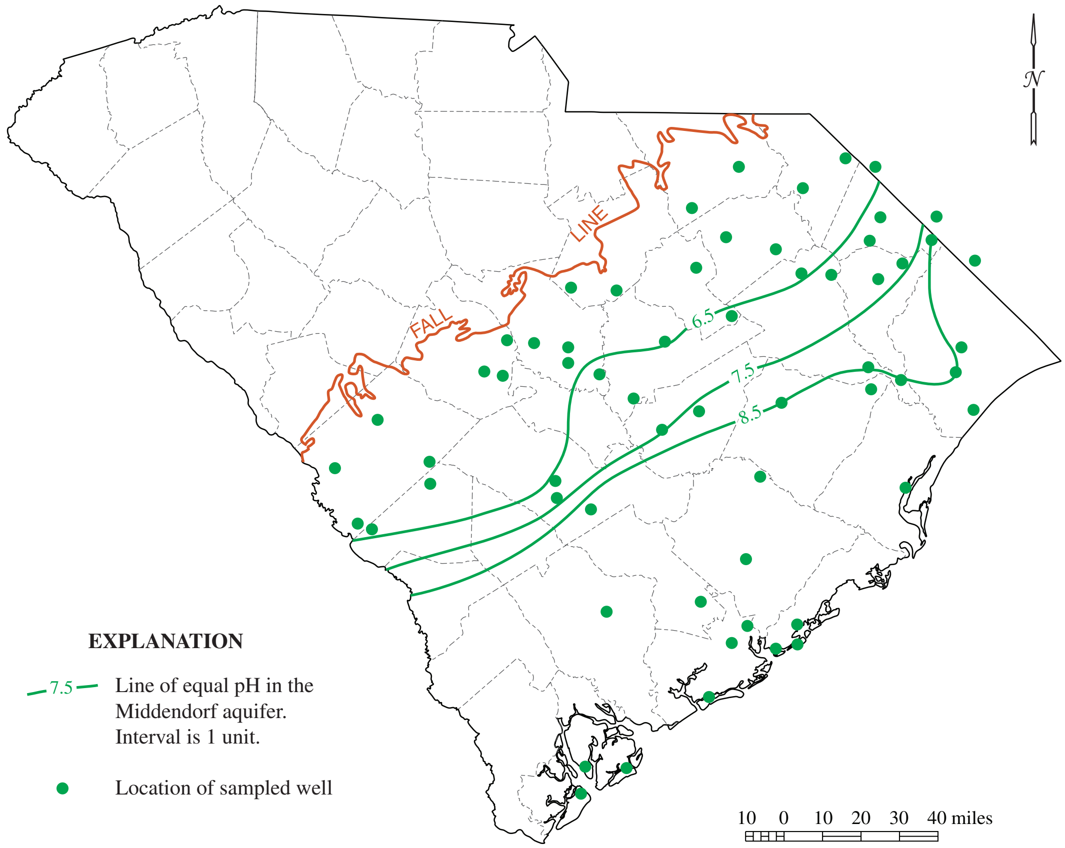

Figure 3-24. (g) Distribution of pH in the Middendorf aquifer (Speiran and Aucott, 1994).

The aquifer crops out in the eastern Coastal Plain along a narrow band extending from Lexington County to Sumter County, thence along a wider band from Sumter County to Dillon County. It dips southeastward toward the coast. The top of the aquifer is at elevation 300, -250, and -1,000 feet msl at Aiken, Little River, and Charleston, respectively. Thickness ranges from about 100 feet near Aiken to more than 400 feet at the coast. Its subcrop area and structure, contoured in feet above msl, are delineated in Figure 3-25.

The Black Creek aquifer is an important source of water supply in, and downdip from, its subcrop area. Well yields are greatest in the counties of the upper and middle Coastal Plain and are least in the coastal counties of Charleston and Beaufort. The average hydraulic conductivites are about 100 gpd/ft^2 between Berkeley and Horry Counties; are between 200 and 320 gpd/ft^2 between Richland and Marion Counties; and are between 360 and 640 gpd/ft^2 in Aiken, Allendale, and Orangeburg Counties. Where the highest possible well yields are desired, the Black Creek is screened in conjunction with the underlying Middendorf aquifer. These multiaquifer-system wells are commonly used by major industrial and public-supply systems in Sumter, Florence, Horry, and Georgetown Counties.

The greatest declines in Black Creek water levels have occurred in the eastern part of the Coastal Plain, mainly in Marion, Georgetown, and Horry Counties. The greatest drawdowns occurred along the coast of Horry County prior to the 1990's as public-supply systems increased their withdrawals to satisfy rapidly-increasing population and tourism: water levels recovered after the region's major utilities converted to surface-water sources but resumed decline with increasing golf-course irrigation. Predevelopment and recent levels are compared in Figure 3-26.

Water from the Black Creek aquifer generally is soft, alkaline, low in dissolved iron, and high in pH and dissolved solids. Total dissolved solids and sodium concentrations commonly exceed EPA's secondary water-quality standards. In the coastal counties, fluoride exceeds the recommended contaminant limits.

Ground water becomes increasingly mineralized downgradient, as in the case of the Middendorf aquifer (Figure 3-27). Concentrations of dissolved solids range from less than 25 mg/L near the outcrop to more than 2,500 mg/L at the coast. Alkalinity, sodium, and chloride range from less than 2.5 mg/L to more than 1,000 mg/L between the outcrop and the coast, and pH ranges between 4.5 and 8.5. The increase in sodium concentration across the Coastal Plain mainly is due to the natural exchange of calcium ions in the water for sodium ions in clay; however, the greatest sodium concentrations occur at the coast where saltwater is not fully flushed from the aquifer. Along the extreme northern coast and the Charleston County coast, concentrations of chloride exceed the 250-mg/L secondary standard: along the southern coast, chloride concentrations locally exceed 1,000 mg/L.

High silica concentrations are found in eastern Sumter County, Florence County, and central Marion County, where dissolved silica locally exceeds 35 mg/L. Turbid water has been reported from Black Creek wells in a belt between Horry and Hampton Counties, but the turbidity, probably caused by the aragonitic form of calcium carbonate precipitate, is uncommon, and usually is temporary. Fluoride concentrations, which are negligible near the subcrop area, increase significantly across the lower Coastal Plain, and they exceed the 4.0 mg/L secondary limit in parts of Horry, Georgetown, and Charleston Counties.

Iron concentrations typically exceed the 300-µg/L secondary drinking-water standard in a broad band across the northern upper Coastal Plain, and iron concentrations there are as great as 3,000 µg/L. Dissolved-iron concentrations greater than 300 µg/L are rare in the middle and lower Coastal Plain.

In the lower Coastal Plain, ground water is predominately a sodium bicarbonate type caused by dissolution of calcium carbonate material and subsequent exchange of sodium for calcium. The pH ranges from 8.0 to 9.2, and exceeds the 8.5 drinking-water standard in much of the area. Dissolved-solids and fluoride concentrations exceed the secondary standards (500 mg/L and 2.0 mg/L, respectively) along the coast. In most of the lower Coastal Plain, dissolved-sodium concentrations are several hundred milligrams per liter.

Tertiary Sand Aquifer. Aucott and others (1986) divided the Tertiary sand aquifer into two parts. The upper part consists of fine- to coarse-grained sand of the Barnwell Group, McBean Formation, and Congaree Formation. They are the sand-facies equivalent of the Floridan aquifer and extend from the vicinity of the Fall Line to the updip limit of the Floridan aquifer. In Allendale, Bamberg, Barnwell, and Aiken Counties, the Congaree Formation is the principal water-bearing unit, and the Barnwell Group and McBean Formation tend to be poorly productive and more significant as confining units. The SCWRC reported a median hydraulic conductivity of 35 gpd/ft^2 (about 4.7 ft^2/day) for the Congaree: individual wells completed in the unit yield up to 660 gpm, and reported specific capacities are about 10 gpm/ft.

The lower part of the Tertiary sand aquifer underlies all of the Floridan aquifer, extends westward into the middle Coastal Plain, and consists principally of the Paleocene-age Black Mingo Formation. The upper 50 to 100 feet of the

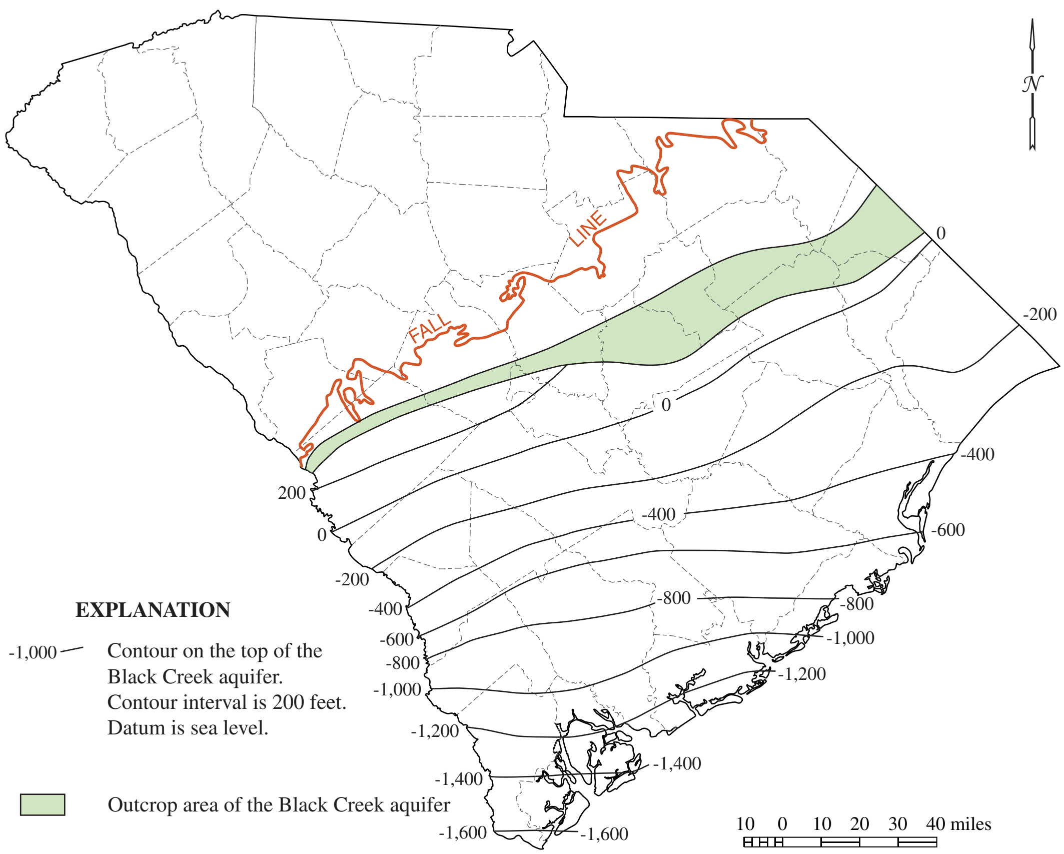

Figure 3-25. Structure contours on top of the Black Creek aquifer (Aucott and others, 1986).

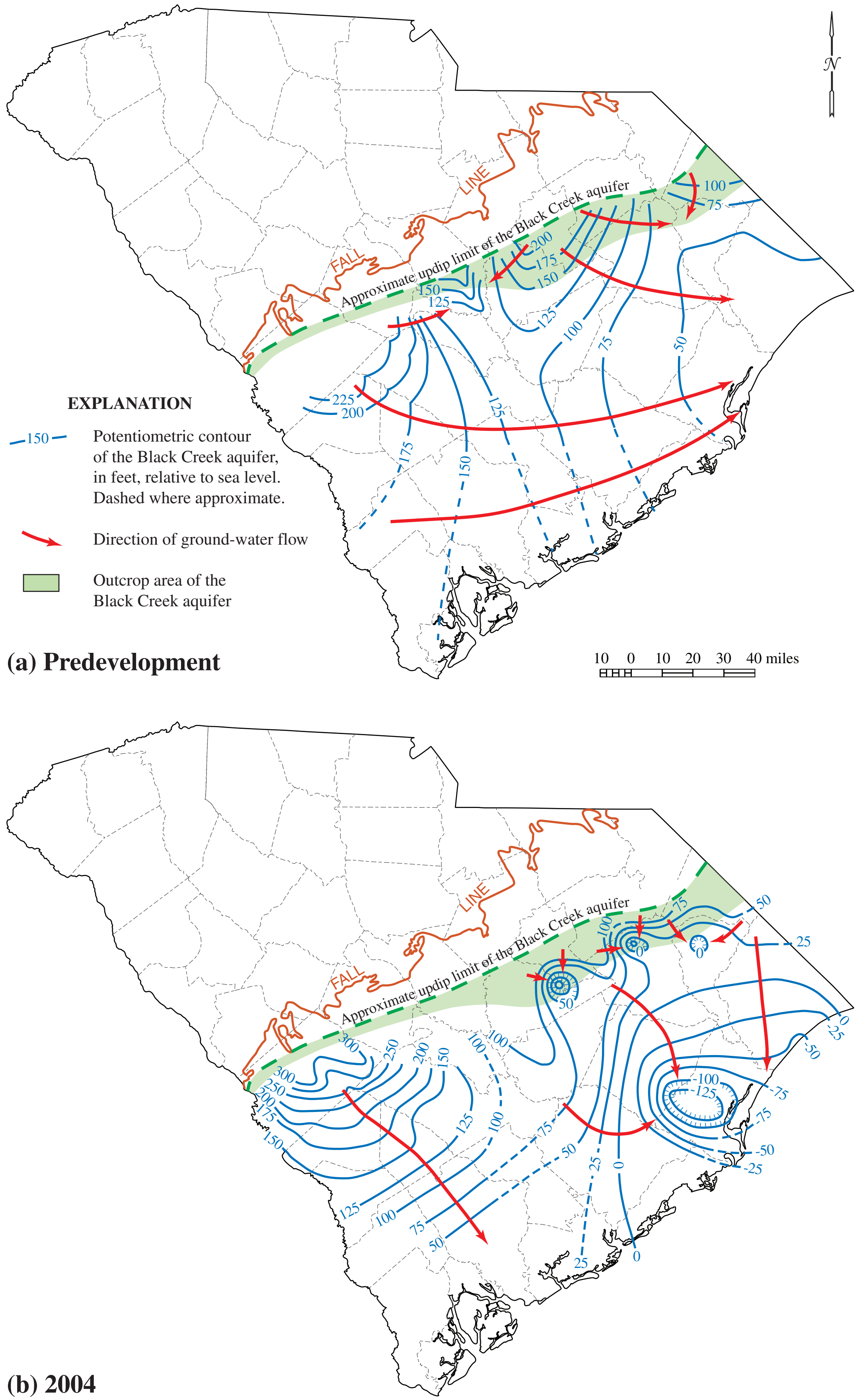

Figure 3-26. Predevelopment (a) and 2004 (b) water levels in the Black Creek aquifer (Aucott and Speiran, 1985; Hockensmith, 2008b).

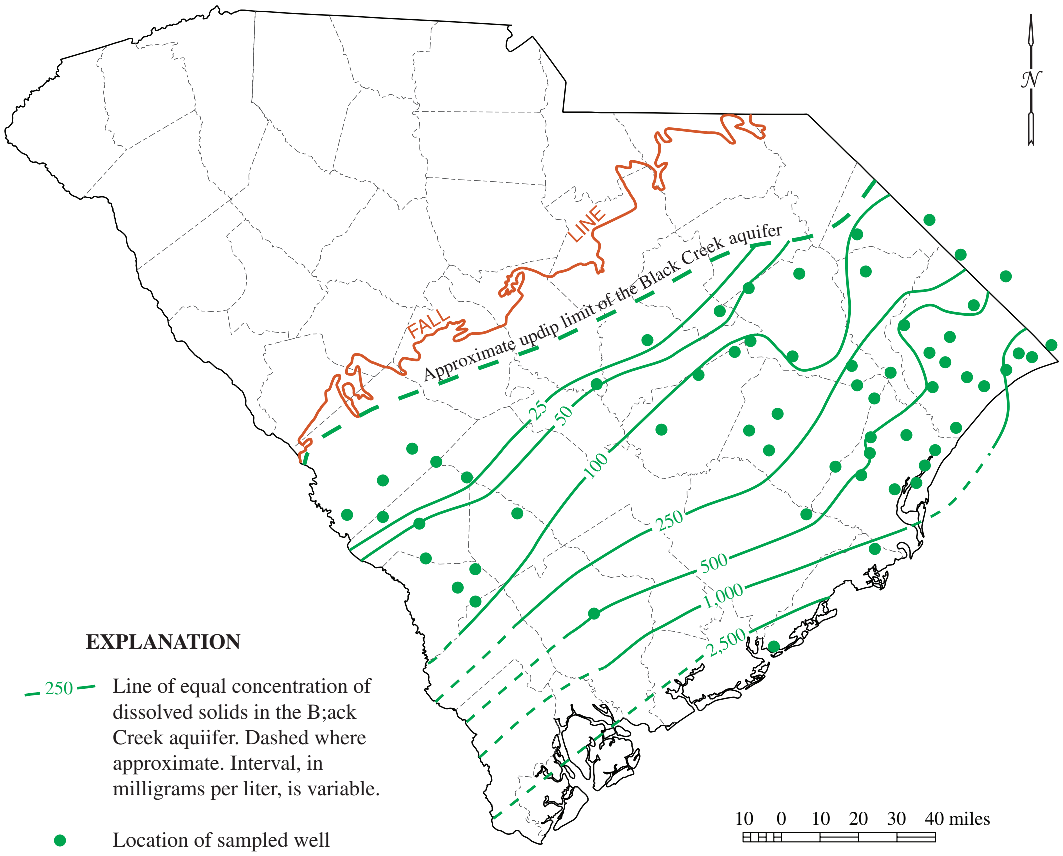

Figure 3-27. (a) Distribution of dissolved solids in the Black Creek aquifer (Speiran and Aucott, 1994).

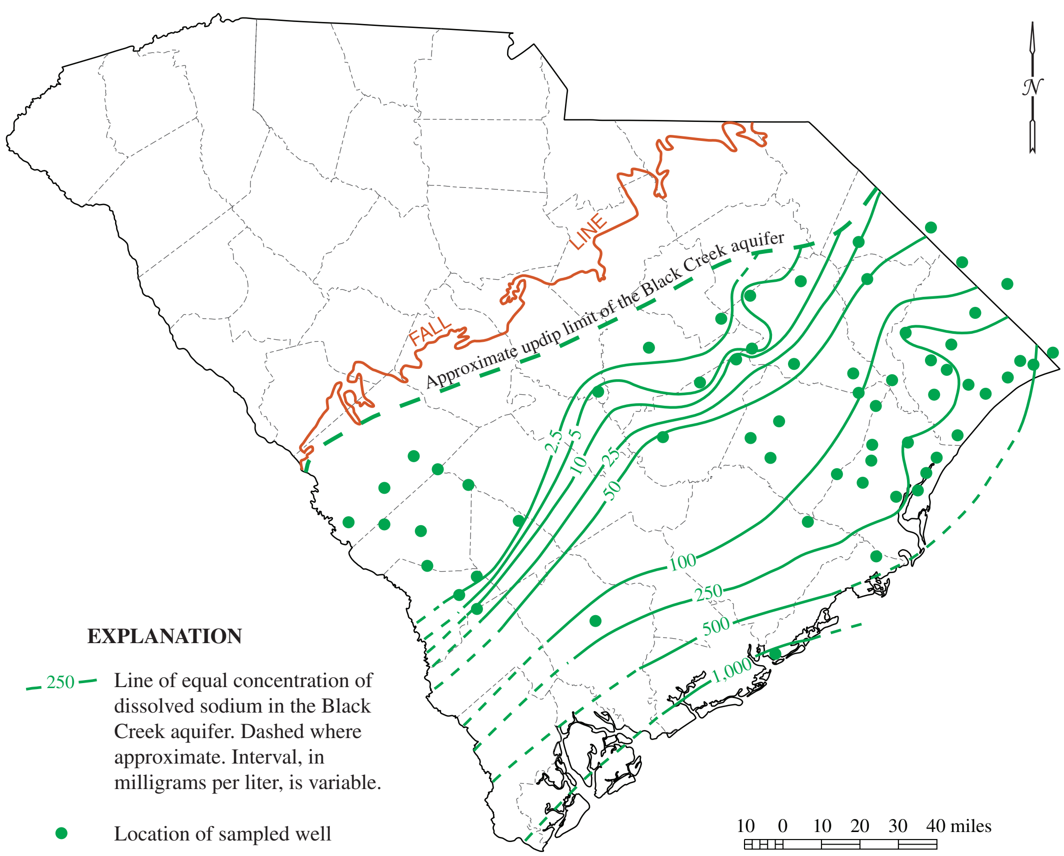

Figure 3-27. (b) Distribution of sodium in the Black Creek aquifer (Speiran and Aucott, 1994).

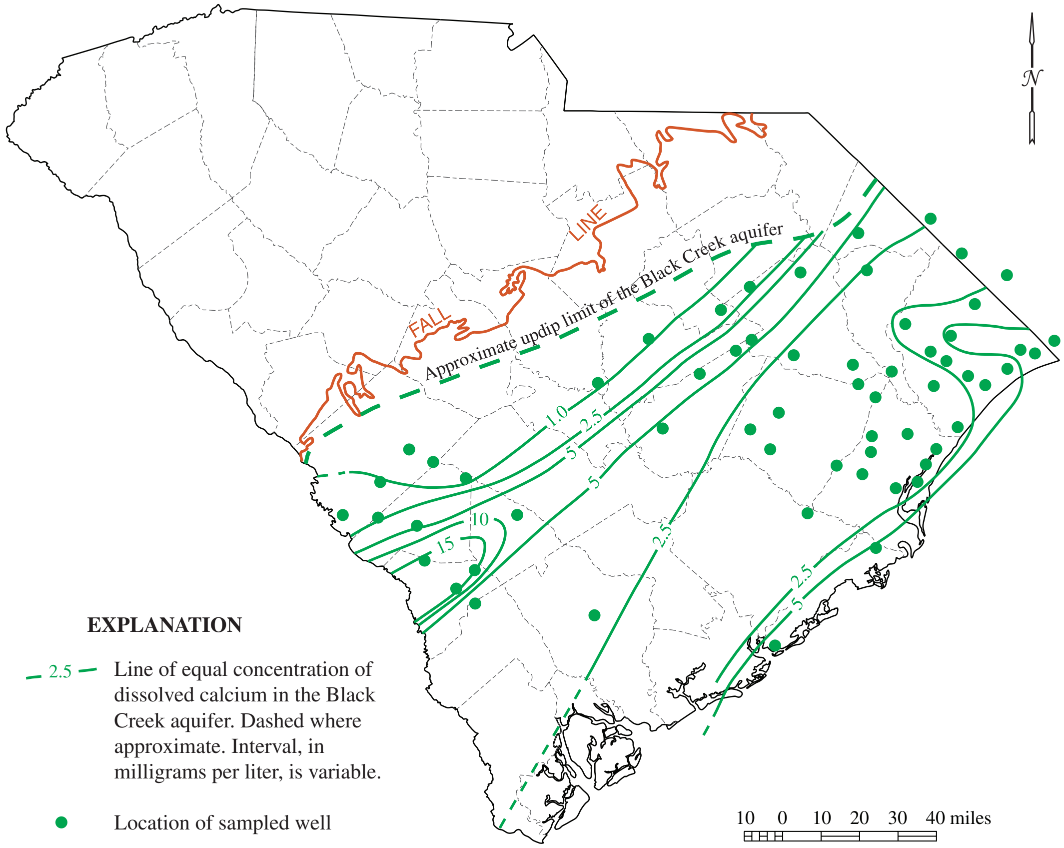

Figure 3-27. (c) Distribution of calcium in the Black Creek aquifer (Speiran and Aucott, 1994).

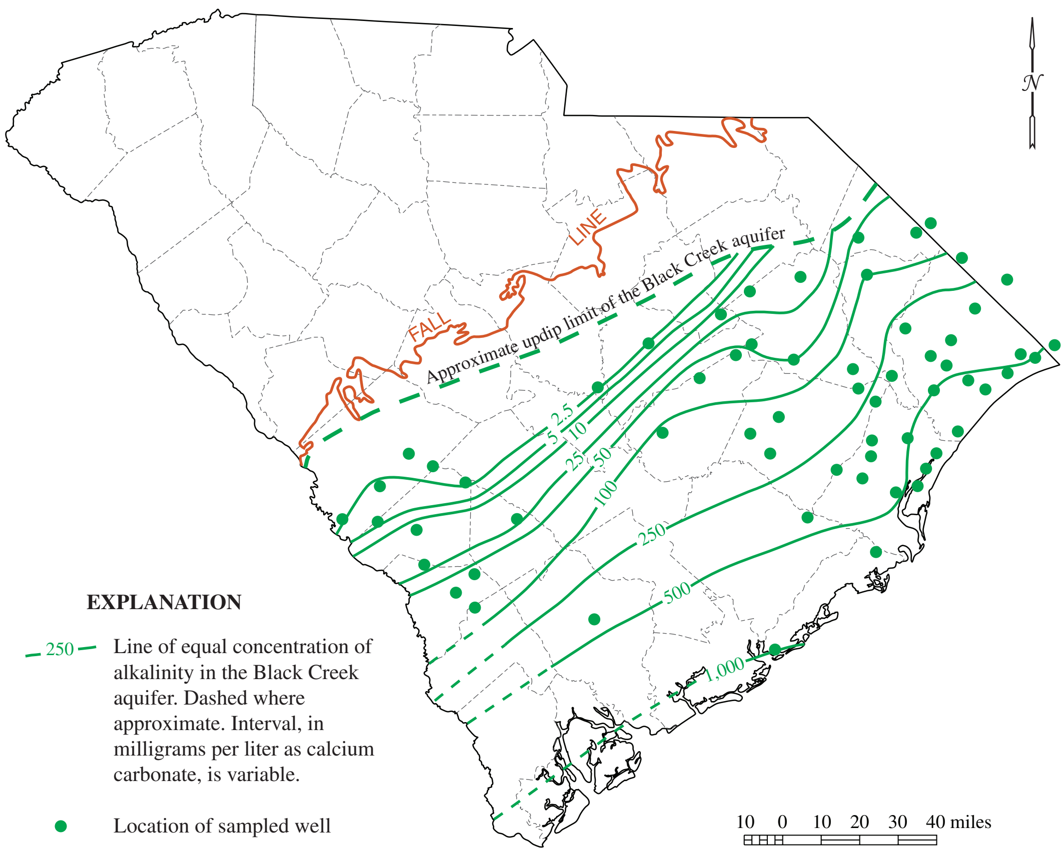

Figure 3-27. (d) Distribution of alkalinity in the Black Creek aquifer (Speiran and Aucott, 1994).

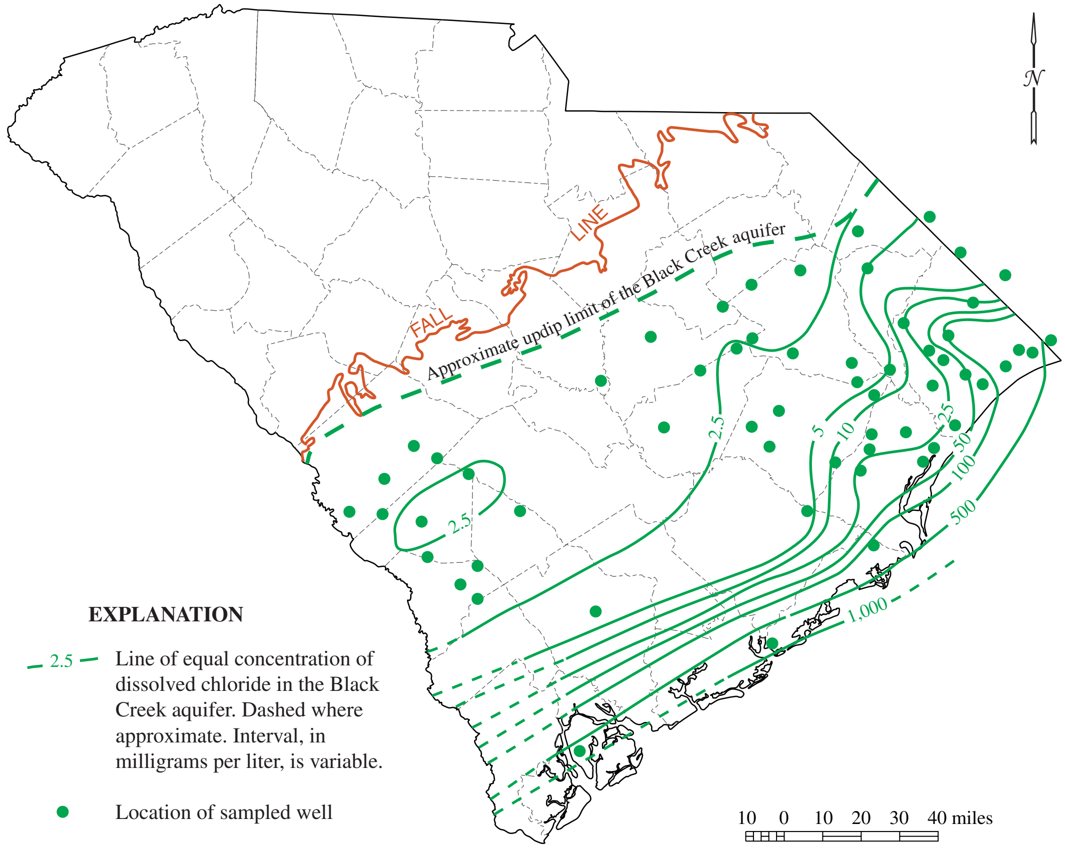

Figure 3-27. (e) Distribution of chloride in the Black Creek aquifer (Speiran and Aucott, 1994).

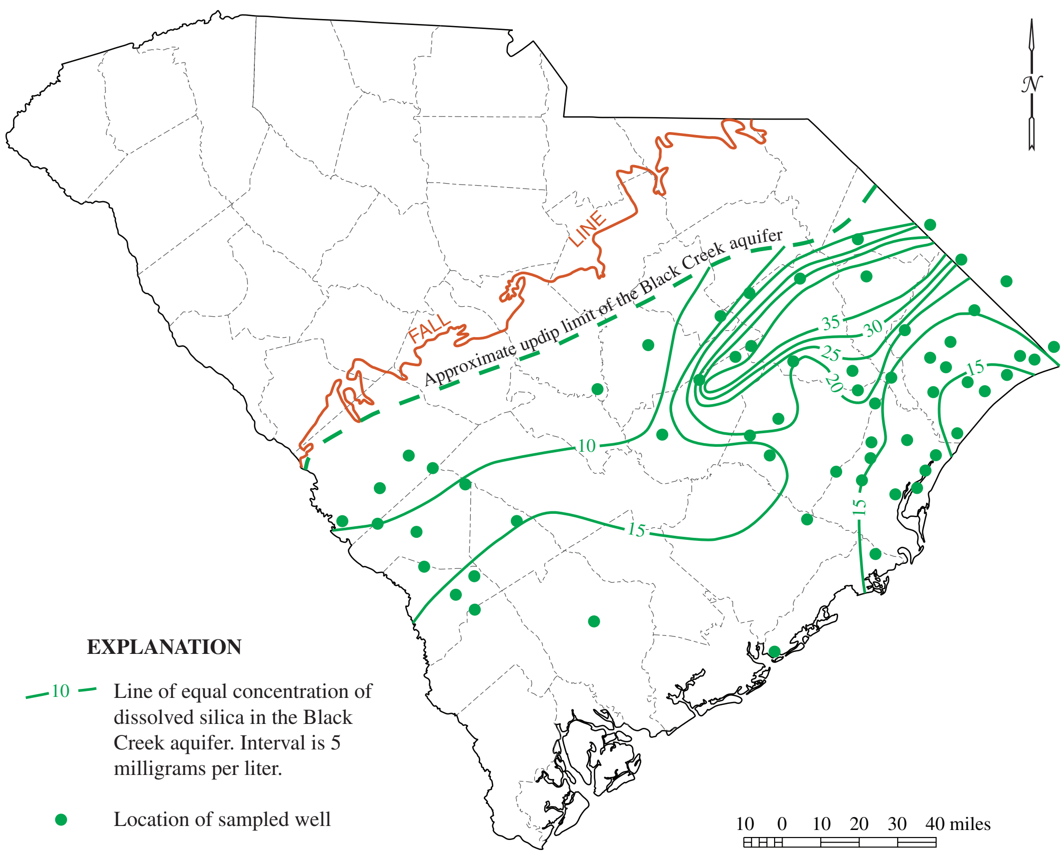

Figure 3-27. (f) Distribution of silica in the Black Creek aquifer (Speiran and Aucott, 1994).

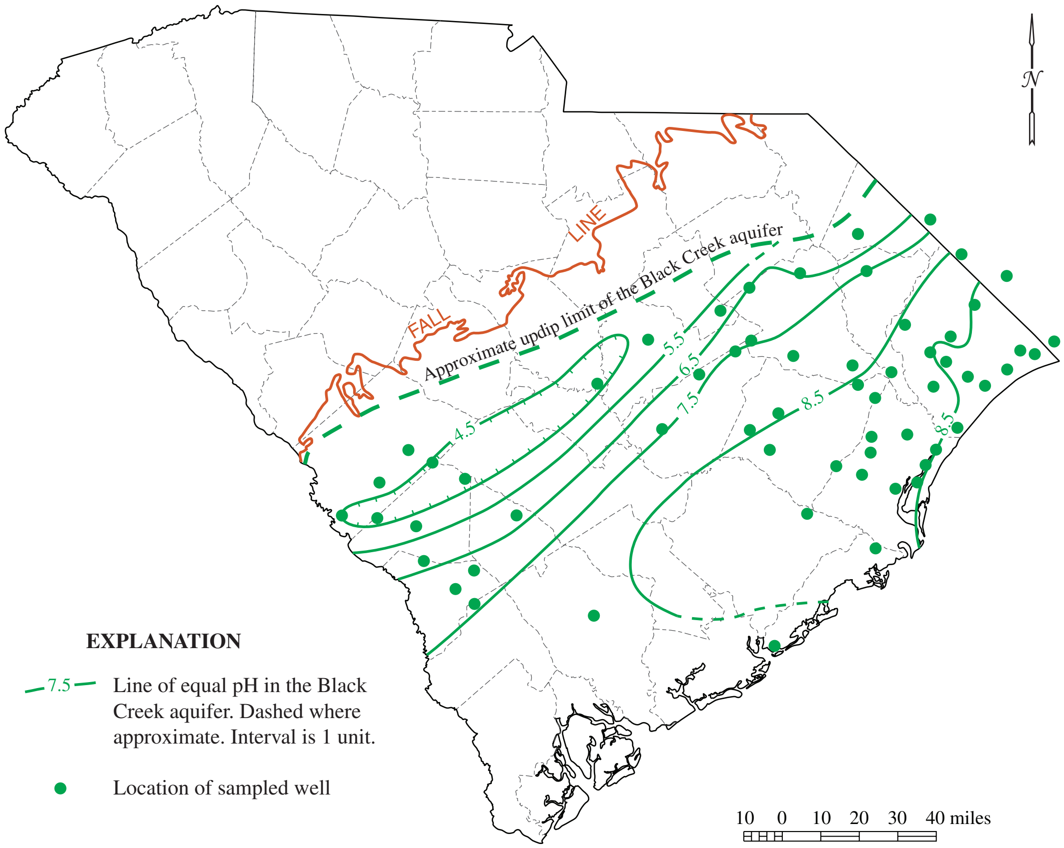

Figure 3-27. (g) Distribution of pH in the Black Creek aquifer (Speiran and Aucott, 1994).

formation consists of interbedded fine- to medium-grained sand and silty sand, carbonaceous and silty clay, sandstone, and sandy limestone. The section is the only significant water-bearing unit in the Tertiary sand aquifer east of its subcrop area. In conjunction with the overlying Floridan aquifer, this unit is widely used in Berkeley, Charleston, Dorchester, Colleton, and eastern Hampton Counties. Open-hole Floridan/Tertiary-sand wells there commonly yield several hundred gallons per minute. Wells open only to the Black Mingo are rare and typically produce less than 300 gpm. Because its transmissivity is low, the formation mainly is used where the overlying Floridan aquifer is poorly productive.

There is wide variation in the water quality of the Tertiary-sand aquifer—variation that stems from the many geologic formations encompassed and the consequent diversity of mineralogy and depositional environment. Within its outcrop region it receives recharge directly from precipitation: the water has dissolved-solids concentrations less than 100 mg/L and is very soft, pH's typically are less than 6.5, and iron concentrations commonly are greater than 300 µg/L. In these areas, the combination of low solids and low pH is corrosive to steel screen and casing.

An increase in calcium carbonate content and the interfingering of the Tertiary sand aquifer with Floridan aquifer limestone alters the water chemistry across the middle Coastal Plain, beginning in lower Barnwell County. The pH generally increases eastward where calcium carbonate has dissolved, and hard water and dissolved solids concentrations above 250 mg/L become increasingly common. Farther down gradient, between the Santee and Savannah Rivers, Tertiary sand aquifers yield sodium bicarbonate type water with pH's near 8.0, dissolved solids above 300 mg/L, and hardness varying from soft to moderately hard. Characteristic of water in the coastal region is low iron concentration and dissolved-silica concentrations between 25 and 50 mg/L; fluoride concentrations of 2.0 mg/L to 5.0 mg/L are reported in the area south of Charleston. Saltwater encroachment also is present south of Charleston, and chloride concentrations there exceed 1,000 mg/L.

Natural radioactivity in excess of acceptable drinking-water standards occurs in isolated areas of Lexington, Orangeburg, and Aiken Counties. The problem has caused some public water suppliers to consider advanced treatment technologies and alternate sources.

Floridan Aquifer. The Floridan aquifer in South Carolina is the northernmost part of one of the most extensive and prolific ground-water sources in North America. It primarily consists of the middle-Eocene Santee Limestone and, in southern and southwestern South Carolina, the upper-Eocene Ocala Limestone. It also encompasses, and is confined by, the Oligocene Cooper Formation in Charleston, Berkeley, Dorchester, and Colleton Counties. The top of the aquifer occurs within 100 feet of land surface, except in southernmost Beaufort and Jasper Counties. Typically, more than 80 percent of the Floridan's thickness acts as confining material owing to the widespread occurrence of impure clayey to sandy limestone and of limestone having interstitial-calcite precipitate; however, sections of clean, permeable, bioclastic limestone are found throughout the Floridan's range of occurrence. These permeable sections almost everywhere yield adequate water for domestic use, small public-supply systems, and light industry, and, locally, they can yield 1 to 3 million gallons per day to individual wells.

The Floridan aquifer subcrops along the Santee River and Wateree River valleys and from eastern Orangeburg County through western Allendale County. The limestone there commonly exceeds 95-percent calcium carbonate, has enlarged secondary porosity owing to dissolution, and locally exhibits cavern and sinkhole formation. The surfaces of the Santee Limestone and Ocala Limestone and the permeable units associated with them dip gently southeastward from 100 feet msl to -200 feet msl. The low-permeability, arenaceous limestone of the Oligocene Cooper Formation overlies the Santee in most of Charleston, Berkeley, and Dorchester Counties, grades into the Ocala Limestone to the southeast, and thickens to more than 250 feet in southern Charleston County. Owing to this geologic complexity, four important and distinct permeable zones occur in the Floridan aquifer.

Limestone in the subcrop area is a major avenue for recharge. Mildly acidic meteoric (from precipitation) water has circulated through the pure limestone at shallow depth, secondary porosity is common and well developed, hydraulic conductivity is high, and water-table to poorly-confined conditions predominate. The limestone downdip of the subcrop region becomes increasingly arenaceous (sandy) and confining, and ground water is obtained from two typically thin and well-separated permeable zones.

The northern zone, underlying Charleston, Berkeley, Dorchester, Colleton, and eastern Hampton Counties, occurs near the base of the Santee Limestone at 50 to -500 feet msl: it typically is 5 to 20 feet thick, is moderately permeable, and, in conjunction with underlying sand of the Tertiary sand aquifer, yields 100 to 400 gpm to individual wells. The southern zone, underlying Jasper County, western Hampton County, and southern Beaufort County, occurs at the top of the Santee Limestone at 0 to -500 feet msl: it typically is 20 to 40 feet thick, has transmissivities as great as 200,000 gpd/ft, and can provide up to 1,000 gpm to individual wells. The geographic distribution of the southern zone roughly coincides with the upper permeable zone of the Ocala Limestone.

The upper permeable zone is the principal source of ground-water supply in Beaufort, Jasper, Hampton, and Allendale Counties. It occurs within the upper 100 feet of the Ocala Limestone and is the most productive aquifer in South Carolina. The top of the unit ranges from -20 feet msl at Beaufort to -250 feet msl near Savannah, Ga. It is more than 100 feet thick in southern Jasper County, has hydraulic conductivities of 1,500 to 3,000 gpd/ft^2, and has transmissivities up to 450,000 gpd/ft. Yields as great as 3,000 gpm are reported, and those exceeding 500 gpm are common.

Floridan aquifer water levels have declined throughout the aquifer's area of occurrence, but the declines are most pronounced along the coast. Levels in the Santee Limestone section (lower Floridan aquifer) are -10 to -50 feet msl in the area of Summerville, Charleston, and Edisto Beach and are about -100 feet msl at Savannah, Ga. Predevelopment levels are not known north of Beaufort, but they probably were 10 to 20 feet above sea level across coastal Charleston and Colleton Counties.

Water levels in the Ocala Limestone section (upper Floridan aquifer) are below sea level everywhere south of Port Royal Sound and have declined to more than -100 feet msl at Savannah, Ga.

Predevelopment levels in the upper Floridan aquifer in Beaufort and Jasper Counties and 2004 levels in the lower and upper Floridan across southern South Carolina are shown in Figure 3-28.

The Floridan's water chemistry is typically the calcium bicarbonate type produced by the dissolution of limestone. The water is moderately hard to very hard, somewhat alkaline, and commonly has dissolved solids concentrations less than 500 mg/L. High iron concentrations are common in permeable zones that are shallow, poorly confined, and recharged by the overlying water table—localities that include the principal subcrop area between Charleston County and Allendale County and a structural uplift in central Beaufort County. Iron concentrations typically are less than 300 µg/L elsewhere in the aquifer.

Water chemistry that is atypical of limestone aquifers occurs mainly in the base of the aquifer between Charleston and southern Hampton Counties and in areas where saltwater encroachment occurs. The lowermost aquifers southwest of Charleston and Berkeley Counties contain water similar to that of the underlying Tertiary sand aquifer—predominantly a sodium bicarbonate water with dissolved silica concentrations up to 50 mg/L and fluoride concentrations up to about 4.0 mg/L.

Saltwater encroaches the Floridan in several areas at and southwest of Charleston. Chloride concentrations above 500 mg/L occur at the base of the aquifer beneath the barrier islands of Charleston County, and concentrations of 500 to 1,000 mg/L are present at Edisto Beach. Concentrations of several thousand milligrams per liter occur in the 500-foot deep middle permeable unit beneath Port Royal Sound, although water in the unit freshens to the south. The most significant contamination occurs at the north end of Hilton Head Island and adjacent part of Beaufort County. Ground water containing more than 10,000 mg/L chloride, or more than 50 percent seawater, now flows southwestward toward pumping areas at Bluffton and Hilton Head Island and at Savannah, Ga. Saltwater-intrusion rates of more than 200 feet per year occur there.

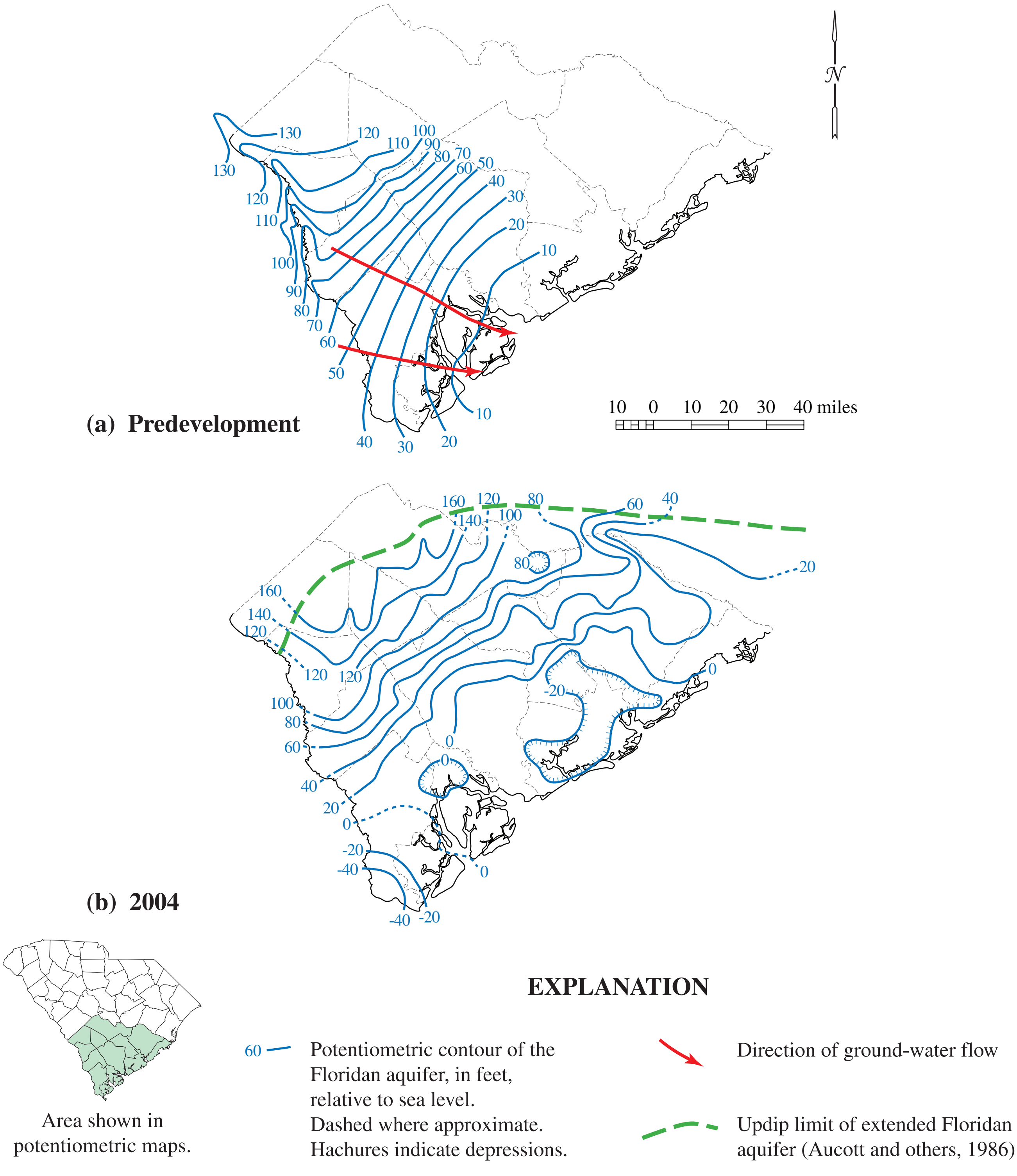

Figure 3-28. Predevelopment (a) and 2004 (b) water levels in the Floridan aquifer (Aucott and Speiran, 1985; Hockensmith, 2009).

Shallow Aquifer. "Shallow aquifer" or "surficial aquifer" is a term of convenience applied to the complex of materials between land surface and the major aquifers of the Blue Ridge, Piedmont, and Coastal Plain. Northwest of the Fall Line, the aquifer comprises saprolite and scattered alluvial deposits: there, the lithologic and hydrologic contrast between bedrock and overlying formations simplifies distinction of the shallow aquifer.

Blue Ridge and Piedmont—The shallow aquifer in the Blue Ridge and Piedmont consists of porous materials overlying the fractured crystalline rock. Saprolite, the residual material from the weathering of bedrock, forms the most geographically extensive shallow unit above the Fall Line. The saprolite typically is 35 to 100 feet thick but thin to absent in some mountainous areas and well over 100 feet in some lower areas. Saprolites are commonly clay rich, but clay content may be low where the parent rock is mainly quartz. It is a source of water to bored wells—augered or dug wells that must be constructed with large diameters owing to low permeability and the consequent need to store large volumes of water. Such wells may yield ground water from the clay-rich saprolite; from relict bedrock fractures and intrusive rock; and from the transition zone, a zone of fractured but relatively unweathered rock debris above the unaltered parent rock. Sustained yields typically are no more than a few gallons per minute; however, the saprolite is the main source of ground-water storage in the region and the main source of ground water in the underlying crystalline-rock aquifer. Where the saprolite is thick, water levels usually respond slowly to precipitation because the low permeability of clay inhibits recharge. Water levels also respond slowly to drought because clay will store large volumes of water and release it slowly.

Shallow aquifers above the Fall Line also include modern and relict alluvial deposits. These alluvial aquifers commonly are unconfined, widely dispersed, and small in extent. Because of the energy of their source streams, Blue Ridge and Piedmont alluvial aquifers tend to be coarser but less uniform than their Coastal Plain counterparts. Consequently, well yields can vary widely, even within distances of a few hundred feet.

Coastal Plain—The shallow aquifer in the Coastal Plain encompasses wide geologic variability. It includes rocks of the principal Cretaceous and Tertiary formations, where water-table conditions occur in their outcrop areas, and the thinner and younger Miocene- to Recent-age rocks. Unconfined conditions, where the surface of the water table is subject only to atmospheric pressure, predominate. Flow direction and flow rate are mainly controlled by topography: the water-table surface subtly imitates that of the land, and flow directions generally are from stream interfluves toward creeks and rivers. The thickness of shallow Coastal Plain aquifers typically are a few tens of feet or less, and their material generally fines coastward from the Fall Line and southwestward into the Georgia Embayment. Consequently, transmissivities generally are less than 3,000 gpd/ft.

Well depths range from about 20 to 100 feet, and well yields are limited by the small amount of drawdown available. Yields of 5 to 20 gpm are the norm, although 100 to 250 gpm are reported from a few upper Coastal Plain wells where well-sorted sand and gravel alluvium are present and hydraulically connected to streams. The shallow aquifer is widely used for domestic and light commercial purposes, and ponds open to shallow aquifers are sources of water for golf course and agricultural irrigation.

Shallow wells typically produce water of good quality, although iron concentrations in excess of the 300 µg/L secondary standard are ubiquitous. Where shell material is absent from the aquifer, as in much of the upper and middle Coastal Plain, shallow water is a soft, acidic, sodium chloride type with total dissolved solids concentrations less than 100 mg/L. Where fossil-shell material is abundant, as in many areas near the coast, hard, alkaline, calcium bicarbonate water is present, and total dissolved solids concentrations of 200 to 300 mg/L occur. The odor of hydrogen sulfide also is common in the lower Coastal Plain, particularly in the sea-island region, and saltwater is present in shallow aquifers in areas near tidal water bodies. Water-quality problems in shallow aquifers are, in the main, the result of man's activities, and, because there is little separation between shallow water and land surface, the shallow aquifer is readily affected by land-use practices.

Manmade Ground-Water Problems

The quantity of water affected by manmade ground-water problems is small relative to the volume of water available to, and used by, South Carolinians. There are, nonetheless, widely scattered, manmade incidents that make ground water unsuitable for our consumption and that restrict the quantity available for our use. The introduction of chemical compounds into a shallow aquifer is the most common problem, but the extent of chemical contamination usually is confined to a few acres. Problems arising from pumping and subsequent water-level declines are less common, but their impacts extend over many square miles.

DHEC began its first Ground-water Contamination Inventory (GCI) of 60 releases in 1980. The number of recorded sites increased to more than 4,100 by 2000 (Figure 3-29), mainly owing to increased effort, Federal funding, and passage of the UST (Underground Storage Tank) Regulations. About 85 percent of the cases are the result of petroleum products leaked from commercial storage tanks, but petroleum-leak sites are more prevalent than indicated by the GCI. Domestic oil-furnace use was common through the 1950's, and many fuel-oil tanks remain buried and corroding and are neither inventoried nor regulated. Other contaminants are derived from solid-waste disposal sites that leach metallic salts and nitrogen and from septic tanks, sewage lagoons, and animal feedlots that release pathogens and nitrogen. Radionuclides are identified in aquifers beneath the Savannah River Site. The distribution of contamination sites in the 2008 GCI is shown in Figure 3-30.

Most of the contaminants identified in the GCI occur in the upper 50 feet of the hydrostratigraphic column, and the potential for deeper and farther-spread contamination would remain if sites were not remediated. The potential for further dispersal is particularly acute in the Piedmont and Blue Ridge, where a contaminant plume might enter bedrock fractures that rapidly conduct ground water away from a site. Contamination also is caused by improper well construction. The most typical well-construction failures are poorly sealed wellheads and faulty grout emplacement around well casings. Either failure can result in surface water entering the well bore and the consequent introduction of fecal-coliform bacteria to drinking-water supplies. Contaminants from septic systems, feed lots, chemical handling areas, and other sources also may enter improperly grouted wells through the subsurface. Contamination within well bores can occur where multiple well screens interconnect aquifers of differing pressure; saltwater contamination can occur in coastal areas where deep, high-pressure brackish-water zones are connected with overlying freshwater zones.

Pumping-related problems occur in the form of land-surface collapse, well interference, and saltwater intrusion. Both sudden and gradual land collapses are documented in Horry, Georgetown, Berkeley, Dorchester, and Orangeburg Counties where limestone deposits were dewatered for mining. Sinkholes occurred locally as pore-water pressure declined in the overburden or fluctuated to cause the spalling of overburden into limestone cavities. Sinkhole diameters usually range from a few feet to tens of feet and are about equal to the overburden thickness.

Well interference—water-level decline caused by pumping of neighboring wells—can occur everywhere. Complaints of well interference are more numerous during droughts, but a well disabled by drought- and pumping-induced water-level declines can be restored if its design permits a deeper pump setting. The main impact of interference is a nominal increase in energy consumption as water must be lifted greater distances to the wellhead.

The most severe interference cases are found in Cretaceous aquifer wells in Charleston County. The growth in ground-water use and potential for interference were not anticipated when designing pump-casing lengths for early wells. Where pump intakes can be lowered no farther owing to casing design, each additional foot of interference reduces a well's potential yield by 10,000 to 20,000 gallons per day. Pump engineering presents another problem where the demand for additional water, the need for maximum available drawdown, and continued static-level decline combine—at some point, increasing horsepower and extending column length are no longer feasible.

Pumping-induced saltwater intrusion occurs along the South Carolina coast, gradually reducing the amount of freshwater available in some of the State's principal artesian aquifers (see the *Special Topics* chapter). Pumping from the Black Creek aquifer around Myrtle Beach and the Middendorf and Floridan aquifers near Charleston captures ancient brackish water and draws it toward the centers of pumping. Both modern and ancient seawater are captured by pumping from the Floridan aquifer at Hilton Head Island and Savannah, Ga., causing intrusion at rates of more than 200 feet per year. Lateral and upward brackish-water intrusions probably are occurring in the Floridan aquifer at Edisto Beach.

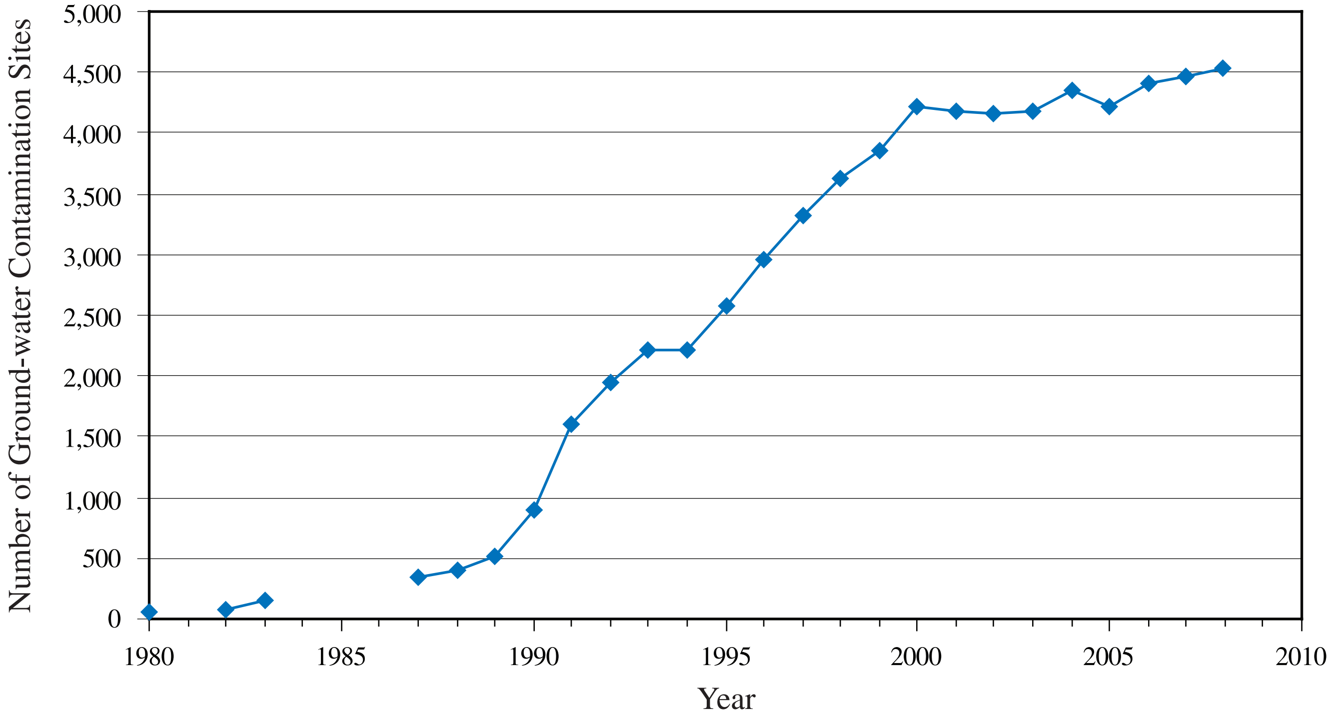

Figure 3-29. Number of known ground-water contamination sites in South Carolina, 1980-2008 (DHEC, 2008).

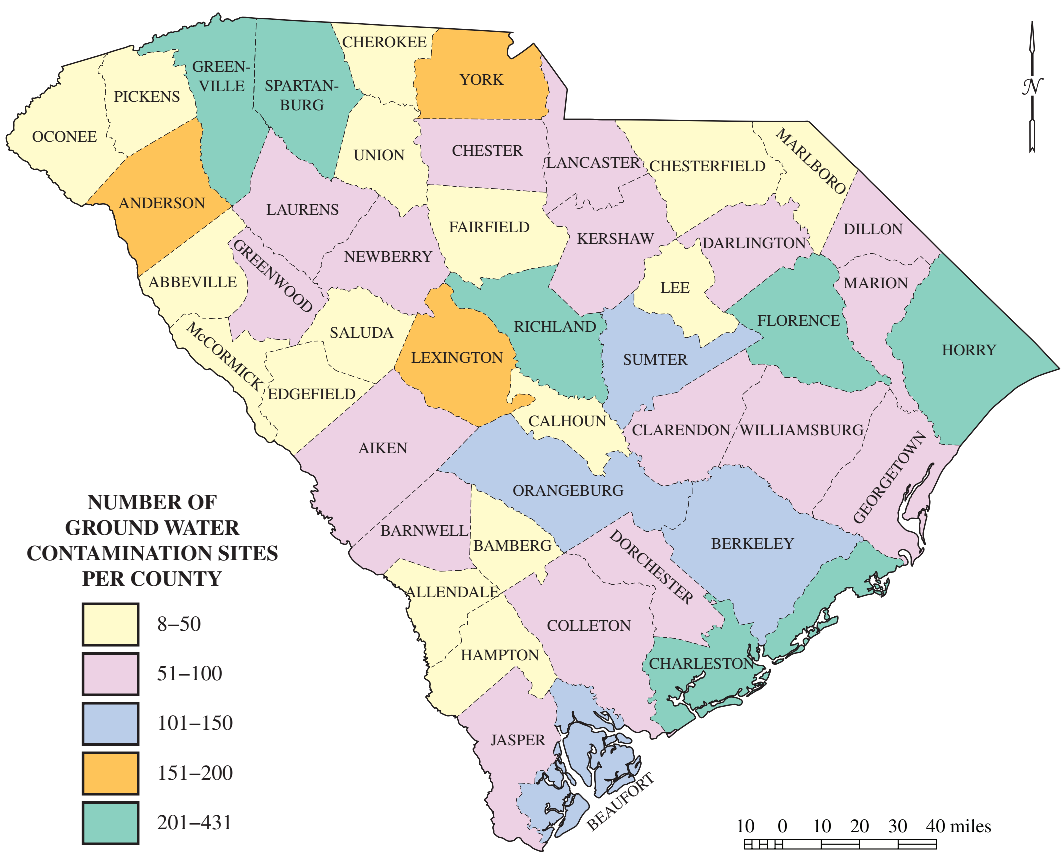

Figure 3-30. Distribution of ground-water contamination sites, 2008 (DHEC, 2008).