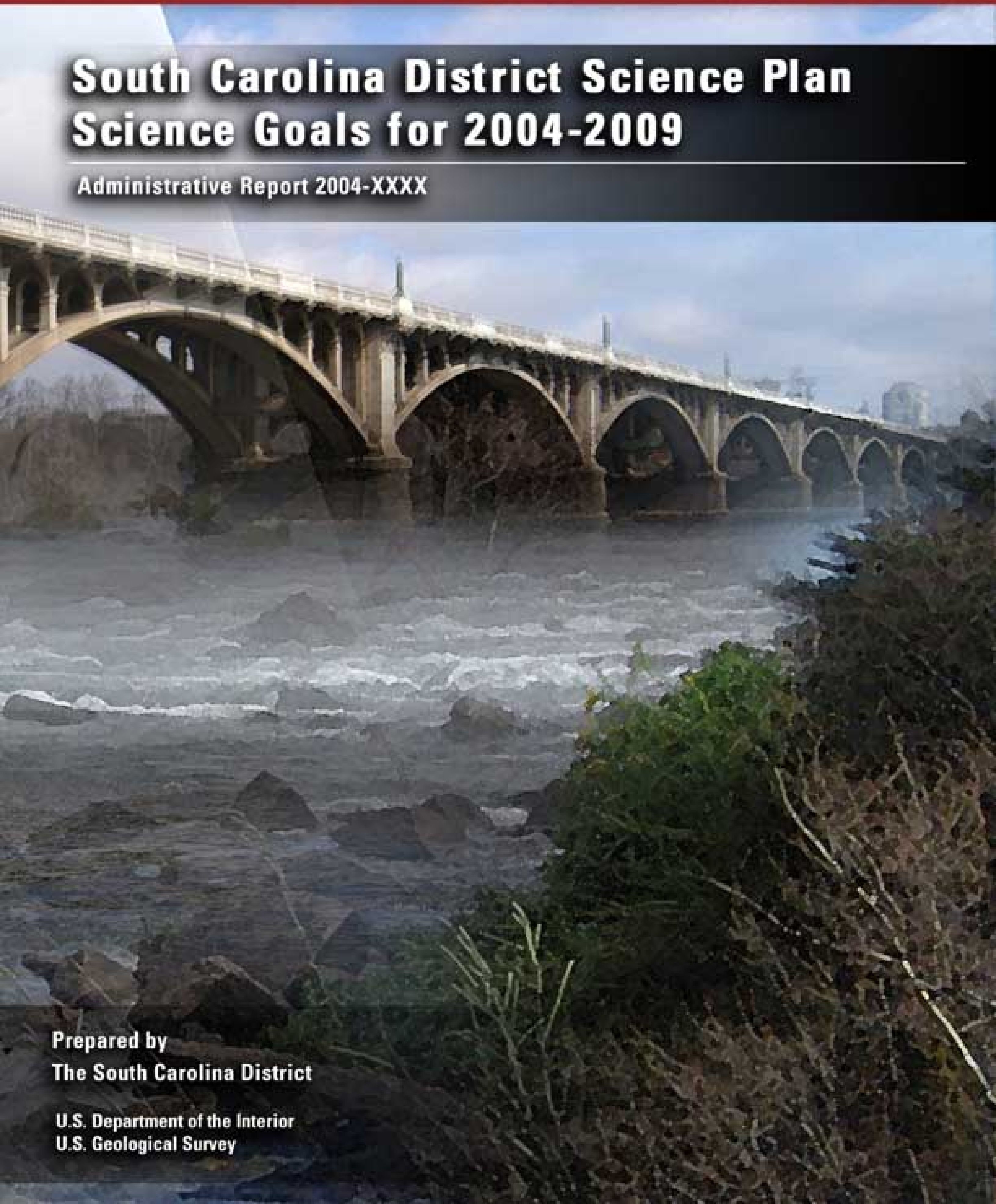
South Carolina District Science Plan Science Goals for 2004-2009

Administrative Report 2004-XXXX



Prepared by
The South Carolina District

U.S. Department of the Interior
U.S. Geological Survey

COVER ILLUSTRATION:
by James R. Douglas

REFERENCE IMAGERY:
Gervais Street Bridge, Columbia, SC, 2004
Saluda River Shoals, Columbia, SC, 2003
Fishing Creek Reservoir, Great Falls, SC, 2003

COVER PHOTOGRAPHY:
by J. Michael Hall and James R. Douglas

Illustrations and photographs incorporated within this Provisional Draft are preliminary with low resolution and color saturation

U.S. Geological
South Carolina District Science Plan

Science Goals for 2004–2009

Prepared by the South Carolina District

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
Gale A. Norton, Secretary

U.S. Geological Survey
Charles G. Groat, Director

For more information about the USGS in South Carolina:
Telephone: 1-803-750-6100
World Wide Web: http://sc.water.usgs.gov/

Photographs in this report were taken by USGS personnel.

Contents

Introduction 1
- USGS Mission and Science Planning 1

USGS Activities in South Carolina 3
- Approach to Hydrologic Science in the South Carolina District 3
- Other USGS Discipline Activities in South Carolina 4
  - Geologic Discipline 4
  - Geographic Discipline 5
  - Biological Resources Discipline 5

South Carolina – Facts, Demographics, and Attributes 6
- Geography 6
- Climate 6
- Geology 8
- Hydrology 9
- Population and Economy 11
- Government Facilities 12
- Water-Resources Management in South Carolina 12

South Carolina District Science Plan 14
- Priority Issues for Science Activities 15
- Data Collection, Integration, and Analysis 15
  - Background 15
  - Current Program 16
  - Program Opportunities 17
  - District Needs for Implementation of Program Opportunities 18
  - Relation of Program Opportunities to USGS and WRD Strategic Plans 18
- Hydrologic and Hydraulic Hazards 18
  - Background 18
  - Current Program 20
  - Program Opportunities 21
  - District Needs for Implementation of Program Opportunities 21
  - Relation of Program Opportunities to USGS and WRD Strategic Plans 21
- Sustainable Water Resources in Piedmont and Coastal Environments 22
  - Background 22
  - Current Program 23
  - Program Opportunities 24
  - District Needs for Implementation of Program Opportunities 25
  - Relation of Program Opportunities to USGS and WRD Strategic Plans 25

Urban Effects on Human and Aquatic Health 25
Background 25
Current Program 27
Program Opportunities 27
District Needs for Implementation of Program Opportunities 28
Relation of Program Opportunities to USGS and WRD Strategic Plans 28
Applied Ecosystem Research 29
Background 29
Current Program 31
Program Opportunities 31
District Needs for Implementation of Program Opportunities 32
Relation of Program Opportunities to USGS and WRD Strategic Plans 32
Selected References 32
Supplemental Data 37

Figures

1. U.S. Geological Survey offices in South Carolina 3
2. Land cover in South Carolina 7
3. Mean annual precipitation in South Carolina, 1961–90 8
4. Generalized geologic map of South Carolina 8
5. Generalized geology of the South Carolina Piedmont 9
6. Generalized geology of Coastal Plain aquifers underlying South Carolina 9
7. Major river basins in South Carolina 10
8. Generalized distribution of population, by county, for South Carolina 11
9. Locations of Federal lands, national parks and monuments, wildlife refuges, national forests, and physiographic provinces in South Carolina 12

Supplemental Data Tables

1. Priority science issues in South Carolina, 2004–2009 38
2. Tactical and strategic actions needed for meeting priority science issues in South Carolina, 2004–2009 39
3. Additional requirements needed for meeting priority science issues in South Carolina, 2004–2009 44

South Carolina District Science Plan

Science Goals for 2004–2009

Prepared by the South Carolina District

Introduction

The South Carolina District of the U.S. Geological Survey (USGS), Water Resources Discipline (WRD), is committed to conducting hydrologic and earth science investigations of the highest quality. South Carolina District staff understand that credible data and useful research lead to better decisions regarding water and environmental resources by managers, planners, regulators, and the public, and generally, to a higher quality of life for the citizens of South Carolina and the Nation.

The water-resources information needs in South Carolina are vast, while the fiscal and staff resources of the South Carolina District are limited. Moreover, District activities must be consistent with and support science programs of the USGS, and fulfill the needs of State and local agencies and the worldwide scientific community.

The South Carolina District Science Plan provides a framework in which decisions can be made to plan for future activities and to appropriately allocate District resources to address the highest priority local, State, regional, and national needs. This plan contains District science goals for priority water-resources and related issues during the next 5 years and provides a summary of short-term (tactical) and long-term (strategic) actions to be taken to achieve these goals. Tactical actions generally are achievable in the short term (1–2 years) with the scientific capabilities and skills of current staff in the South Carolina District and with readily available technologies. In most instances, current customers have an interest and willingness in supporting tactical actions. Strategic actions are more visionary and, with some diligence, can be achieved in the long term (3–5 years). The scientific capabilities and skills needed for such actions may not be available currently within the District, new technologies may have to be developed and tested, and(or) customers having an interest in supporting the USGS in such strategic actions may need to be nurtured. Both tactical and strategic actions require a continued commitment to investments in human resources and technologies. When expending funds, the District will be cognizant of the visions and actions outlined in this Science Plan.

The Science Plan does not include all anticipated District activities but focuses on selected regional and national aspects of hydrologic and related sciences that are appropriate for the USGS, both in terms of Federal role and scientific capabilities. The plan was prepared by the District management staff, discipline specialists, senior scientists, project chiefs, hydrologic technicians, and others. Each science issue presented in the Science Plan was assigned to a team to develop the vision, opportunities, and actions pertinent to the issue. Each team's collective ideas were compiled, shared, and reviewed. This plan is dynamic and will be reviewed and updated as needed; it will be an integral component of the District's annual program planning process.

The science goals presented herein will be used to evaluate the relevance of individual projects and to plan for future activities, including hiring, infrastructure development, and program development. Successful execution of the South Carolina District science program requires broad interdisciplinary and integrated studies; a long-term commitment to high-quality, unbiased data analysis and science; and effective internal and external partnerships. The plan will be used by District and regional management to formulate, justify, and support long-term and short-term water-resources programs; maintain institutional resolve to continue sustained support of monitoring and research; and enhance collaborative opportunities, share information, and maintain a dialogue between the USGS and elected officials, partners, other agencies, and the research community at large.

USGS Mission and Science Planning

The USGS is the lead Federal science agency responsible for addressing water quality, water availability, water conservation, and hydrologic hazards (National Research Council, 1997, 1999, 2001, 2002). The USGS is unique among Federal natural-resource agencies in that it has no regulatory function or advocacy role. The USGS is purely an earth science and information agency, apart from regulatory agencies, with responsibilities to collect, map, develop, archive, and provide continuous, reliable data and cohesive information about the Nation's water, geological, and biological resources and geospatial data. According to the National Research Council (2001), "the USGS in the 21st century will be expected to exercise strong national leadership . . . as the DOI's primary source of science expertise and information and as the principal Federal agency for science information and research related to conservation and management of natural resources and to natural hazard mitigation." The USGS uniquely develops interdisciplinary earth science programs that have regional, national, and global perspectives. The ability of the USGS to integrate geological, hydrological, geographical, and biological capabilities provides unparalleled opportunities to translate good science into useful and usable information.

Science planning in the USGS occurs at a variety of levels. The USGS *Strategic*

Plan 2000–2005 (U.S. Geological Survey, 2000) identifies two **mission goals**:

The **Hazard Long-Term Goal** is to "Ensure the continued transfer of hazards-related data, risk assessments, and disaster scenarios needed by our customers before, during, and after natural disasters, and … increase the delivery of real-time hazards information by increasing the average number of stream gages reporting real-time data on the Internet during each quarter to 5,500 and installing 500 improved earthquake sensors to minimize loss of life and property."

The **Environment and Natural Resources Long-Term Goal** is to "Ensure the continued availability of long-term environmental and natural resource information; and systematic analysis and investigations needed by customers, and … develop 20 new decision support systems and predictive tools for informed decision making about natural systems."

The USGS also has identified eight **future science directions**, which are issues of increasing emphasis for the agency, the Nation, and the world, and for which the discipline mix and capabilities of the USGS create opportunities for significant successes. The eight future science directions are

- Balancing population growth and estuary and wetlands ecology in coastal environments,
- Mitigating the impacts of earthquakes,
- Understanding ecosystem health, sustainability, and land surface change,
- Quantifying energy resources,
- Disseminating environmental science information to safely integrate natural resources and growing communities,
- Sustaining development of ground-water resources,
- Detecting and controlling deleterious invasive species, and
- Resolving conflicts over the management of rivers for multiple purposes.

The *Strategic Directions for the Water Resources Division* (currently referred to as Water Resources Discipline; U.S. Geological Survey, 1999b) identifies nine priority water-resources issues. The document provides plans to address these issues and discusses strategic efforts for enhancing long-term hydrologic data-collection programs, interpretation, and assessment activities; research and development; and investments in new capabilities. Each year, the WRD identifies priority water-related issues that require USGS involvement at State and local levels through the Cooperative Program. Priorities for 2004 (Water Resources Discipline Informational Memorandum 2004.02; G. Patterson, U.S. Geological Survey, written commun., February 2004) include:

- Hydrologic hazards,
- Water quality,
- Hydrologic data networks,
- Water availability and use,
- Wetlands, lakes, reservoirs, and estuaries,
- Water resources issues in coastal zones, and
- Environmental effects on human health.

The WRD Eastern Region Science Plan (accessed April 2004 at http://internal.er.usgs.gov/) includes the following societal and integrated science issues:

I. Urban Dynamics

- Water quality and availability for humans and ecosystems
- Habitat fragmentation
- River and coastal processes
- Urban expansion and landscape change

II. Ecosystem and Natural Resources

- Climate change
- Fish and wildlife health
- Eutrophication and hypoxia
- Biodiversity, habitat integrity and restoration
- Invasive and nuisance species
- Energy and mineral-resource extraction

III. Human Health and Safety

- Arsenic contamination
- Mercury bioaccumulation
- Trace elements and radionuclides
- Synthetic and natural organic contaminants (emerging contaminants)
- Pathogens and disease
- Air quality

IV. Natural Hazards

- Flooding, storms, and drought
- Earthquakes
- Slope failure and subsidence

These science issues are similar to those identified in the 1999 WRD strategic-directions document (U.S. Geological Survey, 1999b). Science planning in the South Carolina District builds on plans developed at regional and national levels, with an emphasis on South Carolina issues and a supporting role in regional and national issues. The science priorities for the South Carolina District include the following, which will be discussed in detail later in this report:

- Data collection, integration, and analysis
- Hydrologic and hydraulic hazards
- Sustainable water resources in piedmont and coastal environments
- Urban effects on human and aquatic health
- Applied ecosystem research

USGS Activities in South Carolina

USGS activities in South Carolina have been ongoing for more than 100 years, and District programs have evolved based on the science needs of our customers. The gaging-station program dates back to 1883 when the first gage in South Carolina was installed. The USGS South Carolina District was established in 1965 with a total budget of $175,200. In contrast, the current (fiscal year (FY) 2004) budget for the District is about $6.3 million. In the mid-1990's, the District budget reached $6.8 million, and the District staff was composed of about 80 employees. In contrast, the District staff in 1965 consisted of five engineers, two geologists, two technicians, and four clerical employ-ees. The FY04 District staff consists of 51 employees, including 18 hydrologists, 4 research hydrologists, 20 hydrologic technicians, 1 biologist, 2 information technology specialists, 1 materials handler, 3 ad-ministrative employees, 1 geographer, and 1 scien-tific illustrator. South Carolina District personnel are located in the District office in Columbia and in field offices at Clemson, Conway, New Ellenton, and Sullivans Island (fig. 1).

Approach to Hydrologic Science in the South Carolina District

The South Carolina District staff maintains contacts with other USGS disciplines and other agencies and scientists in the State by attending meetings and scientific conferences and by sharing information. Through these contacts, scientific programs emerge and develop as water-resources issues or problems, appropriate to the mission of the agency, are identified. For each project, a proposal is prepared, reviewed extensively within the District, sent to the Eastern Region-South for approval, and submitted to the customer agency that is funding or sharing the cost of the work. Colleagues from the university community or other agencies frequently are involved in project formulation and execution. The scope of work, schedule, and funding are finalized as a result of discussions between the USGS and the customer(s).

The USGS mission cannot be accomplished effectively without the contributions of the Cooperative Program—a highly successful cost-sharing partnership between the USGS and water-resource agencies at the State, local, and tribal levels. The USGS can, depending on the availability of Federal funds, provide as much as 50 percent of the cost of cooperative projects. Throughout its history, the Cooperative Program has made important contributions in helping the USGS meet mission requirements, develop meaningful partnerships, share Federal and non-Federal financial resources, and keep focused on current and emerging water-resources problems.

Operating procedures of the South Carolina District science programs are documented in the following:

- Quality-Assurance Plan for Ground-Water Activities in the South Carolina District, updated in 1996 and currently (2004) under revision;
- Quality-Assurance Plan for Water-Quality Activities in the South Carolina District, in review 2004;
- Surface-Water Quality-Assurance Plan for the South Carolina District of the U.S. Geological Survey

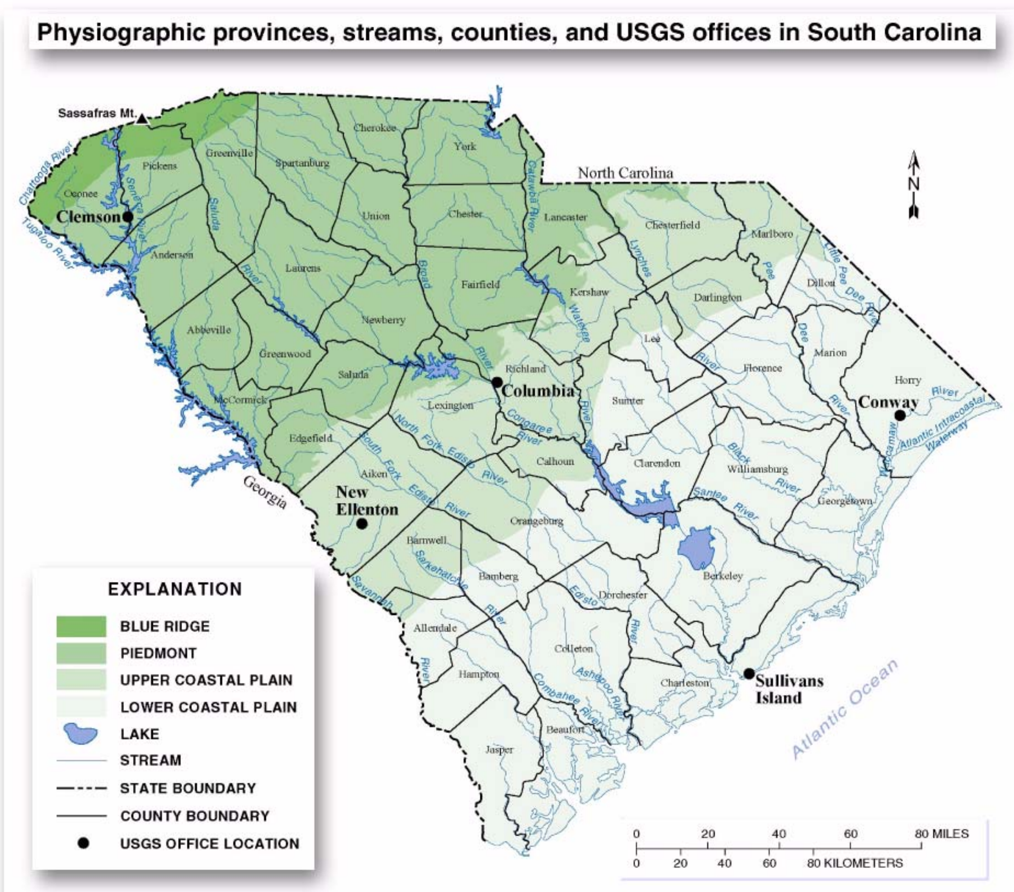


Figure 1. U.S. Geological Survey offices in South Carolina.

(available on the South Carolina District public Website);

- South Carolina District Flood Plan, updated in 2003; and
- South Carolina District Data-Management Plan, currently in preparation.

These plans are dynamic documents that are revised continually as conditions change or new technologies become available. The District intends to publish the updated ground-water quality-assurance plan in 2004 as an Open-File Report and post it on the Web. The quality-assurance plans contain general procedures for investigations, water-quality activities, surface-water activities, ground-water activities, flood response, safety, and chemical hygiene. The District quality-assurance plans are consistent with USGS and WRD policy and technical guidance.

The quality-assurance plans are the guiding documents for USGS projects, most of which involve data collection, data analysis and interpretation, and product preparation. Project results are published in USGS reports and technical journals and presented at scientific and public meetings. All USGS publications prepared in the South Carolina District undergo a rigorous review and approval process that includes reviews by supervisors, discipline specialists, and USGS colleagues inside and outside the District prior to Director's approval, which has been delegated to the Eastern Region-South. All data are published and archived in the USGS National Water Information System (NWIS) database, except for data censored for military or security reasons. Data obtained during developmental research studies are archived in the South Carolina District.

In addition to projects conducted in cooperation with other Federal agencies and with State and local agencies, the South Carolina District conducts investigations as part of national USGS programs, such as the National Water-Quality Assessment (NAWQA) Program, Toxics Substances Hydrology (Toxics) Program, and National Streamflow Information Program (NSIP). These USGS programs have distinct national goals. However, the South Carolina District often leverages these national programs to achieve results of interest to local water-resources managers while meeting national objectives. Federal projects follow the same project development as those performed in cooperation with other agencies.

Other USGS Discipline Activities in South Carolina

The USGS Geologic, Geographic, and Biological Resources Disciplines also conduct scientific programs in South Carolina. These programs, which are briefly described in the following sections, provide excellent opportunities for collaborative research.

Geologic Discipline

The Coastal and Marine, Mineral Resources, and Earth Surface Dynamics Programs of the USGS **Geologic Discipline** include active or recently completed investigations in South Carolina. A focus of the Coastal and Marine Geology Program (CMGP) is to study the physical processes responsible for South Carolina's coastal erosion and assess coastal vulnerability to sea-level rise (U.S. Geological Survey, 1999a). Phase II of the Coastal Erosion Study, conducted South Carolina and Georgia in cooperation with the South Carolina Sea Grant Consortium, produced maps showing the stratigraphic framework of South Carolina's Long Bay from Little River to Winyah Bay in Horry and Georgetown Counties (fig. 1). This area of the State is a heavily populated region that supports a large tourism industry; consequently, property damage and lost revenues due to severe storms and coastal erosion are of great concern (Baldwin and others, 2004). The CMGP includes an investigation of the relative risks of future sea-level rise along the South Carolina coast and other areas through the use of a coastal vulnerability index, which is the relative risk that physical changes will occur as sea-level rises. The relative risk is quantified based on tidal range, wave height, coastal slope, shoreline change, geomorphology, and historical rate of relative sea-level rise (Thieler and Hammar-Klose, 1999). In addition, a CMGP investigation is being conducted to study the effects of hurricanes and extreme storms on the coasts of the United States in order to improve the predictability of coastal modifications resulting from severe tropical and extra-tropical storms and coastal land loss due to reductions in sediment supply or relative sea-level rise. The information derived from these investigations facilitates planning for coastal-change hazards and land loss as a result of natural and induced modifications of South Carolina's coast (Morton, 2003). CMGP scientists recently mapped methane hydrates in the Carolina Trough, a large basin that has accumulated vast sediments off the North and South Carolina coasts. This investigation identified a pair of relatively small areas, each about the size of the State of Rhode Island, that have intense concentrations of gas hydrates. Methane from hydrates could provide an important energy resource for the Nation (W. Dillon, U.S. Geological Survey, written commun., Sept. 1992; accessed April 2004 at http://marine.usgs.gov/fact-sheets/gas-hydrates/title.html).

Scientists in the Mineral Resources Program and the South Carolina Geological Survey conducted a statistical analysis of South Carolina's non-fuel mineral resources in 2002. Results of the study rank South Carolina 29th (up from 31st in 2001) among the 50 States in total non-fuel mineral production. Based on preliminary data, South Carolina's production of non-fuel minerals accounted for more than 1 percent of the total non-fuel mineral production for the Nation (U.S. Geological Survey and South Carolina Geological Survey, 2002).

Two investigations in the Earth Surface Dynamics Program are in the varying stages of progress in South Carolina. The Bedrock Regional Aquifer Systematic Study (BRASS) project includes cooperative research studies with hydrologists from the USGS and elsewhere to better understand ground-water flow, availability, and quality in regions underlain by bedrock (http://geology.er.usgs.gov/eespteam/brass/index.htm). The primary objective is to determine bedrock geologic controls on the behavior of ground water in various geologic settings, partly in order to demonstrate how bedrock geologic mapping can be useful in solving problems related to ground water. A desirable objective of the South Carolina District and the BRASS project team is to identify a study site in South Carolina in the near future. The Southeastern Coastal Plain Project is a regional geologic study that includes USGS research activities that involve regional, subsurface and geologic-map databases and related geologic and paleontologic research in North Carolina, South Carolina, and Georgia (http://geology.er.usgs.gov/eespteam/sergp/sehome.html).

Geographic Discipline

The USGS **Geographic Discipline** is in the process of realigning its programmatic goals to deemphasize data production and focus on partnerships for data sharing. It is recognized that State and local geographic information system (GIS) mapping and private-sector mapping operations have become the primary producers of digital geospatial data. Therefore, the USGS Geographic Discipline is implementing *The National Map* to support the mission to provide data to the Nation with access to current, accurate, and consistent base geographic data in the public domain. One aspect of the implementation plan is to establish a number of distributed offices across the country to foster the development of long-term partnerships that support the availability of high-quality GIS data from *The National Map* viewer. As a Web-based query and download application, *The National Map* viewer is critical to this implementation plan.

As part of an interdisciplinary effort to place Geographic Discipline liaison staff in USGS District offices across the country, an Eastern Region geographer has relocated to the South Carolina District as a State Liaison with responsibilities for coordinating local activities for *The National Map* initiative. The State Liaison is in the early stages of assessing the quality and availability of State and local GIS data together with Web mapping services that may already exist. Activities being pursued through collaborative partnerships include

- Harvesting GIS data that already exist for distribution through *The National Map* viewer,
- Developing long-term partnerships, within 5 years, with data-steward programs that maintain the transferability and availability of data,
- Sharing technical information and expertise with regard to digital standards and product generation,
- Collaborating with local Web mapping services to link distribution through *The National Map* viewer, and
- Assisting in establishing local Web mapping services, where needed, for high-accuracy data considered valuable to GIS mapping.

Biological Resources Discipline

The USGS **Biological Resources Discipline** has scientists located at Clemson University in the Cooperative Fish and Wildlife Unit (Coop Unit) in Clemson, South Carolina. The Coop Unit is sponsored jointly by the USGS, the South Carolina Department of Natural Resources, Clemson University, and the Wildlife Management Institute. The Coop Unit was established to facilitate cooperation among the Federal government, colleges and universities, the States, and private organizations for cooperative research and education programs relating to fish and wildlife. Most of the Coop Unit research projects are field oriented and conducted by graduate students in close cooperation with university and USGS biologists. Some current Clemson Coop Unit research projects (http://virtual.clemson.edu/groups/AFW/COOP/research.htm) include

- The effects of invasive species on native species and the process of invasion;
- Cross-scale ecology and discontinuities in complex systems, especially striving for a better understanding of the generation of structure and resilience;
- Spatial ecology, including spatial aspects of the dynamics and effects of invasions, improving species models, and spatial risk analyses;
- Restoration ecology of endangered species, primarily short nose and Gulf sturgeon, and robust redhorse;
- Behavioral ecology of fish, primarily movement in relation to natural and anthropogenic environmental changes;
- Avian ecology – Investigating reproductive energetics, foraging ecology, diet quality, and habitat associations as they relate to conservation and management, especially in marine and coastal ecosystems; and
- Ecological energetics – Investigating issues pertaining to energetics of vertebrate populations as they pertain to management and conservation needs.

In addition, several national programs are underway with study sites in South Carolina (http://biology.usgs.gov/state.partners/activities/sc-act.html). These include

- The Coosawhatchie River, selected as an initial study site for an innovative data-sharing and research program to restore southern forested wetlands. In cooperation with the paper industry, the Southern Industrial Forest Research Committee, the State of South Carolina, the U.S. Army Corps of Engineers, the U.S. Department of Agriculture-Forest Service, and others, USGS biologists will describe the features of these wetlands. Information obtained under this initiative will be used to help develop recommendations for the restoration of the ecological, recreational, and economic values of southern forested wetlands. This project is one of a series of Biological Resources Discipline regional science initiatives that demonstrate the importance of bringing together biological data from a variety of sources to support public and private decisionmaking.

- Contaminant surveys and field studies are being conducted to assess the quality of water and sediment in the lower Savannah River and Charleston Harbor to assist the U.S. Fish and Wildlife Service in developing appropriate management strategies. Southeastern coastal rivers and estuaries produce abundant fish and shellfish that contribute significantly to the regional economy and provide habitat for endangered species and other wildlife.
- Most National Wildlife Refuges and many State wildlife-management areas maintain impoundments in which water levels are manipulated to benefit waterfowl. The Biological Resources Discipline is investigating the importance of these impoundments to migrating shorebirds in coastal South Carolina. This information will be used to help agencies develop water-management protocols that will maximize available habitat for shorebirds and waterfowl.
- The Biological Resources Discipline is assisting with biological collections in the Santee River basin, as part of the NAWQA Program, to assess the health of our Nation's water resources.
- The Breeding Bird Survey is a cooperative program for gathering and analyzing quantitative information on populations of breeding birds in North America. The program is active in South Carolina, where 20 standardized routes are routinely surveyed.
- Researchers are studying alterations in biogeochemical cycling in Congaree Swamp National Monument; this research is intended to help define the most cost-effective means of protecting natural resources.

South Carolina—Facts, Demographics, and Attributes

Basic information about the characteristics of South Carolina provides the context for water-resources science planning in the South Carolina District. Information presented here includes geography, climate, geology, hydrology, population and economy, government facilities, and water-resources management within the State.

South Carolina's mild temperatures and abundant moisture contribute to a historically productive agricultural economy and support the State's growth as a business, technology, military, and manufacturing center. Clean and abundant water supplies are vital to the State's economic health, the physical health of its residents, and the health of aquatic life in the State's streams, rivers, lakes, and estuaries.

Geography

South Carolina is located in the Coastal Plain, Piedmont, and Blue Ridge Physiographic Provinces of the southeastern United States (fig. 1) and covers a land area of 30,111 square miles (mi^2) making it the Nation's 41st largest State. Inland waters contribute an additional 1,006 mi^2 (http://www.sciway.net/). South Carolina is bordered by North Carolina on the north and the Atlantic Ocean on the east. On the south and west, the Chattooga, Tugaloo, and Savannah Rivers form the border between South Carolina and Georgia (fig. 1).

Land-surface elevation ranges from sea level in the east to 3,554 feet (ft) in the west at Sassafras Mountain, which is part of the border with North Carolina. Sassafras Mountain also is part of the Eastern Continental Divide, which runs through the Blue Ridge Province, with rivers on the west slope draining to the Ohio River and, ultimately, the Gulf of Mexico. Rivers on the east slope drain directly to the Atlantic Ocean through North Carolina, South Carolina, and Georgia. All rivers in South Carolina drain to the Atlantic Ocean.

Land-cover classifications for South Carolina cover a wide range of classes, as represented by the National Land Cover Dataset (fig. 2). Based on 1992 data, the major land-cover categories for South Carolina are forest (51.2 percent), agriculture (20.6 percent), wetlands (14.1 percent), water (7.0 percent), residential/urban (3.7 percent), and barren/transitional (3.5 percent; U.S. Geological Survey, 2003b). For example, Columbia, Greenville, Spartanburg, and Charleston are in the vicinity of the larger red areas indicated on the map. One aspect of a land-use/land-cover map is that it provides resource managers with an overview of the land and water resources that are available with respect to their proximity to urban and residential growth.

Climate

South Carolina's climate is influenced by latitude, the State's proximity to the Atlantic Ocean and the Appalachian Mountains, and elevation. The State's mid-latitude location provides four distinct seasons. Sea breezes, created by the temperature differential between the State's land mass and the Atlantic Ocean, produce cooling winds during the summer and warm winds during the winter in coastal counties. The Appalachian Mountains block many cold air masses trending from the northwest, and down-slope winds cause areas leeward of the mountains to experience slightly higher temperatures than surrounding areas, thus making South Carolina's winters milder. In addition, the mountains promote a leeside rain shadow, an area of decreased precipitation across the middle part of the State, roughly parallel to the Fall Line (Kronberg and Purvis, 1959; Purvis and others, 1990).

The State's mean annual temperature varies from the low 60's along the coast to the mid-50's in the mountains. During the winter, mean temperatures range from the mid-30's in the mountains to the low 50's in the Low Country Counties of Beaufort, Colleton, Hampton, and Jasper (fig. 1).

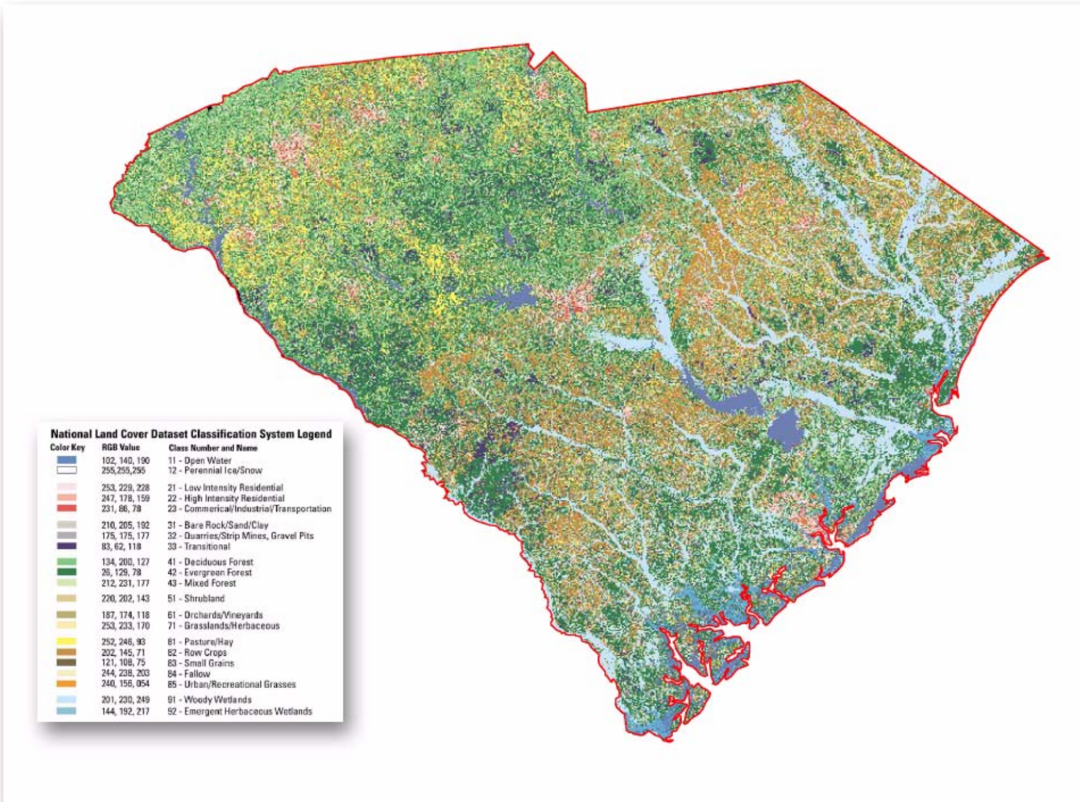


Figure 2. Land cover in South Carolina (from U.S. Geological survey, 2003b).

During the summer, mean temperatures range from the upper 60's in the mountains to the mid-70's in the Low Country (U.S. Department of Commerce, 1992; South Carolina Department of Natural Resources, South Carolina State Climatology Office, 2003).

Precipitation totals in the state vary directly with elevation, soil type, and vegetation. Mean annual precipitation is highest in northwestern South Carolina (fig. 3), where from 70 to 80 inches (in.) of rainfall occur in the mountains. The highest annual rainfall total was recorded at Caesars Head, South Carolina (79.29 in.). Across the Piedmont foothills, mean annual rainfall totals range from 45 to 50 in. As previously noted, the middle portion of South Carolina is, on average, the driest, with annual rainfall totals between 42 and 47 in. Precipitation amounts are slightly higher across the Coastal Plain and average 50 to 52 in. Approximately 10 to 20 miles inland, secondary precipitation maximums occur parallel to the coast as a result of the sea-breeze front thunderstorms prevalent during the summer (South Carolina Department of Natural Resources, South Carolina State Climatology Office, 2003). Snow, sleet, and freezing rain vary from 3.75 events per year in Chesterfield County to less than 0.75 event per year in the Low Country (fig. 1). The highest frequency of winter precipitation, by month, occurs in January (Davis and Gay, 1993).

On a sporadic basis, tropical cyclones affect the South Carolina coast and provide enhanced rainfall inland during the summer and fall months. Tropical depressions, tropical storms, and hurricanes bring strong winds, tidal surges, precipitation, and tornados to the State and can cause significant damage, depending on the storm's intensity and proximity to the coast (South Carolina Department of Natural Resources, South Carolina State Climatology Office, 2003).

The State's high interannual and seasonal variability in precipitation can result in drought conditions. There is a 25-percent probability that drought conditions occur somewhere in South Carolina at any given time (Guttman and Plantico, 1987). During 1998–2002, South Carolina experienced an extreme drought. Below-normal precipitation was observed statewide during 39 of 51 months from May 1998 through August 2002. Ground-water levels in the Piedmont declined up to 11 ft (compared to a normal seasonal variance of 2 ft), and period-of-record low flows were recorded at over 60 percent of the long-term (greater than 30 years of record) gaging stations on unregulated streams. In addition, losing streamflow in some rivers was documented for the first time. The South Carolina Drought Response Act of 1985 lists four levels of drought: incipient, moderate, severe, and extreme. In August 2002, the South Carolina Drought Response Committee declared an extreme (highest level of severity) drought for all 46 counties (South Carolina Department of Natural Resources, Division of Land, Water, and Conservation, 2002).

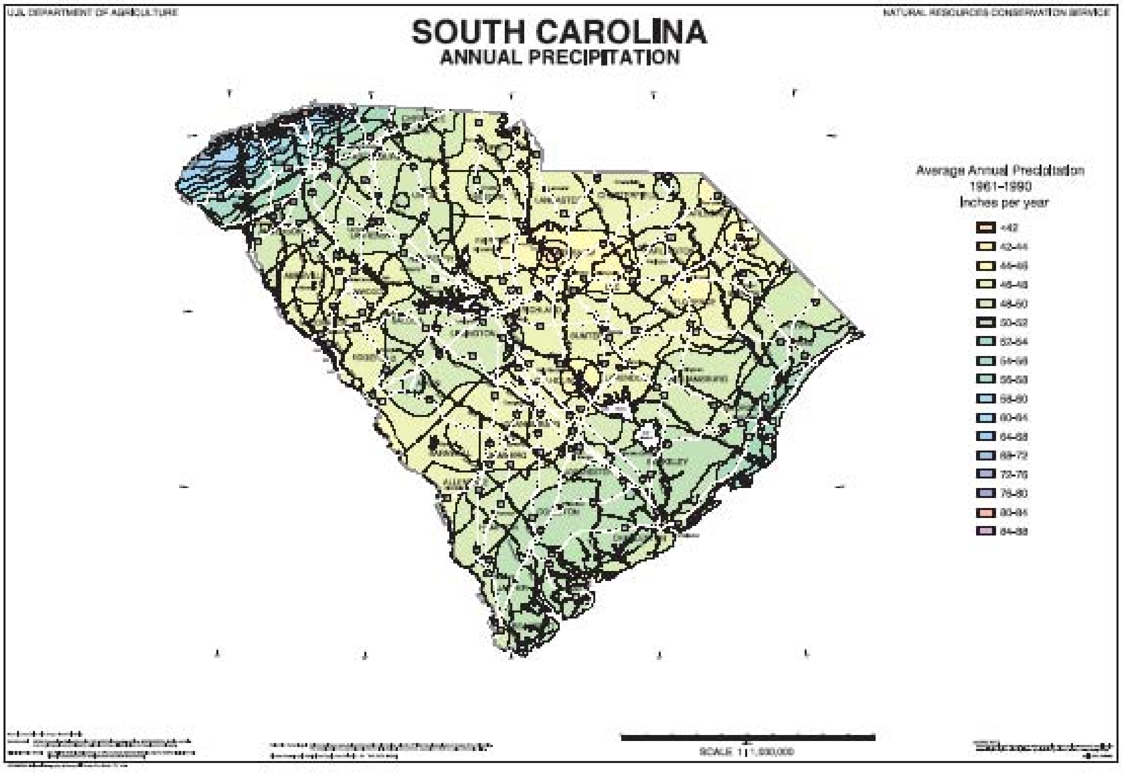


Figure 3. Mean annual precipitation in South Carolina, 1961–90.

Geology

South Carolina's physiographic provinces represent distinct geologic settings (fig. 4). The Piedmont and Blue Ridge Provinces are composed of complex metamorphic, igneous, and metasedimentary rocks that have been exposed to intense heat and pressure related to mountain building and the associated folding and faulting. As a result, these rocks have little or no primary porosity, and most ground water occurs in secondary fracture networks and the overlying weathered regolith (fig. 5).

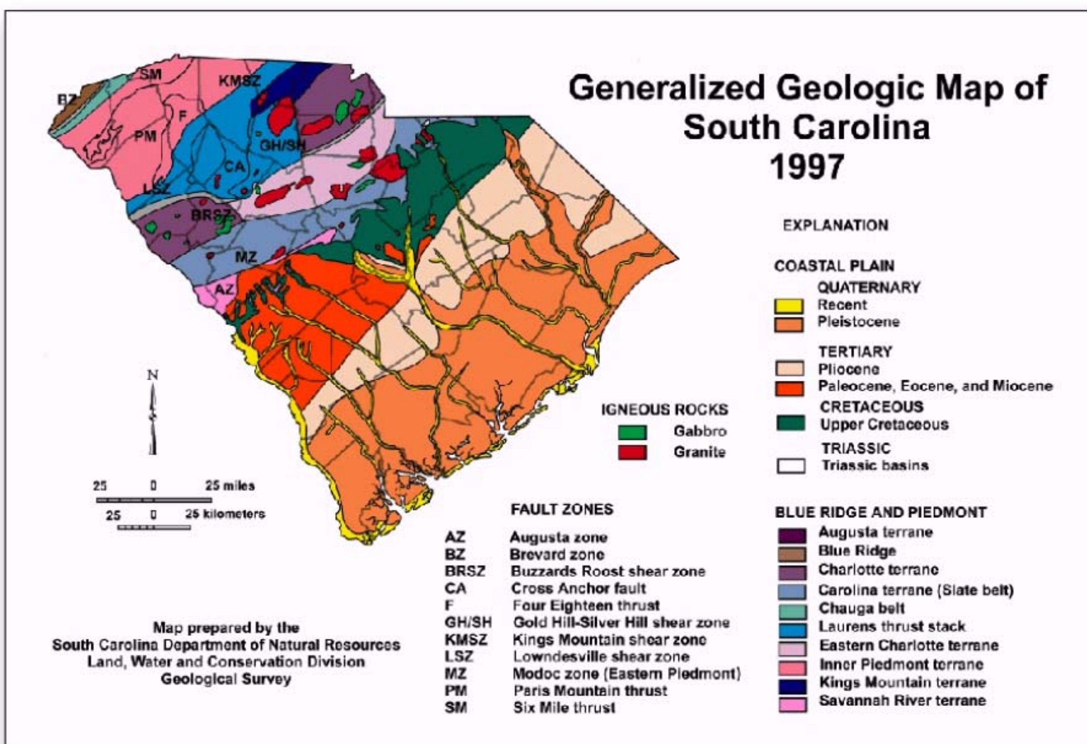


Figure 4. Generalized geologic map of South Carolina (South Carolina Department of Natural Resources, South Carolina Geological Survey, 1997).

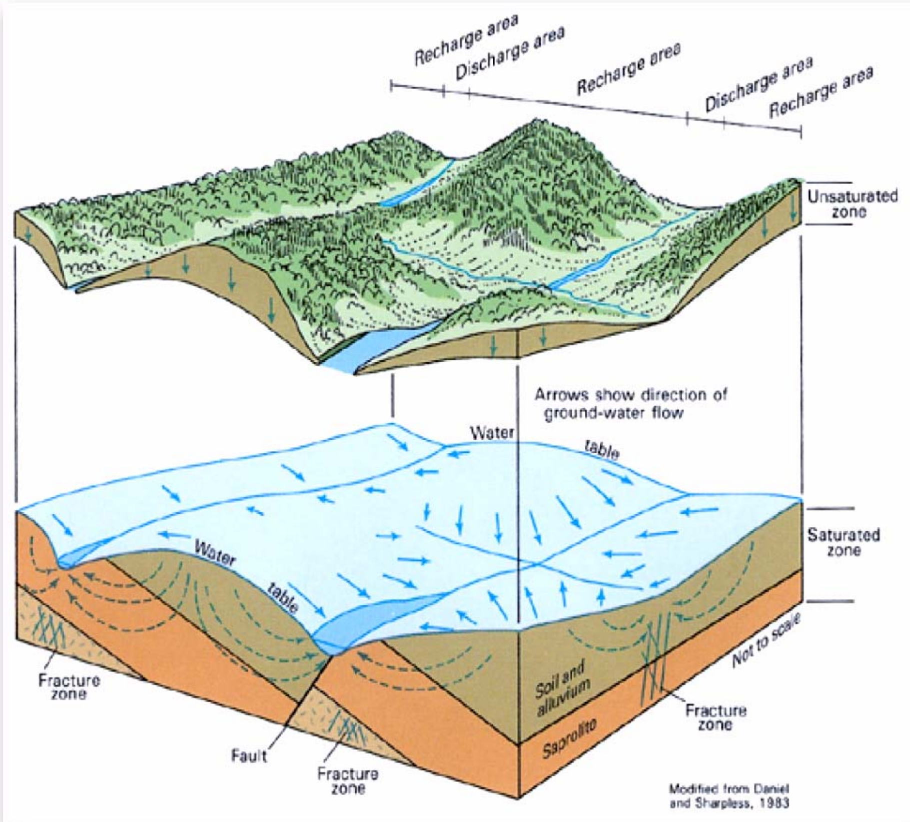


Figure 5. Generalized geology of the South Carolina Piedmont (from Daniel and Sharpless, 1983).

By contrast, the Coastal Plain is composed of layers of sediments and sedimentary rock deposited over millions of years as the Atlantic Ocean transgressed and regressed to the east and the Piedmont and Mountains were eroded from the west. These layers of porous sediments and rock form a series of productive regional aquifers that store vast quantities of ground water (fig. 6).

The soils of South Carolina are a product of their geologic, geomorphic, and climatic environment, in addition to site-specific characteristics such as moisture and vegetation. The Coastal Plain is composed of sandy to clayey unconsolidated sediments. The Piedmont includes a large number of soil systems because of the complex geology of the underlying metamorphic and igneous rocks. Soils in the Blue Ridge Physiographic Province are thinner than those in the Piedmont and Coastal Plain Physiographic Provinces, resulting in lower water-storage capacity.

Hydrology

Sources of freshwater in South Carolina are precipitation, streamflow from adjacent States, and water stored in aquifers underlying the State. Annually, precipitation contributes approximately 48 in. of water, and streamflow from adjacent States contributes about 8 in. of water. Outflow of water from the State principally results from evapotranspiration, streamflow discharge, and aquifer discharge, which account for approximately 34 in., 21 in., and less than 1 in., respectively (Badr and others, 2004).

Over 1,000 mi^2 of South Carolina's land area is covered by water. South Carolina has 11,000 miles of permanently flowing rivers and streams and four major river basins composed of subbasins. The major river basins in South Carolina are the Ashepoo, Combahee, and Edisto (ACE); Pee Dee; Santee; and Savannah basins (fig. 7). The ACE basin is composed of the three subbasins of the

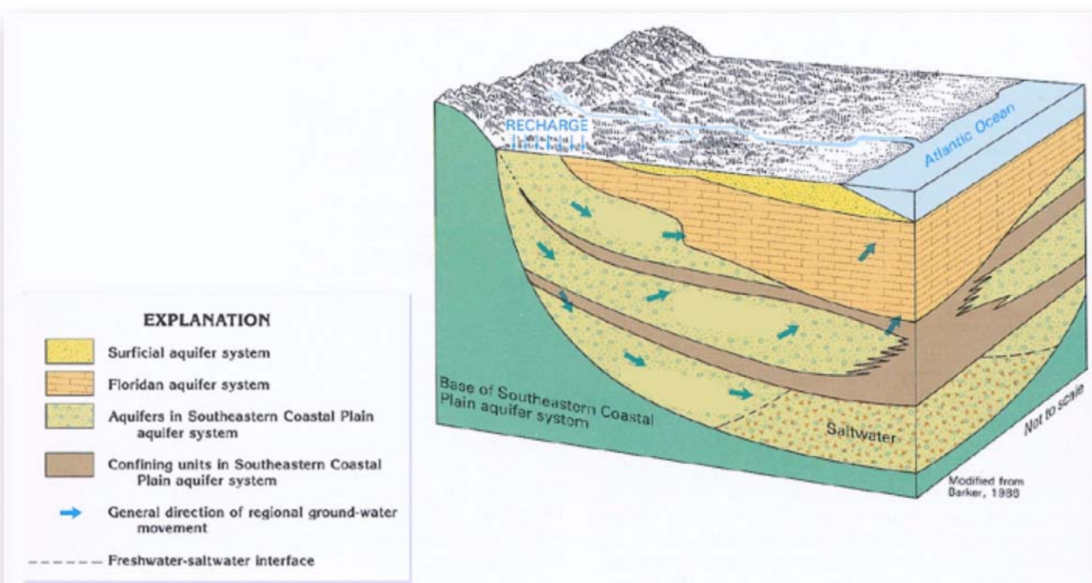


Figure 6. Generalized geology of Coastal Plain aquifers underlying South Carolina (from Barker, 1986; Miller 2000).

Figure 7. Major river basins in South Carolina.

Ashepoo, Combahee, and Edisto Rivers and is the only basin contained entirely within the State boundaries. The Pee Dee River basin originates in North Carolina. In its upper reach, the Pee Dee River basin is known as the Yadkin River basin and includes the Black, Little Pee Dee, Lynches, Great Pee Dee, and Waccamaw River subbasins. The Santee River basin also originates in North Carolina and consists of the Santee, Congaree, Saluda, Broad, Wateree, and Catawba River subbasins. The Savannah River basin spans portions of South Carolina, Georgia, and North Carolina and includes the Seneca and Tugaloo subbasins (figs. 1, 7). The waters from the four main river basins ultimately empty into the Atlantic Ocean along South Carolina's coast.

South Carolina has 1,617 lakes larger than 10 acres. These lakes cover more than 521,700 acres (815 mi^2) and impound approximately 15.1 million acre-feet of water. Nineteen of the State's lakes are larger than 1,000 acres and account for more than 88 percent of the impounded water (South Carolina Department of Parks, Recreation, & Tourism, 2004).

Approximately one-fourth of the land area in South Carolina is wetlands. Ninety percent of the State's wetlands are composed of freshwater and 10 percent consists of saltwater or brackish marshland. South Carolina has the largest concentration of Carolina Bays on the East Coast. The Carolina Bays occur as perfect ovals, ringed by ridges of sand with interiors that are low and swampy. The wetlands of South Carolina compose 12 percent of the total wetland areas in the southeastern United States (South Carolina Department of Parks, Recreation, & Tourism, 2004).

South Carolina has approximately 190 miles of coastline. The Intracoastal Waterway runs approximately parallel to the Atlantic Coast for 240 miles from Georgia to North Carolina, with extensive marshes and numerous bays and sounds. Along coastal Georgetown and Horry Counties, the Grand Strand, a 60-mile stretch of beach, includes some of the Atlantic Coast's longest unbroken beaches (South Carolina Department of Parks, Recreation, & Tourism, 2004).

The aquifers underlying the South Carolina Coastal Plain are a segment of the Southeastern Coastal Plain aquifer system (fig.6). In South Carolina, the Coastal Plain aquifers consist of a wedge-shaped sequence of deltaic and marine deposits that gradually thicken from the Fall Line to the coast (Miller, 2000). With the exception of the Floridan aquifer system, the Coastal Plain aquifers consist predominantly of clastic sediments that grade laterally into one another. The Floridan aquifer system is mainly composed of carbonate sediments of Eocene age (Campbell and van Heeswijk, 1996). Aquifers in the South Carolina Coastal Plain can be divided into six major aquifers (Aucott, 1988). Listed chronologically from youngest to oldest, these aquifers are the surficial, Floridan, Tertiary Sand, Black Creek, Middendorf, and Cape Fear aquifers.

The South Carolina Coastal Plain aquifer system is adjacent to four regional aquifer systems that, to some extent, influence the ground-water flow regimes. In general, the regional ground-water flow direction in the South Carolina Coastal Plain aquifers is parallel to the Atlantic coast, from the southwest to the northeast except for the Floridan aquifer system, where ground-water flow is perpendicular to the coast (Aucott and Speiran, 1985). Since the early 1900's, ground-water withdrawals have caused subregional changes in the ground-water flow pattern and altered the overall regional flow paths (Campbell and van Heeswijk, 1996).

In upstate South Carolina, the unconfined Piedmont and Blue Ridge aquifers are the major sources of ground water. These unconfined aquifers are composed of saprolite underlain by fractured crystalline igneous and metamorphic basement rocks (fig. 5). Chemical weathering of igneous and metamorphic rocks yields a reduced-density residuum called saprolite, which is soft and friable and retains the fabric and structure of the parent rock. In the Piedmont and Blue Ridge aquifers, most of the ground water is stored in the saprolite overlying the bedrock.

As South Carolina's mountains and ridges were formed, the rock formations underwent extensive uplifting, folding, and faulting. The stresses of these movements caused the rock to crack, creating a system of fractures. Individual fractures can extend hundreds of feet or more. These bedrock fractures provide a network of pathways for water movement. Because of many unknowns concerning the geology and hydrogeology in South Carolina's Piedmont and Blue Ridge Provinces, the ground-water flow regimes are largely unknown.

Population and Economy

South Carolina is the 9th fastest growing State in the Nation and ranks as the 26th most populous State, with a population of more than 4.01 million (U.S. Census Bureau, 2000; fig. 8). Between 1990 and 2000, the State's population increased approximately 15.1 percent and was slightly above the Nation's 13-percent increase. Resident population for the State is projected to be 5.08 million by the year 2025 (South Carolina Budget and Control Board, 2004b).

From 1990 to 2000, the five fastest growing counties in South Carolina were Beaufort (39.9 percent), Edgefield (34 percent), Horry (36.5 percent), Jasper (33.5 percent), and Lexington (28.9 percent; South Carolina Budget and Control Board, 2004a). About 60 percent of the State's population is concentrated in the urban areas of Charleston, Columbia, Greenville, and other large cities. Columbia is the largest city in the State with a growing population in the greater metropolitan area of 536,691 (U.S. Census Bureau, 2000).

The rapid population growth in coastal counties is attributed primarily to the influx of retirees to these areas. Populations in the coastal counties of Horry, Beaufort, and Jasper increased by more than 33 percent from 1990 to 2000. Edgefield and York Counties had the highest population growths in the Piedmont Province. Marlboro, Allendale, Bamberg, and Union Counties had decreases in population (South Carolina Budget and Control Board, 2004a).

Tourism is the largest industry in the State, accounting for about 2.9 million visits in 1999 and about $15.6 billion in tourist-related revenue (South Carolina Budget and Control Board, 2004c). Major tourist attractions include the more than 330 golf courses, state and national parks, lakes, gardens, plantations, and the coastal beaches.

Agriculture is an important part of the State's economy; however, agriculture has declined in recent years. Between 1994 and 2000, the number of farms in the State decreased by 4 percent, and total farmland acreage decreased by 7.8 percent.

Forestry is the third largest industry in the State. Since 1958, the volume of standing timber has more than doubled in South Carolina. Forests occupy 12.4 million acres or almost 19,375 mi^2 of the total land area in the State. In 2001, the delivery value of the State's timber was $835 million, making timber the State's most valuable agricultural crop. The forest industry contributes $14 billion annually to South Carolina's economy (South Carolina Budget and Control Board, 2004c).

The commercial fishing industry contributes significantly to the economies of the coastal counties and the State. The chief catches are blue crab and shrimp, followed by fish, clams, and oysters. Between 1996 and 2000, the mean contribution of the fishing industry to South Carolina's economy was $29.9 million. During this time, South Carolina's commercial fisheries increased by 16.2 percent (South Carolina Budget and Control Board, 2004c).

In 2001, nonagricultural employment in South Carolina declined 1.3 percent. The largest sector of nonagricultural employment was the service industry (25 percent) followed by trade (24 percent), manufacturing (18 percent), government (17 percent), construction (6 percent), transportation and public utilities (5 percent), and finance, insurance, and real estate (5 percent). Based on 1998 to 2008 employment projections, employment in the services, construction, and wholesale and retail trade industries will increase (South Carolina Employment Security Commission, 2002). South Carolina's wealth of federally owned and operated lands and facilities also are important to the State's overall economy (fig. 9).

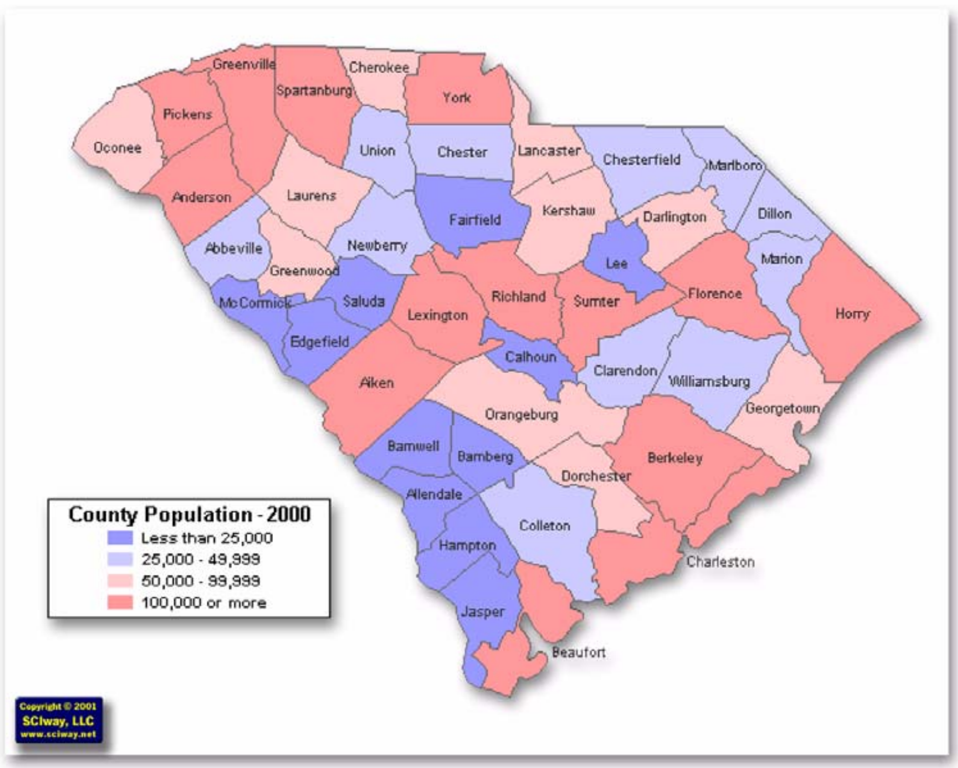


Figure 8. Generalized distribution of population, by county, for South Carolina.

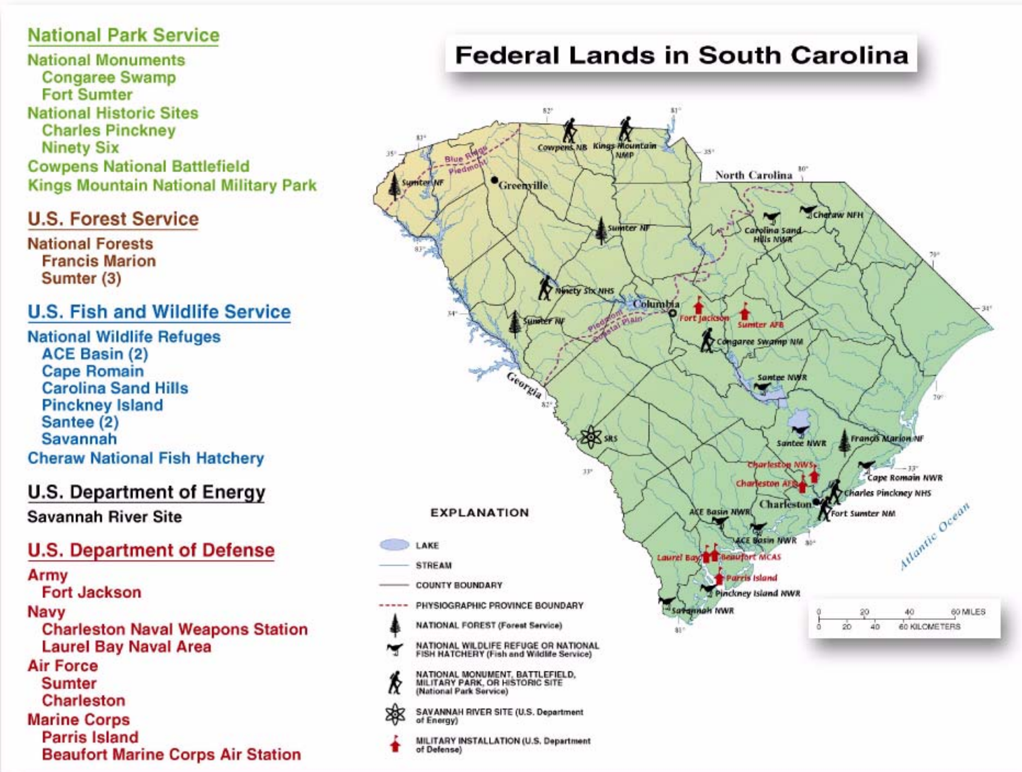


Figure 9. Locations of Federal lands, national parks and monuments, wildlife refuges, national forests, and physiographic provinces in South Carolina.

Government Facilities

South Carolina is home to nearly 1 million acres of national forests, wildlife refuges, and parks (fig. 9). The State has more than 617,000 acres of national forests. Sumter National Forest (composed of the Enoree, Long Cane, and Andrew Pickens Districts) consists of over 364,700 acres in the Piedmont and Blue Ridge Provinces (U.S. Department of Agriculture, 2003b). The Francis Marion National Forest, located in the Coastal Plain, encompasses over 252,800 acres (U.S. Department of Agriculture, 2003a). The State has eight National Wildlife Refuges (NWRs), which are all located in the Coastal Plain. These refuges encompass more than 174,000 acres, ranging from 100 acres at the Tybee NWR to more than 64,200 acres at Cape Romain NWR (U.S. Fish and Wildlife Service, 2004). In addition to seven national historic sites, battlefields, monuments, and trails, South Carolina is home to the newest national park, Congaree Swamp National Park. This 22,200-acre park also is designated an International Biosphere Reserve and a Globally Important Bird Area (National Park Service, 2003). Visitation to the Congaree Swamp National Park exceeds 100,000 annually (T. Yednock, Congaree Swamp National Park, oral commun., January 2004).

The U.S. Army, Navy, Air Force, and Marines are well represented in South Carolina, with seven major Department of Defense facilities in the Piedmont and Coastal Plain Provinces. Fort Jackson, a 52,000-acre facility in Columbia, was established in 1917 to train soldiers for World War I. Today, about one-half of the Army recruits are trained at Fort Jackson (U.S. Army, 2004). The Charleston Naval Weapons Station, a 17,300-acre facility about 20 miles north of Charleston, provides technical and material support to the fleet. Two U.S. Air Force Bases are located in the State. Shaw Air Force Base is in Sumter, and Charleston Air Force Base is about 10 miles south of Charleston. The Parris Island Marine Corps Recruit Depot and the Marine Corps Air Station Beaufort also are active facilities in the State. Parris Island is the boot-camp destination of every Marine Corps recruit east of the Mississippi River.

South Carolina is home to the U.S. Department of Energy Savannah River Site (SRS), located in the upper coastal plain near Augusta, Georgia (U.S. Department of Energy, 2002). The SRS is a secured U.S. Government facility that occupies approximately 310 mi^2 of land adjacent to the Savannah River, principally in Aiken and Barnwell Counties. The SRS has produced nuclear materials for national defense programs, the space program, and for medical, industrial, and research programs. Chemical and radioactive wastes, which are by-products of nuclear-material production processes, have been treated, stored, and in some cases, disposed at the SRS, resulting in soil and ground-water contamination. The U.S. Environmental Protection Agency (USEPA), South Carolina Department of Health and Environmental Control (SCDHEC), and U.S. Department of Energy are addressing these contaminant wastes under a Resource Conservation and Recovery Act (RCRA) permit and Comprehensive Environmental Restoration Compensation and Liability Act (CERCLA) 120 Federal Facility Agreement (U.S. Environmental Protection Agency, 2004).

Water-Resources Management in South Carolina

The **South Carolina Department of Natural Resources** (SCDNR) is the advocate and steward of South Carolina's natural resources, including land, water, wildlife, and fish. The SCDNR provides guidance to the State in developing and managing water resources through planning, research, technical assistance, and public education, and has no regulatory responsibilities except fish and wildlife law enforcement. The SCDNR published a State water plan to "establish guidelines for the effective management of the State's water resources to sustain the availability of water for present and future use to protect human health and natural systems, and to enhance the quality of life for all citizens" (Badr and others, 2004). The plan describes the source, availability, and quality of the State's water and the demands for water. It outlines procedures for accounting for water withdrawals, storage, and discharges. The State water plan establishes policy regarding surface- and ground-water withdrawals and interstate and intrastate conflicting demands for water, especially during periods of water shortage.

The SCDNR also is responsible for the State Flood Mitigation Program. In 1999, the SCDNR published a Flood-Hazard Mitigation Plan for South Carolina (South Carolina Department of Natural Resources, 1999), which contains flood mitigation strategies for the six general categories of prevention measures, property protection, natural resource protection, emergency services, structural projects, and public information.

A second major component of the Flood Mitigation Program is the South Carolina Flood Map Modernization Initiative. In 2002, through a Cooperating Technical Partner Initiative with the Federal Emergency Management Agency (FEMA), the SCDNR initiated a program to update flood-hazard information for all communities in the State over a period of 5 years. This project is estimated to cost $37 million to complete and consists of the following major components:

- Development of accurate high-resolution digital elevation data,
- Development of updated flood-hazard data, and
- Development of an online information system for public access to flood-hazard map information.

The data developed as part of this project will prove valuable for a variety of local, State and Federal agencies (South Carolina Department of Natural Resources, 2002).

The **South Carolina Geological Survey** (part of the SCDNR) collects, studies, interprets, and reports information relating to the geology of South Carolina for enhanced land-use planning, economic development, emergency preparedness, and education. The USGS Geologic Discipline provides limited funding support for selected studies.

The **South Carolina Department of Health and Environmental Control** (SCDHEC), the public health and environmental protection regulatory agency for South Carolina, is charged with enforcing State health and environmental statutes. All USEPA-designated water programs are under the purview of the SCDHEC, which is rare for a State agency in the southeast (D. Baize, South Carolina Department of Health and Environmental Control, oral commun., March 2004).

To assess the quality of the State's water and to protect the population, the SCDHEC operates an extensive water-quality monitoring program that includes over 300 permanent, fixed-location monitoring sites. These sites are sampled once each month for an extended period of time and in a uniform manner to provide baseline data. This network is supplemented with additional data from special-purpose sites, annual watershed water-quality monitoring sites, and randomly selected probability-based monitoring sites (South Carolina Department of Health and Environmental Control, 2004).

The SCDHEC promotes and encourages responsible management of South Carolina's water resources by enforcement of the South Carolina Surface- and Ground-Water Withdrawal and Reporting Acts, which require water users withdrawing 3 million gallons of water or more in any month to register with and report the water use to SCDHEC annually (South Carolina Department of Health and Environmental Control, 2003). The SCDHEC also ensures the safety of public drinking water in South Carolina by using a "multiple barrier" approach. Mechanisms used in this approach include source-water protection, certified water-treatment plant operators, routine sanitary surveys, monitoring, and treatment design and plan review. In partnership with the USEPA and drinking-water professionals throughout the State, the SCDHEC Drinking Water Program staff helps to ensure that safe, high-quality drinking water is available.

The SCDHEC receives an annual Clean Water Act Section-319 grant from the USEPA to implement the South Carolina Nonpoint Source (NPS) Management Program. Through a competitive grant process, some of the funds are allocated to government entities, stakeholder groups, or other agencies to facilitate NPS reductions in priority watersheds. South Carolina strives to reduce or prevent NPS water pollution through the implementation of approved total maximum daily loads (South Carolina Department of Health and Environmental Control, 1999).

The **South Carolina Department of Transportation** (SCDOT) is responsible for more than 41,500 miles of roads and almost 7,900 bridges that span waterways in the State. In addition to routine maintenance and monitoring programs, the SCDOT has provided cooperative funding to the USGS for several investigations and data-collection programs. The results of these investigations and programs have been used to improve the design of new structures and to mitigate potential damage to existing structures. Included in these investigations are the operation of the statewide crest-stage gage network and updated techniques to estimate the magnitude and frequency of floods in rural and urban basins. The SCDOT also is proactive in bridge-scour research. Since 1990, the South Carolina District and the SCDOT have conducted six cooperative bridge-scour investigations.

As part of National Pollutant Discharge Elimination System (NPDES) stormwater program mandated in the Clean Water Act, the SCDOT is required to address the quality of stormwater runoff from State-maintained roadways. In the NPDES program, stormwater discharges from State roadways are considered a large municipal separate storm-sewer system (MS4), requiring the development of a stormwater management program. To mitigate the effects of runoff from State roadways to area water bodies, the SCDOT installed structural best management practices (BMPs), such as grassed waterways, detention ponds, and vendor-supplied systems, throughout the State. The South Carolina District and the SCDOT recently initiated a cooperative investigation to evaluate the performance of four representative BMP's near Beaufort and in Colleton County, South Carolina.

Other State and Federal agencies involved in water-resources programs in South Carolina include the **U.S. Army Corps of Engineers**, **USEPA**, **FEMA**, **U.S. Fish and Wildlife Service**, **National Park Service, U.S. Forest Service**, and **U.S. Department of Agriculture-Natural Resources Conservation Service**, **South Carolina Soil and Water Conservation Districts** and **10 regional Councils of Governments**.

Local government agencies, such as planning commissions and emergency preparedness offices, and public utilities rely on USGS data for routine planning and response actions. These local government agencies depend on the USGS to provide accurate, timely, and unbiased scientific information. These data are used in local planning, zoning, building codes, and water-quality assessment and management.

South Carolina District Science Plan

> ***Water is a key determinant of population growth and distribution, economic development, social and political organization, and the quality of life. . . . Because water resource issues in the United States and elsewhere are unlikely to diminish in upcoming decades, it appears probable that USGS information on streamflows and water use, regional water resource studies, and hydrologic research will be more important in the future than in the past.***
> **(National Research Council, 2001)**

Experience has taught USGS scientists and managers that the agency's viability and prosperity depend on an ability to demonstrate the relevance and significance of USGS science to society. As former (2000) director Gordon Eaton said, and later reiterated by the National Research Council (2001), "It is not enough now for talented scientists to do outstanding work. They must explain and define science's societal payoffs if they are to continue to be funded."

Society—citizens, planners, engineers, water-resources managers, policymakers, those involved in hazard mitigation, and others—needs hydrologic science information for at least three reasons:

- ***Immediate and reliable information on water-resources conditions is needed in order to respond to emergencies, control flows, take remedial actions, protect human health, and use the resource efficiently and wisely.***
  - Are the necessary data available to estimate time-of-travel for accidental spills or incidental contamination (terrorist/homeland security) to reach sensitive areas in surface waters, such as drinking-water-supply intakes or shellfish-harvesting waters?
  - What are the downstream effects of regulated flow releases from impoundments on aquatic ecosystems?
  - During periods of low-flow, how does the water quality of an aquatic habitat respond to reduced assimilative capacity?
  - Are emerging contaminants (such as microbial pathogens, personal-care products, pharmaceuticals, and pesticide degradates) present in the drinking-water supplies in South Carolina?
  - Are observed levels of emerging contaminants in source waters potentially deleterious to human health?
- ***Reliable, predictive information is needed in order to know what future conditions will be as a result of human actions and climatic fluctuations so plans for these conditions and remediation activities can be implemented.***
  - Will flooding be worse if a parcel of land is developed in a particular way?
  - Will droughts become more frequent if global warming continues at the present rate?
  - Will aquatic habitat be restored if the hydrologic regime is modified?
  - Will ground-water supplies of acceptable quality be sufficient if pumping rates increase?
  - Will water quality improve if certain land-management practices are followed or if a total maximum daily load (TMDL) is implemented?
- ***Reliable information on how water-resources systems change through time and the reasons for these changes is needed in order to better use, manage, and protect the resource.***
  - Is flooding becoming worse? If so, why?
  - Is water quality improving as a result of improved wastewater treatment?
  - Are TMDLs resulting in improved water quality?
  - Are minimum streamflows decreasing as a result of urbanization or climate change?

Water-resources issues that will be the focus of science activities in the South Carolina District during the next 5 years are described herein. Background information and a summary of current District program are provided, followed by a summary of program opportunities and short-term (tactical) and long-term (strategic) actions to be taken to capitalize on these opportunities. District requirements to implement these opportunities and their relation to USGS and WRD strategic plans are then discussed.

Priority Issues for Science Activities

Science planning in the South Carolina District builds on an evolving list of priority issues. Currently, these science priorities include the following:

- Data collection, integration, and analysis
- Hydrologic and hydraulic hazards
- Sustainable water resources in piedmont and coastal environments
- Urban effects on human and aquatic health
- Applied ecosystem research

Although presented separately, the issues and activities in this section are linked; those related to one issue will, in all likelihood, be related to another issue. For example, data collection, integration, and analysis are required for all science activities of the South Carolina District. In addition, sustainable water resources in the Piedmont and Coastal Plain are directly related to population growth in urban and suburban areas. In an attempt to provide a complete description of each issue, some elements of individual issues will be duplicated under other issues.

Data Collection, Integration, and Analysis

Background

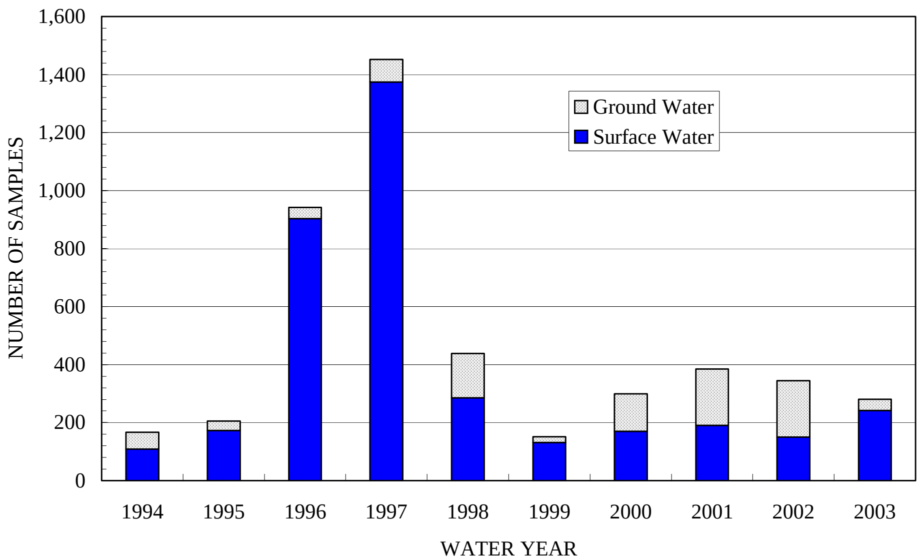
The mission of the USGS is to serve the Nation by providing reliable scientific information to State, local, and other Federal agencies to help better understand the Earth and its resources, minimize loss of life and property from natural disasters, manage natural resources, and protect our quality of life. Sound, comprehensive scientific data are the key to understanding these processes. This information is vital to the Federal, State, and local agencies that directly manage water resources or conduct activities that affect or are otherwise related to water resources. Recent droughts (1998–2002), tropical storms and hurricanes (1995 and 1999), and inland flooding have increased the attention given to the importance of having accurate and timely hydrologic data, which can now be disseminated rapidly to a large number of people without compromising accuracy.

The USGS began collecting surface-water data in South Carolina in the late 1800's. As science needs evolved and data-gathering technology progressed, USGS data-collection and dissemination capabilities grew. In 2004, the South Carolina District operated a hydrologic data network that included 154 surface-water, 20 ground-water, and 57 water-quality continuous-record gaging stations located in all major drainage basins across the State. The current monitoring network is the result of individual cooperative agreements between the USGS and more than 30 Federal, State, and local agencies. These data-collection stations fulfill the mission of the USGS by providing South Carolina government entities with the hydrologic data they need to make scientifically sound decisions regarding the natural resources of the State.

Long-term (greater than 10 years) nutrient, pesticide, and streamflow data for several surface-water sites have been collected and stored in the National Water Information System (NWIS) QWDATA database. These data can be used to evaluate long-term trends. Long-term discrete water-quality data-collection networks are funded predominantly through the USGS NAWQA and National Stream Quality Accounting network (NASQAN) programs. Water-quality data from long-

term sites and additional water-quality data from periodically sampled surface- and ground-water sites are available to the public on the South Carolina District Website through NWISWeb. Over the past 10 years, data from a total of 4,666 discrete samples from surface- and ground-water sites (3,730 and 936 samples, respectively) have been collected, stored in QWDATA, and made available to the public through NWISWeb.

DISCRETE WATER-QUALITY DATA STORED IN QWDATA BY WATER YEAR FOR THE SOUTH CAROLINA DISTRICT



Progress in technology has improved the way the USGS collects and disseminates data. The advent of satellite-telemetry technology in the 1980's and the Internet have made it possible to provide data to cooperators and the public in near real time. The South Carolina District led the way in the use of data-collection platforms coupled with satellite telemetry for near real-time monitoring of water levels and water quality in surface and ground water. The District’s ground-water-monitoring network includes wells funded by the basic data-collection program as well as by specific hydrologic investigations. In the 1980's, many of the wells in the District’s network were located in the Coastal Plain and were used to monitor areas of changing ground-water withdrawals. Other wells were used to monitor water level and water quality in areas of potential saltwater encroachment. In the early 1990's, the South Carolina District and SCDNR redistributed the basic data-collection wells to include more wells in the Piedmont fractured-rock aquifer system. The SCDNR has funded most of the wells in the basic data-collection program in the past and is still the District's dominant cooperator in ground-water-level monitoring.

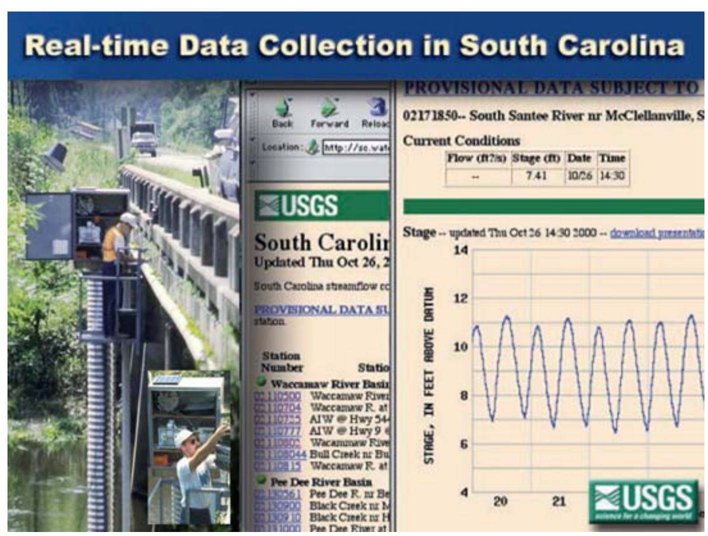
Currently (2004), 98 percent of continuous-record stations in South Carolina are equipped with satellite-telemetry instrumentation that transmits data in near real time. In addition, recent advances in acoustic and radar technologies and in new water-quality monitoring technologies have significantly enhanced data-collection techniques and improved the data quality. These advances also have made it possible to collect data in areas that were previously impractical, such as the tidally influenced reaches of streams and coastal areas.

Responses to changing hydrologic conditions occur on broad spatial and temporal scales, and these responses occur across the three disciplines of the USGS. New geospatial information and tools for integrating hydrologic and geospatial data offer the prospect of providing hydrologic data in increasingly meaningful and useful formats and for gaining new insights into hydrologic processes.

South Carolina’s population is expected to increase by 27 percent to 5.08 million by 2025, and demands on water resources are expected to increase as well. Consequently, the South Carolina District must work with its cooperators, partners, and stakeholders to identify future scientific needs, expand the hydrologic data-collection network accordingly, and design products and information-delivery systems that take full advantage of current and developing technology so that data will be available to prepare subsequent generations for future water-resources challenges.

Current Program

Currently (2004), the South Carolina District water data-collection program includes collecting continuous streamflow data at 107 sites, annual peak streamflow data at 63 sites, continuous water-level data at 47 sites, continuous precipitation data at 23 sites, continuous water-quality data at 57 sites, and continuous ground-water data at 20 sites



in addition to collecting various discrete data at numerous sites.

The continuous network includes sites that are instrumented with acoustics and non-contact sensor technologies. Acoustic Doppler current profiler (ADCP) measurements are made as a regular part of the data-collection program, and acoustic sensors are used to continuously monitor velocity at complex sites in the tidal environment along the coast where determination of continuous discharge previously has been impractical. At selected sites where the use of a stilling well or pressure transducer is impractical, a non-contact radar sensor is used to measure river stage.

Hydrologic data that are collected by the USGS in South Carolina are posted on the Web at http://sc.water.usgs.gov/water-data.html. Most data relayed by satellite or other telemetry have received little or no review. Inaccuracies in the data may be present because of instrument malfunctions or physical changes at the measurement site. Subsequent review may result in significant revisions to the data. Data on the Web, including streamflow, water level, precipitation, and water-quality data, are preliminary and should not be considered final until quality-assurance checks have been completed.

Data from the South Carolina network are integrated into the activities of many State and Federal agencies. Real-time stage and streamflow data are used by the National Oceanic and Atmospheric Administration (NOAA) River Forecast Center in making river-stage predictions. The South Carolina District maintains salinity-alert systems for the Cooper River near Charleston and the Atlantic Intracoastal Waterway near North Myrtle Beach to alert water-resource managers of the proximity of the saltwater-freshwater interface to water-supply intakes. The SCDNR accesses the USGS real-time data to analyze and project water availability for the State. Many municipalities and industries access USGS real-time data to determine the quantities of effluents to release to receiving streams.

Data analysis is the process of transforming data into information. In order to meet the societal needs for timely water-resources information, the South Carolina District has pursued traditional and new technologies to extract information from USGS real-time and historical databases.

The South Carolina District, in cooperation with the Natural Resources Conservation Service, SCDHEC, U.S. Forest Service, and SCDNR, is developing a statewide dataset of watershed and subwatershed boundaries that includes the hydrologic units and the 10- and 12-digit hydrologic unit codes (5^{th} and 6^{th} order basins). Sixth-order basins range in size from 10,000 to 40,000 acres.

The District has developed and continues to update, in cooperation with the SCDOT, the South Carolina bridge scour database (SCBSD), which includes photographs, figures, limited basin characteristics, observed and theoretical scour depths, and theoretical hydraulic data. Data from over 3,500 bridges in South Carolina have been archived and are used regularly to test the accuracy of published regional coefficients and equations for prediction of clear-water abutment and pier scour, and contraction scour. Accuracy of regional equations relates directly to bridge design and cost factors, which must be considered by the SCDOT when designing, repairing, or renovating bridges.

The District has a Cooperative Research and Development Agreement (CRADA) with Advanced Data Mining (ADMi) to develop empirical models of complex systems to address concerns of cooperators along the South Carolina coast. The emerging field of data mining is the process of extracting information from large databases. It consists of several technologies that include signal processing, advanced statistics, multidimensional visualization, artificial neural networks, and Chaos Theory. Data mining can solve complex problems that are unsolvable by any other means. Weiss and Indurkhya (1998) define data mining as "…the search for valuable information in large volumes of data. It is a cooperative effort of humans and computers." The USGS, with its large historical database and real-time network, has a unique opportunity to use data-mining techniques to extract relevant information to meet its mission. The South Carolina District has used data-mining techniques in a number of studies to predict hydrodynamic and water-quality characteristics in the Beaufort, Cooper and Savannah River estuaries (Conrads and Roehl, 1999; Roehl and Conrads, 1999, 2000; Conrads, Roehl, and Cook, 2002; Conrads, Roehl, and Martello, 2002, 2003). These studies demonstrated the advantages of data mining in predicting water level, water temperature, dissolved-oxygen concentration, and specific conductance, and in assessing the effects of reservoir releases and point and non-point sources on receiving streams.

Program Opportunities

The South Carolina District strives to be the premier source of earth science information in South Carolina for Federal, State, and local agencies and the general public. The following program opportunities have been identified as ways in which the South Carolina District can address data collection, integration, interpretation, and application issues as outlined above:

Tactical Actions

- Develop and maintain computer programs to expedite records computation and quality-assurance and quality-control, so approved data can be posted on the Internet prior to publication in the annual water data report.
- With partners, explore potential ways of expanding the types of data collected at gaging stations, such as temperature data at bridges, as an indicator of potential icing conditions, and soil-moisture probes, as an indicator of landslide potential.
- With partners, implement StreamStats, an Internet database of GIS tools that can be used to access hydrologic information and estimate flow characteristics for use during emergencies, such as flood frequency, time of travel, and flow statistics at user-defined sites on any stream.
- Develop easily navigable Websites with more user-friendly databases,

including interactive maps of gaging-station networks.

- Qualify real-time data, such as discharge and dissolved-oxygen concentration, with error bars to indicate the potential uncertainty associated with rating curves and sensor drift and fouling, respectively.
- With partners, develop a long-term strategic data-collection plan, based on development regions, for South Carolina.
- Develop methodology to estimate long-term hydrographs for ungaged sites.
- With partners, determine ways to maximize the use of USGS monitoring capabilities in addressing a wide variety of hydrologic issues, such as TMDLs, BMPs, minimum in-stream flow, environmental restoration, climatic trends, floods and droughts, declining ground-water levels, and water use.
- Expand the ground-water network by collecting ground-water levels from discontinued gaging stations during routine field trips.
- Test the prototype real-time data and advanced visualization computer application developed in the District to assist in monitoring the salt front on the Cooper River as an alert system to protect freshwater intakes for industries.
- Develop internal relational database(s) to integrate District information for data-collection activities, including sites, parameters, cooperators, field trips, period of record, instrumentations, and so on.

Strategic Actions

- With partners, integrate data-collection networks between State and local agencies, and neighboring States to determine adequate coverage, eliminate redundancies, and secure funding for selected long-term gages, especially ground-water monitoring stations.
- Investigate the use of wireless Web technology or similar technology that would allow field crews to interact with the USGS database to upload field data and disseminate data to the public in a much shorter time than is presently possible.
- With partners, expand the current data-collection network to include a sediment-monitoring program to assist other agencies in addressing sediment-impairment issues, the most frequently cited impairment in South Carolina streams.
- With partners, develop a user-friendly database for water-use reporting.
- With partners, develop real-time precipitation and flood-tracking network on a local scale with a goal of expanding the network throughout the State.
- With partners, implement a Web-based real-time flood-inundation mapping program.
- Investigate and pursue additional application of data mining techniques to facilitate the operational needs of the District's data-collection activities.

District Needs for Implementation of Program Opportunities

The data, information, and equipment needed to address most of the tactical and strategic actions listed above currently exist within the District. Additional personnel will be needed only if several studies are developed within a 1- to 2-year period. An assessment of available and needed personnel will be done before pursuing development of the investigations. Specialized skills are required to conduct some of the investigations; thus, a personnel assessment will need to include available and needed skills and the feasibility of training available personnel. Additional skills are needed to upgrade the navigability of the District's Website and to develop databases of data-collection activities.

Relation of Program Opportunities to USGS and WRD Strategic Plans

The program opportunities and actions outlined above are compatible with the nine priority water-resources issues listed in the *Strategic Directions for the Water Resources Division, 1998–2008* (U.S. Geological Survey, 1999b):

- **Issue 1.** Effects of urbanization and suburbanization on water resources.
- **Issue 2.** Effects of land use and population increases on water resources in the coastal zone.
- **Issue 3.** Drinking water availability and quality.
- **Issue 4.** Suitability of aquatic habitat for biota.
- **Issue 5.** Waste isolation and remediation of contaminated environments.
- **Issue 6.** Hydrologic hazards.
- **Issue 7.** Effects of climate on water-resource management.
- **Issue 8.** Surface-water and ground-water interactions as related to water-resource management.
- **Issue 9.** Hydrologic-system management, including optimization of ground-water and surface-water use.

Hydrologic and Hydraulic Hazards

Background

South Carolina is subject to a number of environmental hazards, including inland and coastal floods, tidal surges, and other related damage from tropical storms and hurricanes, droughts, earthquakes, and environmental terrorism. To assist other Federal, State, and local agencies in understanding and mitigating the effects of these hazards, the USGS in South Carolina operates an extensive real-time gaging-station network, provides timely data to emergency management officials, and collects data to document the severity

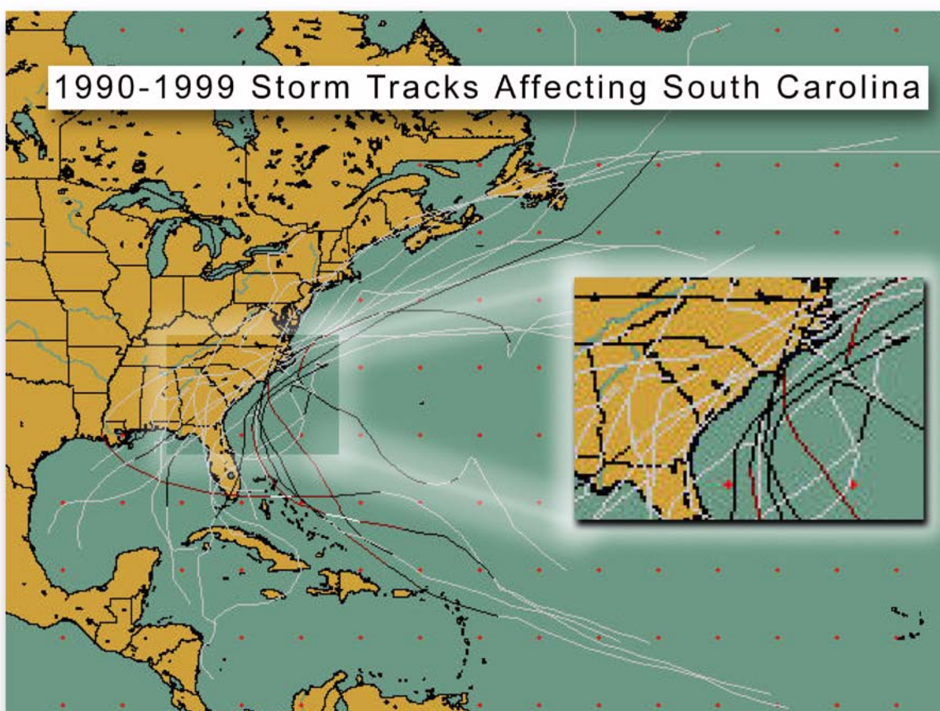
and extent of selected events. The South Carolina District strives to increase direct participation with the emergency management community to provide the data and tools necessary to make rapid, informed decisions to reduce loss of life and property damage.

Floods can adversely affect highway infrastructure and pose a significant threat to the general public. Adverse affects include damaging, destroying, or temporarily closing bridge and culvert crossings, and at times, the loss of life. During the past 15 years, South Carolina has experienced five major floods, four of which were the result of rainfall or storm surge from tropical systems. The following statistics highlight the need for improved understanding of hydraulic and geomorphological processes that cause bridge failures during floods and the need for flood-warning systems to minimize risk to life.

In September 1989, Hurricane Hugo caused storm-surge flooding from Charleston to Myrtle Beach, and the highest measured water level exceeded 20 feet above mean sea level in the Awendaw-McClellanville area (Schuck-Kolben, 1990). Floods caused by rainfall (up to 17 in. during a 3-day period) from Tropical Storms Klaus and Marco (1990) caused 80 bridges in central South Carolina to fail (Hurley, 1996). In the 1990 flood, more than 120 bridges were closed, damaged, or destroyed by floodwaters (R.N. Cherry, U.S. Geological Survey, written commun., January 1991,) and 5 lives were lost.

In October 1992, approximately 9 in. of rain fell in 24 hours in Allendale, Bamberg, Colleton, and Hampton Counties and caused extensive flooding in the Coosawhatchie and Salkehatchie River basins. Flow magnitudes exceeded the 100-year recurrence interval at several streams, and several culverts and bridges were destroyed and 3 lives were lost (T.H. Lanier, U.S. Geological Survey, written commun., December 1993). In 1995, rainfall (up to 20 in. in 4 days) from Tropical Storm Jerry caused extensive flooding throughout the South Carolina Piedmont. Peak flows exceeded the 100-year recurrence interval at many sites; 4 bridges failed and 10 to 15 bridges were temporarily closed (A.W. Caldwell, U.S. Geological Survey, written commun., January 1996).

Hurricane Floyd (1999) produced as much as 14 in. of rainfall in South Carolina. While the majority of the flooding associated with Hurricane Floyd occurred in North Carolina, extensive flooding occurred in South Carolina in the Waccamaw River basin where flows exceeded the 500-year recurrence interval (N.M. Hurley, Jr., U.S. Geological Survey, written commun., February



(*Source: PC Weather Products, Inc.)

2000). Ironically, as the Waccamaw River basin was experiencing historic flooding in 1999, the remainder of South Carolina was suffering through the second year of a 5-year drought. While South Carolina floods tend to subside within a span of days or a few weeks, droughts, even though initially less dramatic, cause prolonged (months or years) hardship.

In the past 25 years, South Carolina has had three significant droughts: 1980-82, 1985-88, and 1998-2002. The most recent drought was the most oppressive. The South Carolina Drought Response Act of 1985 lists four levels of drought—incipient, moderate, severe, and extreme. In August 2002, the South Carolina Drought Response Committee declared an extreme (most severe) drought for all 46 counties. Statewide, from May 1998 through August 2002, below-normal precipitation occurred in 39 of 51 months. Ground-water levels in the Piedmont declined up to 11 ft (compared to a normal seasonal variance of 2 ft), and period-of-record low flows were recorded at over 60 percent of long-term (greater than 30 years of record) gaging stations on unregulated streams. In addition, losing streamflow in some rivers was documented for the first time.

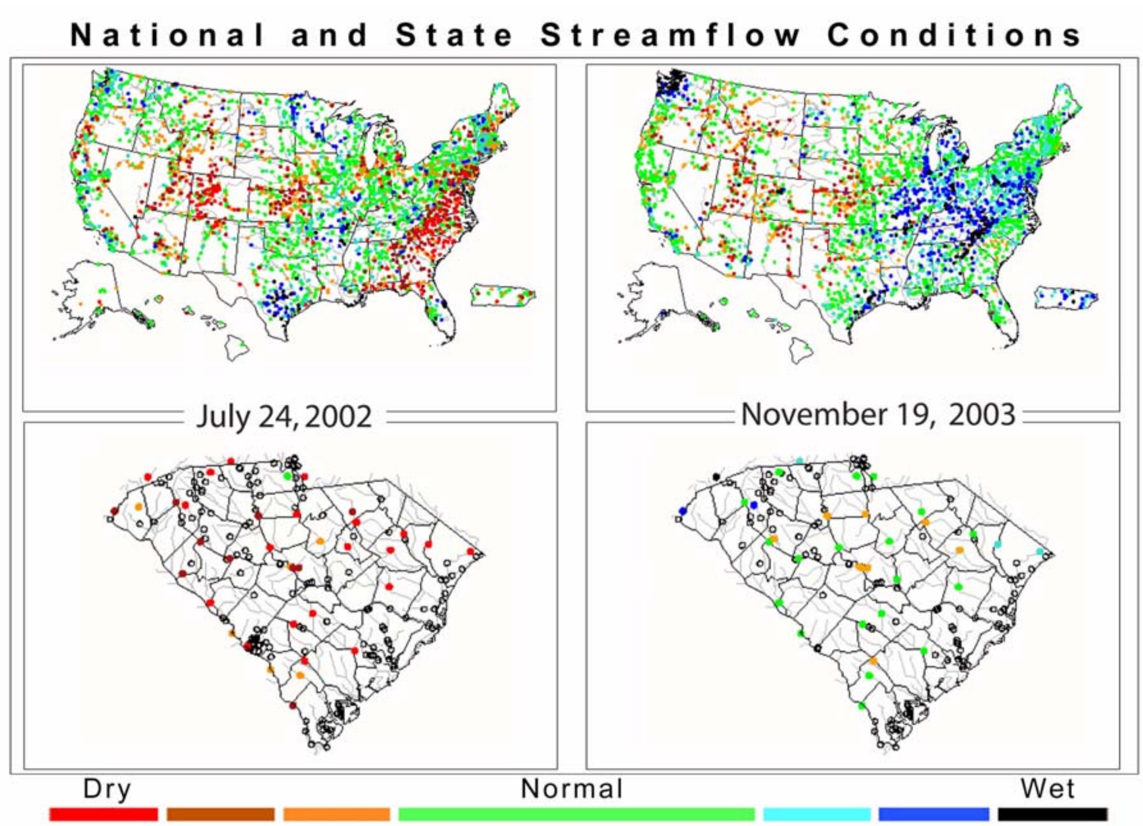
Recent terrorist activities have emphasized the vulnerability of the Nation's water supplies. As new technology becomes available for detection of water and airborne contaminants, it is incumbent upon the USGS to be a leader in testing such devices and in refining the technology to provide current, real-time data to water suppliers and emergency responders. Travel-time and dispersion-estimation equations, developed as part of the State's source-water protection plan, can be refined and expanded to support the security and integrity of water-supply intakes.

Current Program

The foundation of USGS hydrologic hazard information is the hydrologic gaging-station network that has been in operation in South Carolina since the 1880's. The network consists of gages that measure surface-water level (stage), streamflow, ground-water levels, and reservoir elevation. The current (2004) continuous streamflow-gaging network in South Carolina consists of 107 stations (plus an additional 23 precipitation gages). All of these stations have data-collection platforms that provide real-time streamflow data. Streamflow and reservoir elevation data assist emergency managers in making informed decisions during floods. Data also are collected to monitor the status of ground-water resources in South Carolina. Water-level information is of particular importance during drought conditions. These data are summarized graphically at http://sc.water.usgs.gov/water-data.html and are archived and available for interpretive studies designed to provide a better understanding of floods and droughts.

Various interpretive studies pertinent to defining or characterizing the extent of hydrologic hazards have been completed recently or are currently in progress in the South Carolina District:

- Defining clearwater abutment, contraction, and pier-scour processes in the Piedmont and Coastal Plain
- Determining flood-frequency characteristics for rural and urban basins
- Updating low-flow statistics for selected gaging stations



- Documenting selected high-flow events
- Participating with the SCDNR and other State and Federal agencies in the South Carolina Flood Map Modernization initiative

Program Opportunities

The mission of the USGS includes providing accurate, real-time data to the public and to Federal, State, and local emergency officials to assist in decisionmaking during crisis conditions resulting from hydrologic hazards. Consistent with this mission, the South Carolina District aspires to be recognized as the principal agency providing reliable formation and real-time data needed by resource- and emergency-management officials to respond to and mitigate the effects of floods and droughts and to protect the drinking-water supply in South Carolina. In addition, these data will be provided to the general public in easily accessed and understandable venues. The following program opportunities have been identified as ways in which the South Carolina District can address hydrologic hazard issues as outlined above:

Tactical Actions

- With partners, document the recent drought by updating low-flow statistics at gaging stations and determining critical conditions (thresholds) for water use, aquatic habitat, and so on.
- Within the bridge-scour program:
  - Improve understanding of hydraulics at bridges,
  - Develop regional-scale understanding of scour processes,
  - Expand current scour databases,
  - Develop less complex methods to estimate scour, and
  - Develop understanding of live bed-scour mechanisms at bridges.
- Construct and test low-cost gages to document storm surge and salinity in coastal water bodies.
- With partners, determine runoff characteristics and responses at very small (acres), single land-use basins to refine regional regression equations for runoff prediction.
- During emergencies, assign USGS personnel to FEMA Disaster Field Offices as appropriate.
- Work with Federal, State, and local agencies to develop monitoring and early detection plans to protect water supplies from biological and chemical terrorism.
- Use District expertise in ground-water flow and contaminant-transport modeling to delineate protective zones for ground-water supplies.
- Conduct seminars to inform local officials of USGS data availability and potential uses.
- With partners, implement StreamStats, a Web-based set of GIS tools that serves as a database for hydrologic information as well as a set of tools to estimate flow characteristics, such as flood frequency, time of travel, and flow statistics, at user-defined sites on any stream.
- Harden critical gages to ensure data integrity during extreme or hazardous events.

Strategic Actions

- Quantify ground-water and surface-water interactions in response to extreme hydrologic events.
- With partners, develop real-time precipitation and flood-tracking networks on a local scale with a goal of expanding the network throughout the State.
- With partners, implement a real-time flood-inundation mapping program.
- Investigate methods to develop flood-frequency estimates for regulated streams.
- With partners, create a time-of-travel database and develop time-of-travel and dispersion equations for South Carolina streams for use in disaster response and water-supply protection.
- Field test new technology to detect waterborne contaminants and incorporate into the real-time network to assist in the protection of the State's water-supply intakes.
- With partners, develop a precipitation and stream-stage gaging-station network and use rainfall-runoff or neural-network modeling to provide information to expedite road closure during hazardous events.
- With partners, expand the urban streamflow gaging-station network to verify rainfall-runoff models, define urban flow characteristics, and provide the basis for robust hydrologic modeling.

District Needs for Implementation of Program Opportunities

Some of the data, information, and equipment needed to address most of the tactical and strategic actions listed above already exist within the District. However, the following steps will need to be taken to complete the actions:

- Train selected members of existing staff in the use of rainfall-runoff modeling tools.
- Increase the number of personnel who are proficient in GIS technology.

Relation of Program Opportunities to USGS and WRD Strategic Plans

The program opportunities and actions outlined above are compatible with priority issue 6, "hydrologic hazards," in the *Strategic Directions for the Water Resources Division, 1998–2008* (U.S. Geological Survey, 1999b). The document states that "Better understanding of hydrologic hazards, better warning systems, and better risk information can minimize the consequence of [hydrologic] hazards." In addition, these actions also support priority issue 1, "effects of urbanization and suburbanization on water resources," and issue 2, "effects of land use and population increases on water resources in the coastal zone."

Sustainable Water Resources in Piedmont and Coastal Environments

Background

South Carolina has always considered itself blessed with an abundance of available water resources. From colonial times, the economic growth of the State was dependent on water for transportation, irrigation, drinking water, and simple hydropower. As the State developed, the demand for water increased. With the rise of industrialization at the beginning of the 20th century, hydropower reservoirs were built on the major rivers to provide an adequate supply of water, produce electricity, and provide flood protection. By the end of the 20th century, concerns of water availability broadened from quantity to include quality. The Clean Water Act of 1972 established Federal and State regulations for drinking-water standards and water-quality standards for receiving streams.

As South Carolina enters the 21st century, the demands and stresses on the ground water and surface water are increasing tremendously. By the end of the recent 5-year (1998-2002) drought, the potential of a severe water shortage had become an immediate concern. Although the interaction of surface-water and ground-water is understood in the hydrologic cycle, the recent drought highlighted the ground-water and surface-water system as a whole and how this interaction changes during extreme events.

In South Carolina, surface water is estimated to be as little as 1 percent of the available freshwater by volume (Badr and others, 2004). However, the State relies on surface water for 70 percent and ground water for 30 percent of the combined domestic- and public-water supplies (Solley and others, 1998; South Carolina Department of Health and Environmental Control, 2003). In the 1980's, ground-water withdrawals were predominantly from Coastal Plain aquifers and equaled an estimated 200 million gallons per day (Mgal/d), in contrast to 15 Mgal/d from the Piedmont aquifer system (Stringfield, 1987). Since then, water-distribution lines from surface-water treatment facilities have expanded into more of the State's rural areas. In addition, ground-water supplies in several Coastal Plain communities were replaced or supplemented by new surface-water treatment facilities. Even with an increase in population from 1985 to 1995, the expansion of surface-water use resulted in a subtle decline in total ground-water withdrawals for domestic and public supplies to approximately 180 Mgal/d in 1995 (Solley and others, 1998). However, a projected growth in the State's population of more than 25 percent between 2000 and 2025 will further increase demand on the State's water-resources, particularly during drought years, and will require water-resource providers and planners to consider all water-resource options.

Throughout the 1980's and 1990's, the demand on ground-water resources in the Coastal Plain resulted in substantial water-level declines in areas with the greatest withdrawals, such as Aiken, Barnwell, Beaufort, Charleston, Dorchester, Florence, Georgetown, and Horry Counties. Ground-water withdrawals from the Floridan aquifer in Beaufort County, South Carolina, and in neighboring Chatham County, Georgia, also appeared to be the cause of saltwater encroachment, which threatens the long-term sustainability of freshwater resources in the aquifer. In response, the USGS worked with local and State cooperators to document the status and the sustainability of the State's ground-water resources through basic data collection and interpretive hydrologic investigations.

The coastal counties of South Carolina have experienced tremendous growth over the last 10 years. The beauty of the coast and its vast water resources has transformed a summer vacation destination to a year-long tourist industry. Retirement communities and related service industries also have increased along the coast. The large land-use changes and demographic pressures along the coast have the potential to stress the water resources of the region. The tourist and retirement industries are built on the extensive water resources of the coast, and it is imperative that the quality of these systems is maintained. Increased population along the coast has put greater demands on the municipal water supplies from surface- and ground-water sources and the treatment of wastewater and protection of receiving streams.

Surface-water quantity concerns increase during extreme events (floods and droughts). Of the four major river basins in the State, the Pee Dee, Santee, Ashepoo-Combahee-Edisto (ACE), and Savannah, only the ACE basin is essentially unregulated and contained within the State boundaries. The majority of the surface water in the State is stored in 12 manmade reservoirs that aid in flood control and increasing minimum flows (P.A. Contads, U.S. Geological Survey, written commun., April 2004). Many of these reservoirs will be relicensed by the Federal Energy Regulatory Commission

(FERC) in the next 5 to 8 years. The regulation of these reservoirs for surface-water supply presents some challenging questions for addressing sustainable water resources.

Water storage in these reservoirs was critical for maintaining water supplies during the recent drought and during droughts of the 1980's. The timing and the quantity of flow from the dams also can have a critical effect on sustaining downstream water resources for fisheries, aquatic habitat, navigation, and control of salinity intrusion along the coast. In the 1980's and 1990's, the District conducted hydrologic investigations of the effects of dam releases on striped bass fisheries on the Wateree and Congaree Rivers and the control of the salt front in the Cooper River. In addition, to determine the magnitude of extreme events, the District recently (2003) updated flood-frequency statistics through the 1999 water year.

The Clean Water Act established the regulation of point-source discharges to surface water and the determination of TMDLs for streams. The South Carolina District, in cooperation with local consortiums of municipal utilities and Councils of Government, applied dynamic-flow and water-quality models and artificial neural-network models to determine the assimilative capacities of many of the major rivers in the State. These models allow water-resource managers to assess various scenarios to determine the maximum allowable effluent discharge while maintaining the water-quality standard of the receiving stream.

Since the 1980's, the South Carolina District has conducted hydrologic investigations to interpret the hydrogeology and document water levels, water quality, and hydraulic properties of the major water-supply aquifers in the Coastal Plain. The basic data-collection effort and these hydrologic investigations supported the development of digital models to simulate ground-water flow for multicounty study areas in the Coastal Plain. Once calibrated, these models were used to test water-use scenarios concerning the sustainability of ground-water resources in the vicinity of Aiken, Barnwell, Charleston, Dorchester, Florence, and Beaufort Counties. Other investigations in the District assessed and modeled saltwater encroachment in Beaufort County and the feasibility of injecting potable water into aquifers for short- and long-term storage in Charleston County. Hydrologists from the South Carolina District have been working with hydrologists from the Georgia District on hydrogeologic and ground-water-modeling investigations of ground-water resources beneath counties along the Georgia-South Carolina border.

During the 1980's and 1990's, several smaller public and industrial water-supply systems in the Piedmont relied on ground water, particularly in rural areas; however, larger municipal and industrial water-supply systems in the Piedmont relied on surface water and progressively expanded their distribution systems to include developing rural areas. Since 1993, the South Carolina District, in cooperation with the SCDNR, has monitored water levels in several Piedmont wells, although local interest in ground-water data collection and hydrologic investigations of ground-water sustainability has been limited.

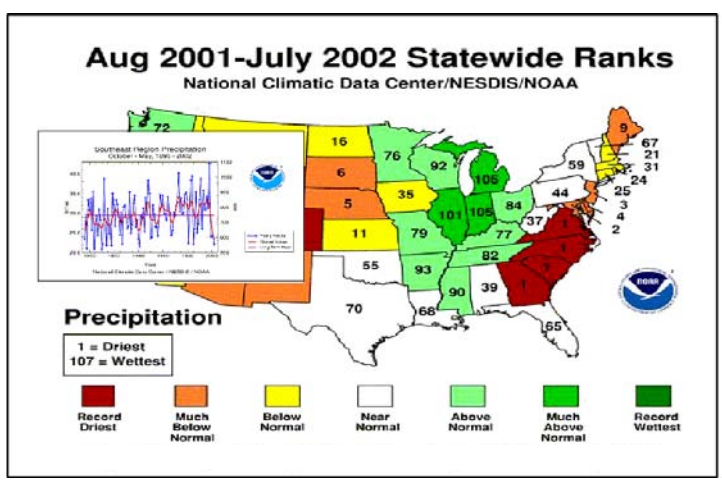
Two recent events have affected the District's efforts in basic data collection and hydrologic investigations. One is a hydrologic event—the 1998–2002 drought. The other is an economic event—State budget cuts since 2001.

From May 1998 through August 2002, drought conditions affected the Southeastern United States, including South Carolina. Statewide average precipitation was below normal for 39 of 51 months. Statewide declines in ground-water levels occurred throughout this period and resulted in reduced baseflow and record low-flow conditions in most of the State's streams. Two drinking-water supply facilities—the Georgetown County surface-water treatment facility on the Waccamaw River and a special-purpose ground-water facility in western Aiken County—were forced to restrict their withdrawals. The 1998–2002 drought also stimulated dialogue between local, State, and Federal water-resource managers and planners. As a result, operators of water-supply facilities across the State in the Coastal Plain and the Piedmont are reviewing current and future needs relative to the potential effects of drought on their resources and are more inclined to consider the conjunctive use of surface- and ground-water resources.

Since 2001, State budget cuts have greatly reduced the operating budgets of State agencies. The SCDNR, a long-time cooperator with the District on data collection and hydrologic investigations, has experienced a 33-percent cut in funding and may receive further cuts in State fiscal year 2005. With State budget cuts and the rising cost of maintaining real-time monitoring of water resources, the District has seen a subsequent decline in the number of USGS ground-water-level recorders supported by cooperative funding from the State.

Current Program

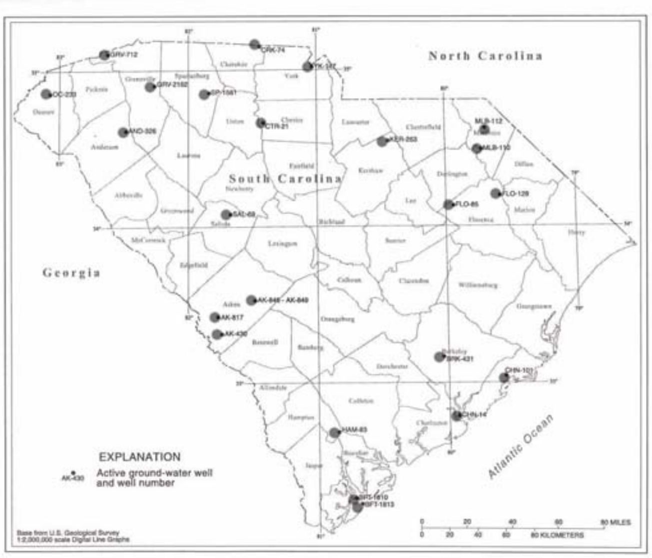
The USGS is actively involved in hydrologic investigations to document the sustainability and the availability of the State's ground-water resources. Basic data collection and hydrologic investigations are conducted with local and State cooperators and with other Federal agencies. Currently (2004), South Carolina District monitors 32 wells, which includes 20 wells for basic data collection and 12 wells for a hydrologic investigation. This limited number of



ground-water monitoring wells does not provide the level of surveillance needed to predict trends due to climatic change and the effects of pumping in the aquifers underlying South Carolina. Additional information on the basic data-collection network is given in the *Data Collection, Integration, and Analysis* Section.

Hydrologic investigations currently include a modeling investigation of the major water-supply aquifers of the entire South and North Carolina Coastal Plain. The South Carolina District also is assessing ground-water response in the alluvium of the Congaree National Park to modified "run-of-river" flow in the Congaree River. As part of the Savannah Harbor Expansion Project, the District is developing artificial neural-network models to simulate salinity and water-level responses in the tidal marshes of the Savannah Harbor to changing hydrologic conditions and alternative harbor configurations. The District continues to assist the SCDNR in investigating saltwater encroachment behind Hilton Head Island in Beaufort County and along the coastal border with Georgia.

Several ground-water investigations in the NAWQA Santee Study Unit have resulted in the development of a database for ground-water quality in select, major water-supply aquifers, including the Piedmont aquifer system. These data identify natural water-quality issues and issues of aquifer susceptibility to anthropogenic contaminants. Selected sites are scheduled for further sampling as part of the NAWQA water-quality trends network.



Program Opportunities

The mission of the USGS includes the collection and dissemination of water-resources data and interpretive results to the public and local, State, and Federal officials involved in managing and planning the use and protection of water resources. The South Carolina District is actively working with local, State, and Federal decisionmakers in the assessment of surface- and ground-water resources through basic data collection and interpretive hydrologic investigations of the State's water resources. The following program opportunities have been identified as tactical and strategic actions in which the District can continue to participate in the ongoing efforts to assess water sustainability and availability.

Tactical Actions

- Expand the District's ground-water-level monitoring network by identifying additional wells for intermittent water-level measurements, as opposed to adding more continuous-record monitoring wells, to create a low-cost representative well network for monitoring ground-water levels during climatic extremes.
- Coordinate ground-water database management with the SCDHEC and SCDNR to formalize the interagency exchange of ground-water information for use in program development and hydrologic investigations, and fund an appropriate amount of District time to maintain this data exchange.
- With partners, quantify recharge and evapotranspiration in the upper Coastal Plain aquifers, particularly along the Fall Line and in the unconfined aquifer systems, for use in water-availability studies.
- Use regional-scale models to develop more localized models.
- With partners, document the effects of the recent drought on ground-water levels, stream base flow, and the sustainability of the State's water resources. Re-compute low-flow statistics at gaging stations using data through the most recent drought.
- Continue to refine measurement and analytical approaches to determine daily, seasonal, and annual net streamflows for tidal systems.
- With partners, investigate the occurrence and sources of uranium, thorium, radium, and radon in Piedmont and Coastal Plain ground-water resources.
- With partners, identify wells and secure funding for two monitoring networks, each to include wells for continuous trend analysis and wells with monthly or quarterly data collection for expanded physiographic and hydrogeologic coverages. The two networks are a water-use and water-quality monitoring network, where applicable, and a climatic-events monitoring network.
- Improve communication between the USGS and State agencies in regard to data gathering and archiving; establish protocols to transfer and store (relational database) data in the District for program-development efforts and hydrologic investigations.
- Establish closer working relationship with other USGS disciplines for program development in Piedmont fractured-rock hydrology, ecohydrology, and subsidence.

Strategic Actions

- Use existing relational-database software to house and maintain water-use data acquired from the SCDHEC water-use database and formalize the procedures for updating the database.

- With partners, collaborate with the Geologic Discipline in the Bedrock Systematic Regional Aquifers Study (BRASS) program to investigate issues of ground-water availability, sustainability, and water quality in the Piedmont aquifer system.
- With partners, quantify the effects of ground-water quality on surface-water quality and ecology.
- Collaborate with the Biological Resources Discipline and other Federal and State agencies to develop an ecohydrologic investigation of the effects of ground-water use and quality on ecosystems.
- With partners, develop a subsidence-monitoring program in coastal communities where ground-water withdrawal or storage can alter the current elevation of land surface and explore the potential application of new techniques, such as interferometric synthetic aperture radar (InSAR), to coastal-zone subsidence issues.
- With partners, develop a monitoring program to obtain the necessary data to compute nutrient and other constituent loads from the major watersheds to the coastal waters.
- Establish closer collaborative relationships with NOAA and the Sea Grant Consortium to better fulfill agency missions.
- Assist Federal and State partners (U.S. Fish and Wildlife and SCDNR) in addressing the sustainability of the water resources downstream from reservoirs during the FERC re-licensing process.

District Needs for Implementation of Program Opportunities

Some of the data, information, and equipment needed to address most of the tactical and strategic actions listed above already exist in the District. However, the following action will need to be taken:

- Train District personnel in statistical analysis of hydrologic data and GIS.

Relation of Program Opportunities to USGS and WRD Strategic Plans

The program opportunities and actions outlined above are compatible with seven of the nine priority water-resource issues listed in the *Strategic Directions for the Water Resources Division, 1998–2008* (U.S. Geological Survey, 1999b), particularly issue 9, "hydrologic-system management, including optimization of ground-water and surface-water use." This priority issue emphasizes data collection, hydrologic investigations, and modeling of water resources to better quantify the effects of stress—natural or anthropogenic—on the availability and sustainability of water resources, and the application of data and investigative results to maintain water resources for the health and well being of the public and aquifer-life communities. Other issues directly related to surface- and ground-water use and availability include issue 3, "drinking water availability and quality;" issue 7, "effects of climate on water-resource management;" and issue 8, "surface-water and ground-water interactions as related to water-resource management." The relation of land use to surface- and ground-water quality and their potential influence on the health of aquatic life also connect this topic to issue 1, "effects of urbanization and suburbanization on water resources;" issue 2, "effects of land use and population increases on water resources in the coastal zone;" and issue 4, "suitability of aquatic habitat for biota."

Urban Effects on Human and Aquatic Health

Background

In South Carolina, urbanization is a relevant issue to water-quality management on state and local levels because of the increasing population and urban growth. The U.S. Department of Agriculture National Resource Inventory report indicates that 539,700 acres in South Carolina were converted from rural to urban and suburban land from 1992 to 1997 (London and Hill, 2000). This is a 30.2-percent increase in developed land, which ranks South Carolina 6th nationally in the percentage of farm and forest land converted to urban and suburban land use (Marsinko and Zawacki, 1999; Allen and Kang, 2000; London and Hill, 2000).

The State's population is predicted to increase more than 25 percent from 2000 to 2025 (South Carolina Budget and

Control Board, 2004b). The rapid development of land into residential, commercial, and industrial properties identifies urbanization as one of the top water-resource issues in South Carolina. Recent studies near the Charleston area corroborate other studies nationwide that indicate the growth rate of urban land use is accelerating at a greater pace than the population growth rate (Berkeley, Charleston, and Dorchester Council of Government, 1997; Allen and Kang, 2003). According to the 2000 census, the city of Columbia has a population of 116,278. However, the population for the two-county (Richland and Lexington) metropolitan statistical area of Columbia is reported to be 536,691 (U.S. Census Bureau, 2000). In June of 2003, the U.S. Census Bureau added four more counties to the metropolitan statistical area, making the population of record more reflective of the increasing growth in the Columbia area. The current (2002) metropolitan statistical area has an estimated population of 647,158, consisting of 320,677 in Richland, 216,014 in Lexington, 52,647 in Kershaw, 23,454 in Fairfield, 15,185 in Calhoun, and 19,181 in Saluda Counties.

Charlotte, North Carolina, which borders South Carolina to the north, is a rapidly expanding metropolitan area, and this rapid growth has spilled over into York and Lancaster Counties, South Carolina. An indication of potential future growth in the neighboring South Carolina counties is the anticipated population increase in Mecklenburg County, North Carolina, from 800,000 in 2004 to 1 million in 2010 (Charlotte Chamber of Commerce, 2003). This is of significance to South Carolina as a whole because the Charlotte metropolitan area covers a substantial portion of the headwaters of the Catawba-Santee River basin, and increased urbanization in the Charlotte area can affect the quantity and quality of natural resources in South Carolina.

As urban land use increases in a watershed, many anthropogenic changes affect the hydrological, ecological, and water-quality conditions of the receiving water. One example of the effects of increased urbanization is increased water movement through the hydrologic system as a result of increased impervious surfaces, construction of stormwater drainage systems, and channelization of streams. The hydrologic system of a watershed is affected by these changes by increased runoff from the land surface, quicker runoff response in streams, faster streamflows of shorter duration, and changes in flood characteristics. In addition, impervious surfaces can reduce ground-water recharge, resulting in lower base flows. Changes in flow and rapid fluctuations in water levels can significantly alter aquatic habitat, strand fishes, and expose the eggs of aquatic organisms. Reduced base flow can interfere with breeding cycles of aquatic biota (Finkenbine and others, 2000). Modification of watershed characteristics and hydrology can result in increased loadings of contaminants, such as pesticides, metals, and sediments. Such contaminants can adversely affect fish and macroinvertebrate communities (Richards and Host, 1994; Booth and Jackson, 1997; Finkenbine and others, 2000; Wang and others, 2000; Walsh and others, 2001).

Urbanization can affect water-quality conditions in ground- and surface-water systems. However, most research to date has focused on the degradation of water-quality conditions in the surface-water system, generally related to storm runoff. These degraded water-quality conditions often translate to degraded ecosystem health. Construction activities and increased runoff associated with urbanization also tend to increase the delivery of sediment to streams and lakes in urban areas. A majority of aquatic invertebrates live in close association with the sediment in streams and impoundments. Excessive sedimentation causes sediment to fill the interstitial spaces in the streambed where many aquatic organisms reside, killing off the less tolerant organisms, and limiting the degraded habitat to more tolerant organisms.

Ultimately, sedimentation can result in a decrease in diversity of the aquatic community.

Aging infrastructure, illicit connections on municipal sewer lines, poorly functioning septic systems, and animal wastes are just a few potential urban processes contributing to elevated concentrations of fecal coliform bacteria (indicator bacteria that signal the presence of disease-causing organisms, or pathogens). The presence of pathogens in the water is the most common human-health risk associated with water quality. Levels of indicator bacteria, such as fecal coliform and *Escherichia coli*, are used to determine the safety of water for swimming, fishing, and shellfish harvesting. Elevated indicator bacteria in water can result in closures of recreational beaches and shellfish beds, which can have significant economic effects locally and statewide. The SCDHEC has reported that about 60 percent of the impaired surface-water in South Carolina is a result of elevated fecal coliform concentrations.

Toxic contaminants, both organic and inorganic, can have detrimental effects on water quality and biological communities. Toxic contaminants commonly are associated with commercial and industrial activities in urban areas; however, recent findings from studies as part of the USGS NAWQA program indicate that residential development can be a source of these contaminants, especially pesticides. More persistent contaminants tend to adsorb to sediment particles that are deposited in streambed sediments. Metals, organochlorine insecticides, and polycyclic aromatic hydrocarbons (fuel by-products) are examples of these contaminants (Horowitz, 1985; Boudou and

Ribeyre, 1989). Benthic biota exposed to accumulated contaminants in sediments can transfer potentially toxic contaminants through the food chain to organisms in higher trophic levels. Exposure to these pollutants can cause chronic and acute toxic effects.

In summary, stream degradation in urbanized watersheds is widely documented (Leopold, 1968; Hammer, 1972; Hollis, 1975; Dunne and Leopold, 1978; Klein, 1979; Driver and Tasker, 1990; Booth, 1991; Booth and Reinelt, 1993; Schueler, 1994; Booth and Jackson, 1997; Novotny and others, 2000; Couch and Hamilton, 2002; U.S. Environmental Protection Agency, 2003); however, better understanding is needed of how and what anthropogenically driven stressors and processes degrade streams. Comprehensive scientific research that produces reliable information is needed to focus on the areas of South Carolina experiencing rapid changes in urban land use. State and local water managers must have a better understanding of the effects of urbanization on the overall quality of the hydrologic systems they manage. Innovative tools, such as models that provide simulations of the effects of potential land-use changes on water and interactive Websites that display water-quality and ecological findings, would be highly useful products of this research.

A multidisciplinary monitoring strategy that includes ground-water and surface-water interaction, stream hydrology, water quality (as related to chemistry and contaminants), and aquatic community structure provides the scientific data that are needed to assess the health of urban streams and to evaluate the effectiveness of the restoration or BMP projects. Expanding this monitoring strategy to regional applications would allow the USGS to evaluate the susceptibility of stream ecosystems to urbanization as functions of both the type of anthropogenic stressors present in the watershed and the natural environmental setting of the stream. Ideally, the design of monitoring networks in urban systems would reflect a gradient of urban intensity and, when implementation of restoration activities are proposed, include pre-construction, construction, and post-construction phases. This monitoring design would include ground-water and atmospheric contributions of contaminants and contaminant transformations at the ground-water and surface-water interface.

Water-quality managers in South Carolina will continue to be tasked by State and Federal regulatory agencies to invest additional resources to mitigate or restore beneficial uses to streams affected by urban land uses and to protect streams that are susceptible to future urban development. Mitigation and restoration measures can be achieved by implementing efficient water-management strategies. Protective measures can be achieved by establishing long-term management plans. To ensure the best results from investments of time and public funds, more comprehensive, high quality, scientific information will be required to enhance the understanding of the ecological and water-quality effects of urbanization and to evaluate the efficiency of restoration and protection strategies.

Current Program

Currently, the District water-quality and basic data programs address the effects of restoration and remediation in urban areas of South Carolina. These programs include

- Collection of basic data for use in monitoring current streamflow and water-quality conditions across a range of urban intensities
- Characterization of water-quality and aquatic ecosystem conditions in an urban stream (Gills Creek) that drains Columbia, South Carolina, as part of the USGS NAWQA program
- Collection of water-quality and streamflow data for municipalities in and around the Charleston area to support such programs as the National Pollutant Discharge Elimination System (NPDES)
- Determination of pre-development water-quality and flow characteristics in creeks and rivers in and around Bluffton, a small coastal community near Hilton Head, South Carolina.
- Determination of flood-frequency characteristics for urban basins
- Evaluation of the performance of four BMPs for highway runoff. Data from this investigation will provide the SCDOT with quantitative water-quality data to evaluate the effectiveness of these BMPs for enhancing the quality of stormwater runoff from roadways and rest areas.
- Investigation of the fate of gasoline compounds, fuel oxygenates, and chlorinated solvents at the ground-water and surface-water interface in streams and lakes that receive discharges of contaminated ground water.
- Investigation of the fate of emerging contaminants specifically associated with urbanization, such as human hormones, endocrine disrupters, and so on.
- Determination of the use of readily measurable water-quality parameters as surrogates to estimate the loads of fecal bacteria to recreational waters

Program Opportunities

The following program opportunities have been identified as ways in which the South Carolina District can address restoration and remediation issues:

Tactical Actions

- Restore urban streamwater quality and flow hydraulics
    - Collaborate with partners who are involved in the planning and implementation of urban restoration projects to develop and implement a consistent, multidisciplinary monitoring strategy for the evaluation of the effectiveness of the restoration effort.
    - With partners, apply integrated surface-water and water-quality modeling techniques to urban stream systems to provide better quantification of the effects of

urbanization on water-quality conditions.

    - With partners, investigate occurrence and temporal changes in concentrations of emerging contaminants in urban streams (wastewater indicators, pharmaceuticals, and personal-care products).
    - With partners, use DNA-based technology to identify sources of water-resources contamination by bacteria and pathogens to better understand their fate.
    - Expand the ongoing, long-term, multidisciplinary monitoring of trends at Gills Creek in Columbia to encompass the needs of State and local agencies in the Columbia area.
- Document the effects of urban development on the aquatic community structure, such as population, diversity, and recruitment
    - With partners, target three geographically and geologically distinct, rapidly developing urban areas in South Carolina (such as, Greenville—Piedmont; Columbia—Upper Coastal Plain, and Charleston—Lower Coastal Plain, tidal) and develop urban gradient studies following the approaches of the NAWQA program and the SCDHEC Bio-assessment program.
    - With partners, develop tools, such as models and indices, to predict the effects of urbanization on habitat.
- Investigate the effects of sediments on water-quality and aquatic community structure, such as population, diversity, and recruitment
    - With partners, investigate links between sediment contamination and aquatic community structure.
    - With partners, expand urban water-quality programs to include reconstructed water-quality trends based on the sediment chemistry of reservoirs.
    - Collaborate with the USGS Biological Resources Discipline in evaluating sublethal effects of sediment-bound contaminants on aquatic organisms.

Strategic Actions

- With partners, develop innovative approaches to integrated atmospheric, ground-water, surface-water, and water-quality modeling techniques that provide a comprehensive quantification of the effects of urbanization on water-quality conditions.
- Identify opportunities to collaborate with the USGS Biological Resources Discipline in the area of aquatic habitat restoration and community structure monitoring.
- Expand ongoing aquatic habitat monitoring by collaborating with other disciplines to apply remote sensing techniques (including hyperspectral imaging) in the evaluation of changes in aquatic habitats from urbanization.
- With partners, develop a statewide sediment-monitoring network that includes representative urban sites to determine current quantity and quality, historical changes in quantity and quality, measurement by surrogate parameter (for example, turbidity), and linkage to topographic and geomorphic conditions.
- Participate collaboratively with interested agencies in areas targeted for dam removal and stream restoration efforts to evaluate water-quality, aquatic community, and sediment-quality conditions prior to, during, and after these activities.
- With partners, develop regionally applicable techniques to characterize the hydraulic and ecological effects of channel modifications.
- With partners, expand ongoing or target new monitoring in areas experiencing rapid coastal growth to evaluate the effects of urbanization on commercial fisheries in freshwater and saltwater environments.

District Needs for Implementation of Program Opportunities

Some of the data, information, and equipment needed to address most of the tactical and strategic actions listed above already exist within the District. However, the following steps will need to be taken to complete these actions:

- Increase the number of District personnel proficient in ArcView GIS data analysis.
- Develop and enhance District expertise in hydrologic and water-quality models, such as SPARROW, AGNPS, or BASINS.
- Increase the number of District personnel who are expert in USGS protocols for water-quality sampling.
- Increase the number of District personnel who are proficient in hydrologic surface-water modeling.

Relation of Program Opportunities to USGS and WRD Strategic Plans

Evaluation of the effects of urban development on human and aquatic health addresses several priority water-resource issues in the *Strategic Directions for the Water Resources Division 1998–2008* (U.S. Geological Survey, 1999b). Specifically, this topic aligns itself with the following priority issues:

- **Issue 1.** Effects of urbanization and suburbanization on water resources
- **Issue 2.** Effects of land use and population increases on water resources in the coastal zone
- **Issue 4.** Suitability of aquatic habitat for biota
- **Issue 5.** Waste isolation and remediation of contaminated environments

This topic also addresses other important USGS focus issues, including (1) providing more qualitative understanding of the sources of chemicals entering the stream, including atmospheric deposition; (2) determining the effects of land-use practices on surface- and ground-water quality; and (3) understanding the relation between water quality and the health of stream ecosystems.

Applied Ecosystem Research

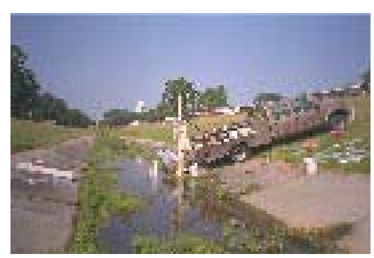
Background

Ecosystem research focuses on the dynamic interactions among living organisms (plants, animals, and microorganisms) and the physical and chemical factors (climate, soils, topography, salinity) in a watershed. Applied ecosystem research provides a comprehensive approach to water-resource management by integrating and addressing a broader range of resource and environmental protection issues and by more thoroughly evaluating important linkages between land and water, surface water and its aquatic biota, surface and ground water, and water quality and quantity. Research areas commonly addressed by this approach include biogeochemical cycles, interactions in terrestrial and aquatic systems, and effects of land use on hydrological, chemical, and biological processes in ground and surface water.

Hydrologic characteristics that make South Carolina so conducive to storing and transmitting surface- and ground-water supplies are also the same characteristics that attract the types of development that have led to some form of degradation of water quality and quantity. Contamination of water supplies in South Carolina, in general, is not a recent phenomenon. For example, the growth of Charles Town, known today as Charleston, in the early 18th century was slowed by the degradation of shallow ground-water supplies by human sewage, which made ground water unfit for use as a source of drinking water. More recently, however, the rapid growth of permanent and temporary populations in South Carolina, especially since the 1960's, has caused increased demand on available water for municipal drinking-water supply and for industrial effluent dilution. This juncture between population density and contaminant sources has essentially resulted in a higher probability of water-quality degradation directly affecting people. Even today, some 200 years after the Charles Town experience, bacterial contamination of surface- and ground-water systems occurs from human, animal, point, and nonpoint sources.

The beneficial hydrological characteristics of South Carolina that provide relatively easy access to surface and ground water also have resulted in the potential contamination of both sources. Contaminants released into streams in the high-gradient part of the State can be transported easily great distances to downstream receptors where aquatic biota may be affected. This scenario is exacerbated when rapid development results in increased impermeable surfaces, and contaminants are not attenuated by percolation through soils or wetlands before they reach surface-water resources. The same rapid transport of contaminants can occur in ground-water systems because of the porous nature of the sandy aquifers, which may allow extensive contaminant transport to down-gradient areas.

Fortunately, naturally occurring processes act to eliminate or reduce the level of contamination of both surface- and ground-water supplies in South Carolina. For example, rivers that receive allocated amounts of pollutants can, up to a point, assimilate these pollutants and still maintain water-quality levels suitable to support biological processes for alternative uses. This assimilative capacity is derived from nonbiological components, such as dilution with cleaner water, and biological components, such as microbial and plant biodegradation of pollutants. In ground-water systems, the same assimilative capacity exists, although in most contaminated aquifer systems, the effect of microbial and plant processes can play a greater role in contaminant destruction.



Places where ground water discharges to surface water are characterized by high microbial biomass and multiple redox zones, which can combine to degrade contaminants in ground water before the surface-water bodies are affected. These processes, however, represent a sink for contaminants released to aquifers in South Carolina. A potential action would be to investigate areas of the State known to have contaminated ground-water discharge to surface-water bodies.

Acceptance by regulators and the scientific community of the use of plants to clean-up contaminated surface- and ground-water systems has outpaced its scientific foundation. Around the country, and at some sites in South Carolina, trees and shrubs are being planted with no regard for how to monitor these systems to determine if they help reach remediation goals of clean up or hydraulic control. Additional work is needed at additional sites; because of South Carolina’s semitropical climate, the State is poised to be the host of research sites that could be designed specifically to address the current lack of monitoring data. Partnering with the USEPA could help achieve this goal and make the results immediately transferable to the development of a protocol for site monitoring.

In general, BMPs are used to contain or control degradation of a particular water body. For example, if sediment loading is identified as a factor in reduced surface-water quality or use, a BMP could be to install a buffer of plants along the banks of the affected water body to reduce the amount of sediment that enters the water. This type of BMP typically is referred to as a riparian buffer and is used widely along the East Coast. However, the question remains of whether such riparian buffers work in the hydrogeologic setting of South Carolina. Although installation of a riparian buffer may result in a reduction of sediment deposition in a particular river, the same buffer also may reduce the amount of water that is discharged to the river, rendering it harder to achieve other water-quality criteria, such as $7Q_{10}$ flows. A potential action is to evaluate the positive and negative effects of such a BMP on several rivers in South Carolina.

Tourism generates more than $15 billion per year in South Carolina, with the majority of tourists' dollars being spent along the coast. This area also has been characterized by numerous beach closures as a result of levels of enteric bacteria above regulatory limits. Although the low-lying areas along the coast are not appropriate for septic systems and municipal sewer systems predominate, the sources of these bacteria are not well understood. In addition, recent USGS studies have identified various chemicals in surface water that are related to humans. Although such studies reveal the recent advances in analytical techniques that make it possible to detect concentrations in the parts-per-trillion range, they also indicate that certain chemicals can be used to identify whether a contaminant event is a result of a manmade release or an alternative source. A potential action could be to use DNA-based methods to identify potential sources of bacteria and combine DNA-based methods with analyses for wastewater indicators and pharmaceuticals to assist in the determination of the source(s) of bacterial contamination of recreational waters along the coast. Moreover, such combined studies also could be used to investigate the source(s) of bacterial contamination common in shallow ground-water systems often used for residential supply. If the sources of bacteria can be identified, then possible solutions to remediate these sources can be developed.

South Carolina has a large number of impoundments and slow-moving rivers—two types of water bodies that tend to accumulate sediments. In some cases, the sediments that enter such water bodies are either previously contaminated or become contaminated after deposition due to releases. Contaminants are deposited in layers at the bottom of lakes and streams, and sufficient oxygen to destroy the contaminants often is not available. As such, sediment-bound contaminants can act as long-term sources of contamination, which may restrict the future uses of such water bodies. Current examples of contaminated-sediment issues can be found at harbor sites along the coast (Charleston and a proposed site in Jasper County), which are undergoing permit applications for existing and new construction. A possible action is to team with the U.S. Army Corps of Engineers and the South Carolina Ports Authority to develop investigations to determine the fate of contaminated sediments in harbor areas.

As might be expected, South Carolina is characterized by areas of interaction between surface-water resources and ground-water supplies. These interfaces between surface water and ground water, such as wetlands and swamps, often support lush vegetation, which results in waters characterized by high amounts of organic acids, acidic pH, and the accumulation of organic debris. Mercury levels are known to be high in many surface-water bodies throughout South Carolina, but the source of these high levels is currently unknown. For example, the mercury may be from atmospheric deposition associated with the combustion of coal-fired power plants, from point-source discharges associated with industrial activities, from the naturally occurring lithology, or a combination. An additional concern is that the surface waters of South Carolina provide the correct environment for mercury to become highly toxic through microbiological methylation. Currently, the factors that control this extensive mercury methylation can only be hypothesized. It is clear, therefore, that a potential action to help unravel the mercury problem in South Carolina would be to investigate the sources and rates of methylation in representative surface-water systems. A recent study by the USGS NAWQA in such areas detected some of the highest efficiencies of mercury methylation (the most toxic form of mercury) in the country (Krabbenhoft and others, 1999).

The above short paragraphs indicate the types of contaminants that occur in South Carolina that may pose a risk to various ecosystems. This brief background also illustrates that a more complete understanding is needed of the causes of contamination and the various types of transport through the hydrologic cycle. Applied research into these ecosystem-driven problems hopefully will lead to solutions to reduce their negative effects on the ecosystems involved. Water managers that are tasked with the need to sustain economic and cultural benefits of water resources while preserving ecological integrity will benefit from this type of ecosystem-based research.

Current Program

A wide range of applied ecosystem research investigations are currently underway in the South Carolina District. These investigations are being led by four USGS Research Grade Evaluation hydrologists who work both independently and collaboratively to address such applied research topics as the following:

- Fate of gasoline containing various fuel oxygenates following release to ground-water systems
- Effects of engineered approaches (biostimulation/bioaugmentation) on ground water contaminated by petroleum hydrocarbon and chlorinated solvents
- Effects of engineered phytoattenuation, or the specific use of ground-water loving plants, to remediate contaminated ground-water systems through hydraulic control or contaminant degradation
- Use of readily measurable water-quality parameters as surrogates to estimate the loads of fecal bacteria to recreational waters
- Extent of saltwater leakage from the Atlantic Ocean into the Upper Floridan aquifer through confining-bed material
- Fate of gasoline compounds, fuel oxygenates, and chlorinated solvents in the ground-water and surface-water interface at streams and lakes that receive discharge of contaminated ground water
- Fate of arsenic under a variety of microbially mediated reactions in surface and ground water
- Methods of estimating remediation times of plumes of various ground-water contaminants, based on assimilative capacity and the rate of source-area dissolution
- Fate of various chlorinated ethenes in ground-water and surface-water ecosystems
- Fate of organometallics in ground water at gasoline spills and in riverine environments where surficial releases of organotin have occurred
- Fate of chlorinated solvents upon discharge to wetlands
- Fate of chlorinated solvents using engineered remediation, such as zero-valent iron
- Application of novel technologies for monitoring ground-water contamination
- Fate of chlorinated benzenes in ground water, under natural and engineered remediation systems

Program Opportunities

There is no shortage of environmental issues related to ecosystem interactions between surface and ground water in South Carolina. Although the identification of such current or future problems is a major goal of program development in South Carolina, it would follow that a greater chance of success would exist if solutions for these identified problems also could be offered. As such, the list below contains ways in which current and new research into applied ecosystem problems can be used to identify successful program opportunities:

Tactical Actions

- With partners, investigate potential DNA-based approaches for identifying sources of bacteria and pathogens in fecal-contaminated waters
- With partners, develop a quality-assured approach to using wastewater indicators, pharmaceutical compounds, and endocrine disrupters to understand the sources and fate of effluents
- Develop a regional monitoring strategy that applies an ecosystem-based approach for evaluating the contaminant-reduction efficiency of implemented BMPs in collaboration with Federal (USDA-NRCS, USEPA, NOAA), State (SCDHEC, SCDNR, SCDOT), and local (County Conservation Districts, City or County Storm Water Management) agencies
- With partners, develop a regionally applicable monitoring strategy for the application of phytoattenuation processes to restore impacted sites
- With partners, develop a regionally applicable ecosystem-based approach at evaluating the fate of mercury in surface-water bodies in South Carolina

Strategic Actions

- With partners, evaluate the sources, fates, and biological effects of contaminated sediments in ecologically sensitive areas
- With partners, expand on the real-time data-collection network to develop a statewide network of long-term stations that provide timely,

reliable, comprehensive, ecologically based data

- With partners, identify sites and investigate the fate of ground-water contaminants at ground-water and surface-water interfaces

District Needs for Implementation of Program Opportunities

Some of the data, information, and equipment needed to address most of the tactical and strategic actions listed above already exist within the District. Additional personnel will be needed only if several of the above investigations were to be funded. If water-quality data collection were added at all streamflow-gaging sites, additional training of technicians for water-quality data interpretation will be required.

Relation of Program Opportunities to USGS and WRD Strategic Plans

Program opportunities regarding the effects of human activities on surface- and ground-water resources in South Carolina are compatible with several of the water-resources issues in the *Strategic Directions for the Water Resources Division, 1998–2008* (U.S. Geological Survey, 1999b):

- **Issue 1.** Effects of urbanization and suburbanization on water resources
- **Issue 2.** Effects of land use and population increases on water resources in the coastal zone
- **Issue 5.** Waste isolation and remediation of contaminated environments
- **Issue 8.** Surface-water and ground-water interactions related to water-resources management

Selected References

Allen, J.S., and Kang, S.L., 2000, Cultivated agricultural lands at risk from potential urbanization in the Tri-County area: Clemson, SC, South Carolina Water Resources Center and Strom Thurmond Institute, Clemson University, July 2000, accessed May 7, 2004, at http://www.strom.clemson.edu/teams/water_resources/ag-at-risk.pdf

Allen, J.S., and Kang, S.L., 2003, Modeling and prediction of future urban growth in the Charleston region of South Carolina: A GIS-based integrated approach: Conservation Ecology, v. 8(2), accessed March 2, 2004, at http://www.ecologyandsociety.org/vol8/iss2/art2/main.html

Aucott, W.R., 1988, The predevelopment ground-water flow system and hydrologic characteristics of the Coastal Plain aquifers of South Carolina: U.S. Geological Survey Water-Resources Investigations Report 86–4347, 66 p., 14 pls.

Aucott, W.R., and Speiran, G.K., 1985, Potentiometric surfaces of November 1982 and declines in the potentiometric surfaces between the period prior to development and November 1982 for the Coastal Plain aquifers of South Carolina: U.S. Geological Survey Water-Resources Investigations Report 84–4215, 7 map sheets.

Badr, A.W., Wachob, Andrew, and Gellici, J.S., 2004, South Carolina water plan, second edition: South Carolina Department of Natural Resources, 120 p.

Baldwin, W., Morton, R.A., Denny, J.F., Dadisman, S.V., Schwab, W.C., Gayes, P.T., and Driscoll, N.W., 2004, Maps showing the stratigraphic framework of South Carolina's Long Bay to Winyah Bay: U.S. Geological Survey Open-File Report 2004–1013, accessed March 16, 2004, at http://pubs.usgs.gov/of/2004/1013/summary.html

Barker, R.A., 1986, Preliminary results of a steady-state model of the southeastern Coastal Plain aquifer system, *in* Southern Regional Ground Water Conference proceedings, San Antonio, TX, 1985: National Water Well Association, Association of Groundwater Scientists and Engineers, p. 315–338.

Berkeley-Charleston-Dorchester Council of Governments, 1997, Twenty year time series analysis of satellite remote sensor data for environmental and developmental change along Coastal Georgia and South Carolina: accessed May 2004 at http://www.bcdcog.com/NASA_cd/htm/coverpg.htm

Booth, D., 1991, Urbanization and the natural drainage system—Impacts, solutions, and prognoses: Northwest Environmental Journal, 7(1), p. 93–118.

Booth, D.B., and Jackson, C.R., 1997, Urbanization of aquatic systems: Degradation thresholds, stormwater detection, and the limits of mitigation: Journal of the American Waterworks Research Association, v. 33, no. 5, p. 1077–1090.

Booth, D., and Reinelt, L., 1993, Consequences of urbanization on aquatic systems—Measured effects, degradation thresholds, and corrective strategies, *in* Proceedings of the Watersheds '93 Conference, March 21–24, 1993, Alexandria, VA: Washington, D.C., U.S. Government Printing Office, p. 545–550.

Boudou, A., and Ribeyre, F., 1989, Aquatic ecotoxicology: Fundamental concepts and methodologies, v. 1: Boca Raton, FL, CRC Press, 332 p.

Brown, K.B., 2000, Urban stream restoration practices: An initial assessment: Elliot City, MD, The Center for Watershed Protection, accessed March 19, 2004, at http://www.cwp.org/site_map.htm

Campbell, B.G., and van Heeswijk, Marijke, 1996, Documentation of model input and output values for the simulation of the ground-water flow system in the Cretaceous-age Coastal Plain aquifers of South Carolina: U.S. Geological Survey Open-File Report 96–212, 2 p., 1 CD.

Charleston Naval Weapons Station, accessed May 20, 2004, at http://www.pcscharlestonnws.com/dspbasemain.cfm

Charlotte Chamber of Commerce, 2003, 2003 population estimates & projections: accessed April 2004 at http://www.charlottechamber.com/content.cfm?category_level_id=134&content_id=186

Cherry, R.N., and Badr, A.W., 1998, South Carolina water plan: South Carolina Department of Natural Resources, 62 p.

Cooney, T.W., 2001, Surface-water quality-assurance plan for the South Carolina District of the U.S. Geological Survey: U.S. Geological Survey Open-File Report 01–121, 48 p., accessed March 16, 2004, at http://sc.water.usgs.gov/publications/pdfs/OFR-01-121-QW.pdf

Conrads, P.A., and Roehl, E.A., 1999, Comparing physics-based and neural network models for simulating salinity, water temperature, and dissolved oxygen in a complex, tidally affected river basin, *in* South Carolina Environmental Conference proceedings, Myrtle Beach, March 15–16, 1999: 6 p.

Conrads, P.A., Roehl, E.A., and Cook, J.B., 2002, Estimation of tidal marsh loading effects in a complex estuary, *in* 2002 AWRA Spring Specialty Conference on Coastal Water Resources proceedings, New Orleans, LA, May 2002: American Water Resources Association, 6 p.

Conrads, P.A., Roehl, E.A., Jr., and Martello, W. P., 2002, Estimating point-source impacts on the Beaufort River using artificial neural network models, *in* 2002 AWRA Spring Specialty Conference on Coastal Water Resources proceedings, New Orleans, LA, May 2002: American Water Resources Association, 6 p.

Conrads, P.A., Roehl, E.A., and Martello, W.P., 2003, Development of an empirical model of a complex, tidally affected river using artificial neural networks, *in* National TMDL Science and Policy 2003 Specialty Conference proceedings, Chicago, IL, November 2003: Water Environment Federation, 30 p.

Couch, C.A., and Hamilton, P.A., 2002, Effects of urbanization on stream ecosystems: U.S. Geological Survey Fact Sheet 042–02, accessed March 2, 2004, at http:// water.usgs.gov/pubs/FS/fs04202

Daniel, C.C., III, and Sharpless, N.B., 1983, Ground-water supply potential and procedures for well-site selection, upper Cape Fear basins: North Carolina Department of Natural Resources and Community Development and U.S. Water Resources Council, Cape Fear River basin study, 1981–83, p. 15.

Davis, R.E., and Gay, D.A, 1993, Freezing rain and sleet climatology of the southeastern U.S.A.: Columbia, SC, Southeast Regional Climate Center Research Paper #052593.

Driver, N.E., and Tasker, G.D., 1990, Techniques for estimation of storm-runoff loads, volumes, and selected constituent concentrations in urban watersheds in the United States: U.S. Geological Survey Water-Supply Paper 2363, 51 p.

Dunne, T., and Leopold, L.B., 1978, Water in environmental planning: New York, W.H. Freeman and Company, 818 p.

Finkenbine, J.K., Atwater, J.W., and Mavinic, D.S., 2000, Stream health after urbanization: Journal of the American Waterworks Research Association, v. 36, no. 5, p. 1149–1160.

Guttman, N., and Plantico, M., 1987, Drought history and chance of recurrence, *in* Sidlow, S.F., ed., Climate report G-30, Southeast Drought Symposium proceedings, March 4–5, 1987: Columbia, SC, South Carolina Department of Natural Resources (Formerly South Carolina Water Resources Commission), Water Resources Division.

Hammer, T.R., 1972, Stream and channel enlargement due to urbanization: Water Resources Research, v. 8, p. 1530–1540.

Hollis, G., 1975, The effects of urbanization on floods of different recurrence intervals: Water Resources Research, v. 11(3), p. 431–435.

Horowitz, A.J., 1985, A primer on sediment trace-element chemistry: Chelsea, MI, Lewis Publishers, 136 p.

Hurley, N.M., Jr., 1996, Assessment of scour-critical data collected at selected bridges and culverts in South Carolina, 1990–92: U.S. Geological Survey Open-File Report 96–350, 119 p.

Kindinger, J.L., Flocks, J.G., Harris, M.S., Gayes, P.T., Schwab, W.C., and Katuna, M.P., 1998, Quaternary stratigraphy and depositional history of the central South Carolina coast and inner shelf: Implications to coastal change: U.S. Geological Survey Center for Coastal Geology, accessed April 1, 2004, at http://coastal.er.usgs.gov/scerosion/quaternary/

Klein, R.D., 1979, Urbanization and stream quality impairment: Water Resources Bulletin, 15, p. 948–963.

Krabbenhoft, D.P., Wiener, J.G., Brumbaugh, J.G., Olson, W.G., DeWild, M.L., and Sabin, T.J., 1999, A national pilot study of mercury contamination of aquatic ecosystems along multiple gradients, *in* Morganwalp, D.W., and Buxton, H.T., eds., U.S. Geological Survey Toxic Substance Hydrology Program Conference, Charleston, S.C.: U.S. Geological Survey Water-Resources Investigations Report 99-4018-B, p. 147–160.

Kronberg, Nathan, and Purvis, J.C., 1959, Climates of the states: South Carolina, *in* Climatography of the states: Washington, D.C., U.S. Department of Commerce.

Leopold, L.B., 1968, The hydrologic effects of urban land use: Hydrology for urban land planning—A guidebook of the hydrologic effects of urban land use: U.S. Geological Survey Circular 554.

London, J.B., and Hill, N.L., 2000, Land conversion in South Carolina: State makes the top 10 list: Clemson, SC, Jim Self Center on the Future, Clemson University, February 2000, 6 p., accessed May 7, 2004, at http://www.strom.clemson.edu/publications/london/conversion.pdf

Marsinko, A., and Zawacki, W., 1999, Current status and changes in forest land use and ownership in South Carolina: Clemson, SC, Strom Thurmond Institute, Clemson University, 16 p., accessed May 7, 2004, at http://www.strom.clemson.edu/publications/sclanduse.pdf

May, C.W., Horner, R.R., Karr, J.R., Mar, B.W., and Welch, B.W., 1997, Effects of urbanization on small streams in the Puget Sound lowland ecoregion: Watershed Protection Techniques, v. 2, no. 4, p. 483–494.

Miller, J.A., 2000, Ground-water atlas of the United States, Segment 6, Alabama, Florida, Georgia, and South Carolina:

U.S. Geological Survey Hydrologic Investigation Atlas 730-G, 28 p.

Morton, R.A., 2003, An overview of coastal land loss, with emphasis on the southeastern United Sates: U.S. Geologic Survey Open-File Report 03–337, accessed March 16, 2004, at http://pubs.usgs.gov/of/2003/of03-337/index.html

National Park Service, 2003, Congaree National Park, South Carolina: accessed April 1, 2004, at http://www.nps.gov/cosw/index.htm

National Research Council, 1997, Water research in the U.S. Geological Survey: Washington, D.C., National Academy Press, 86 p.

National Research Council, 1999, Hydrologic science priorities for the U.S. Global Change Research program—An initial assessment: Washington, D.C., National Academy Press, 34 p.

National Research Council, 2001, Future roles and opportunities for the U.S. Geological Survey: Washington, D.C., National Academy Press, 179 p.

National Research Council, 2002, Estimating water use in the United States: A new paradigm for the National Water-Use Information program: Washington, D.C., National Academy Press, 158 p. + appen.

Novotony, V., Booth, D., Clark, D., Griffin, R., Giese, J., Bartosova, A., and O'Reilly, N., 2000, Reconciling flood and diffuse pollution control objectives in urban watershed management, *in* Proceedings of the 4th International Conference on Diffuse Pollution, IWQ, January 2000, Bangkok, Thailand: accessed March 2, 2004, at http://www.mu.edu/environment/THAI.pdf

Purvis, J.C., Tyler, W., and Sidlow, S.F., 1990, Climate report G-5: General characteristics of South Carolina's climate: Columbia, SC, South Carolina Department of Natural Resources (formerly South Carolina Water Resources Commission), Water Resources Division.

Richards, C., and Host, G., 1994, Examining land-use influences on stream habitats and macroinvertebrates: A GIS approach: Journal of the American Waterworks Research Association, v. 30, no. 5, p. 729–738.

Roehl, E.A., and Conrads, P.A., 1999, Real-time control for matching wastewater discharges to the assimilative capacity of a complex, tidally affected river basin, *in* South Carolina Environmental Conference proceedings, Myrtle Beach, March 15–16, 1999: 5 p.

Roehl, E.A., and Conrads, P.A., 2000, Real-time control of the salt front in a complex tidally affected river basin, *in* ANNIE 2000, American Society of Mechanical Engineers Conference, v. 10: New York, ASME Press, p. 947–954.

Schuck-Kolben, R.E., 1990, Storm-tide elevations produced by Hurricane Hugo along the South Carolina coast, September 21–22, 1990: U.S. Geological Survey Open-File Report 90–386, 45 p.

Schueler, R.L., 1994, The importance of imperviousness: Watershed Protection Techniques, v. 1, no. 3, p. 100–111.

Solley, W.B., Pierce, R.R., and Perlman, H.A., 1998, Estimated use of water in the United States in 1995: U.S. Geological Survey Circular 1200, 71 p.

South Carolina Budget and Control Board, Office of Research and Statistics, 2004a, Comparison of 1990 and 2000 population and percent change: accessed March 31, 2004, at http://www.ors2.state.sc.us/census2000/1990_2000_County_Compare.htm

South Carolina Budget and Control Board, Office of Research and Statistics, 2004b, South Carolina population reports: accessed March 31, 2004, at http://www.ors2.state.sc.us/population/pop2025/pop25c47.asp

South Carolina Budget and Control Board, Office of Research and Statistics, 2004c, South Carolina statistical abstract 2004: accessed May 28, 2004, at http://www.ors2.state.sc.us/abstract/index.asp

South Carolina Department Health and Environmental Control, 2004, Total maximum daily load (TMDL) program: accessed March 16, 2004, at http://www.scdhec.net/water/html/tmdl.html

South Carolina Department of Health and Environmental Control, Bureau of Water, 1999, SC nonpoint source management program: South Carolina Department of Health and Environmental Control, Bureau of Water, 1999 update, 175 p., accessed March 31, 2004, at http://www.scdhec.net/water/pubs/nps.pdf

South Carolina Department Health and Environmental Control, Bureau of Water, 2003, South Carolina water use report, 2001 summary: accessed March 18, 2004, at http://www.scdhec.net/eqc/water/pubs/wtruse2001.pdf

South Carolina Department of Health and Environmental Control, Bureau of Water, 2004, State of South Carolina monitoring strategy for calendar year 2004: South Carolina Department of Health and Environmental Control, Bureau of Water, Technical Report 001–04, 72 p., accessed March 31, 2004, at http://www.scdhec.net/eqc/water/pubs/strategy.pdf

South Carolina Department Health and Environmental Control, 2004, Water grants: accessed March 16, 2004, at http://www.scdhec.net/water/html/grants.html

South Carolina Department of Natural Resources, 1999, Flood hazard mitigation: A plan for South Carolina: accessed March 18, 2004, at http://www.dnr.state.sc.us/water/envaff/flood/img/floodhazardplan.pdf

South Carolina Department of Natural Resources, 2002, South Carolina flood map modernization initiative: accessed April 1, 2004, at http://www.dnr.state.sc.us/water/envaff/flood/mapping.html

South Carolina Department of Natural Resources, Division of Land, Water, and Conservation, 2002, State drought information center: accessed April 2004 at http://www.dnr.state.sc.us/climate/sco/drought.html

South Carolina Department of Natural Resources, South Carolina Geological Survey, 1997, Generalized geologic map of South Carolina: accessed March 16, 2004, at http://www.dnr.state.sc.us/geology/geologic.htm

South Carolina Department of Natural Resources, South Carolina State Climatology Office, 2003, General description of South Carolina's climate: accessed March 16, 2004, at http://www.dnr.state.sc.us/climate/sco/sc_climate.html

South Carolina Department of Parks, Recreation & Tourism, 2004, Official tourism Website of South Carolina: accessed March 16, 2004, at http://www.discoversouthcarolina.com/scfacts

South Carolina Employment Security Commission, 2002, 2001 year-end review: accessed March 16, 2004, at http://www.sces.org/lmi/data/trends/YearEnd_2001.htm

Stringfield, W.J., 1987, South Carolina water supply and use, *in* National Water Summary 1987: U.S. Geological Survey Water-Supply Paper 2350, p. 453–459.

Team South Carolina, 2003, Searchable data bases: accessed March 16, 2004, at http://www.teamsc.com/search_dat.html

Thieler, E.R., and Hammar-Klose, E.S., 1999, National assessment of coastal vulnerability to future sea-level rise: Preliminary results for the U.S. Atlantic Coast: U.S. Geological Survey, Open-File Report 99-593, 1 sheet: accessed March 16, 2004, at http://woodshole.er.usgs.gov/project-pages/cvi/index.html

U.S. Army, 2004, United States Army Training Center, Fort Jackson, South Carolina: accessed May 2004 at http://www.jackson.army.mil/

U.S. Census Bureau, 2000, Census 2000 data for the State of South Carolina: accessed March 16, 2004, at http://www.census.gov./census2000/states/sc.html

U.S. Department of Agriculture, 2003a, U.S. Forest Service, Francis Marion National Forest monitoring and evaluation annual report, fiscal year 2002: accessed April 1, 2004, at http://www.fs.fed.us/r8/fms/forest/publications/FM2002.pdf

U.S. Department of Agriculture, 2003b, U.S. Forest Service, Sumter National Forest monitoring and evaluation annual report, fiscal year 2002: accessed April 1, 2004, at http://www.fs.fed.us/r8/fms/forest/publications/Sumter02.pdf

U.S. Department of Commerce, 1992, Census of agriculture, 1:51 United States summary and state data: Washington, D.C., Bureau of the Census.

U.S. Department of Energy, 2002, Savannah River Site: accessed April 2004 at http://www.srs.gov/general/srs-home.html

U.S. Environmental Protection Agency, 2003, Urbanization and streams—Studies of hydrologic impacts: accessed March 2, 2004, at http://www.epa.gov/owow/nps/urbanize/report.html

U.S. Environmental Protection Agency, 2004, Land cleanup and wastes: accessed May 20, 2004, at http://www.epa.gov/region4/waste/npl/nplsc/savrivsc.htm

U.S. Fish and Wildlife Service, 2004, Southeast Region, South Carolina: accessed April 1, 2004, at http://southeast.fws.gov/maps/sc.html

U.S. Geological Survey, 1999a, South Carolina coastal erosion study: Center for Coastal Geology, accessed March 16, 2004, at http://coastal.er.usgs.gov/scerosion/index.html

U.S. Geological Survey, 1999b, Strategic directions for the Water Resources Division, 1998–2008: U.S. Geological Survey Open-File Report 99–249, 27 p., accessed March 16, 2004, at http://water.usgs.gov/pubs/of/ofr99-249/html/exec.html

U.S. Geological Survey, 2000, U.S. Geological Survey strategic plan 2000–2005: Reston, VA, 20 p.

U.S. Geological Survey, 2002, Eastern mineral resources: accessed March 16, 2004, at http://minerals.usgs.gov/minerals/pubs/state/2002/scstmyb02.pdf

U.S. Geological Survey, 2003a, BRD activities in South Carolina: USGS Biological Resources Discipline, accessed May 20, 2004, at http://biology.usgs.gov/state.partners/activities/sc-act.html

U.S. Geological Survey, 2003b, National land cover characterization: accessed May 6, 2004 at http://landcover.usgs.gov/natllandcover.asp

U.S. Geological Survey, 2004, Eastern Region science plan: accessed March 16, 2004, at http://internal.er.usgs.gov/docs/er_science_plan-ver8-01-20-04.doc

U.S. Geological Survey and South Carolina Geological survey, 2002, The mineral industry of South Carolina: Memorandum of Understanding, accessed April 2004 at http://minerals.usgs.gov/minerals/pubs/state/2002/scstmyb02.pdf

Walsh, C.J., Sharpe, A.K., Breen, P.F., and Sonneman, J.A., 2001, Effects of urbanization on streams of the Melbourne region, Victoria, Australia: I. Benthic macroinvertebrate communities: Freshwater Biology, v. 46, p. 535–551.

Wang, L., Lyons, J., Kanehl, P., Bunnerman, R., and Emmons, E., 2000, Watershed urbanization and changes in fish communities in southeastern Wisconsin streams: Journal of the American Waterworks Research Association, v. 36, no. 5, p. 1173–1189.

Weiss, S.M., and Indurkhya, N., 1998, Predictive data mining—A practical guide: San Francisco, CA, Morgan Kaufmann Publishers, Inc., p. 1.

Supplemental Data

Table 1. Priority science issues in South Carolina, 2004–2009

Table 2. Tactical and strategic actions needed for meeting priority science issues in South Carolina, 2004–2009

Table 3. Additional requirements needed for meeting priority science issues in South Carolina, 2004–2009

Table 1. Priority science issues in South Carolina, 2004–2009

Priority Issues	
1.	Data Collection, Integration, and Analysis
2.	Hydrologic and Hydraulic Hazards
3.	Sustainable Water Resources in Piedmont and Coastal Environments
4.	Urban Effects on Human and Aquatic Health
5.	Applied Ecosystem Research

Table 2. Tactical and strategic actions needed for meeting priority science issues in South Carolina, 2004–2009

Priority issue 1—Data collection, integration, and analysis	
Tactical actions	**Strategic actions**
1. Develop and maintain computer programs to expedite records computations and quality-assurance and quality-control processes so approved data can be posted on the Web prior to publication of the annual water-data report.	1. With partners, integrate data-collection networks to determine adequate coverage, eliminate redundancies, and secure funding for long-term gages.
2. With partners, explore potential to expand the types of data collected at gaging stations.	2. Investigate technology to allow field personnel to interact remotely with USGS databases to enhance data distribution.
3. With partners, implement StreamStats.	3. With partners, expand the current data-collection network to include a sediment-monitoring program.
4. Develop navigable Web pages with more user-friendly databases.	4. With partners, develop user-friendly database for water-use reporting.
5. Qualify real-time data with error bars.	5. With partners, develop real-time precipitation and flood-tracking network on a local scale with a goal of expanding the network throughout the State.
6. With partners, develop a long-term strategic data-collection plan for the State based on development regions.	6. With partners, implement a Web-based real-time flood-inundation mapping program.
7. Develop methodology to estimate long-term hydrographs for ungaged sites.	7. Investigate and pursue additional application of data mining to facilitate operational needs of the District's data-collection activities.
8. Work with other agencies to determine ways to maximize the use of USGS monitoring capabilities.	
9. Explore and develop innovative ways that USGS data can be used to manage the natural resources of South Carolina.	
10. Expand the ground-water network by collecting water levels from discontinued gaging stations during routine field trips.	
11. Test the prototype real-time data and advanced visualization computer application to assist in the monitoring of the salt front on the Cooper River.	
12. Develop internal relational database(s) to integrate District information on data-collection activities.	

Priority issue 2—Hydrologic and hydraulic hazards	
Tactical actions	**Strategic actions**
1. With partners, document recent drought by updating low-flow statistics and determining critical conditions.	1. Quantify groundwater and surface-water interactions in response to extreme hydrologic events.
2. With partners, and within the bridge scour program: • Increase understanding of hydraulics at bridges, • Develop regional-scale understanding of scour processes, • Expand well-developed data sets, • Develop less complex methods to estimate scour, and • Understand live-bed scour mechanisms at bridges.	2. With partners, develop real-time precipitation and flood-tracking networks on a local scale with a goal of expanding the network throughout the State.
3. Construct and test low-cost gages to document storm surge and salinity in coastal water bodies.	3. With partners, implement a real-time flood-inundation mapping program.
4. Determine runoff characteristics and responses at very small (acres) basins to refine regional regression equations.	4. Investigate methods to develop flood-frequency estimates for regulated streams.
5. During emergencies, assign USGS personnel to FEMA Disaster Field Offices as appropriate.	5. With partners, create a time-of-travel database and develop time-of-travel and dispersion equations for South Carolina streams.
6. Work with Federal, State, and local agencies to develop monitoring and early-detection plans to protect water supplies from biological and chemical terrorism.	6. Field test new technology to detect water-borne contaminants and incorporate with the real-time network.
7. Use District expertise in ground-water flow and contaminant-transport modeling to delineate protective zones for ground-water supplies.	7. With partners, develop a precipitation and stage gaging network and use rainfall-runoff or neural-network modeling to provide information to expedite road closure during hazardous events.
8. Conduct seminars to inform local officials of USGS data availability and potential uses.	8. With partners, expand the urban streamflow gaging network to verify rainfall-runoff models, define urban flow characteristics, and provide the basis for robust hydrologic modeling.
9. With partners, identify partners to help implement StreamStats.	
10. Harden critical gages to ensure data integrity during extreme or hazardous events.	

Priority issue 3—Sustainable water resources in Piedmont and Coastal environments	
Tactical actions	**Strategic actions**
1. Expand the District's ground-water-level monitoring network by identifying additional wells for intermittent water-level measurements.	1. Use existing relational-database software to house and maintain water-use data acquired from the SCDHEC water-use database and formalize the procedures for updating the database.
2. Coordinate ground-water database management with the SCDHEC and the SCDNR.	2. With partners, collaborate with the Geologic Discipline's Bedrock Systematic Regional Aquifers Study (BRASS) program to investigate issues of ground-water availability, sustainability, and water quality in the Piedmont aquifer system.
3. With partners, quantify recharge and evapotranspiration in the upper Coastal Plain aquifers for use in water-availability studies.	3. With partners, quantify the effects of ground-water quality on surface-water quality and ecology.
4. Use of regional-scale models to develop more localized models.	4. Collaborate with the Biological Resources Discipline and other Federal and State agencies to develop an ecohydrologic investigation of the effects of ground-water use and quality on ecosystems.
5. With partners, document the effects of the recent drought on ground-water levels, stream baseflow, and the sustainability of the State's water resources. Recompute low-flow statistics.	5. With partners, develop a subsidence-monitoring program in coastal communities where ground-water withdrawal or storage can alter the current elevation of land surface.
6. Continue to refine measurement and analytical approaches to determine daily, seasonal, and annual net streamflows for tidal systems.	6. With partners, develop a monitoring program to obtain the necessary data to compute nutrient and other constituent loads from major watersheds to coastal waters.
7. With partners, investigate the occurrence and sources of uranium, thorium, radium, and radon in the Piedmont and Coastal Plain ground-water resources.	7. Establish closer relations with NOAA and the Sea Grant Consortium.
8. With partners, identify wells and secure funding for a water-use and water-quality monitoring network, and a climatic-events network.	8. Assist our Federal and State partners (U.S. Fish and Wildlife and SCDNR) in addressing the sustainability of the water resources downstream from reservoirs during the FERC re-licensing process.
9. Improve communication between the USGS and State agencies regarding data gathering and archiving.	
10. Establish a closer working relationship wih other USGS disciplines for program development in Piedmont fractured rock hydrology, ecohydrology, and subsidence.	

Priority issue 4—Urban effects on human and aquatic health	
Tactical actions	**Strategic actions**
1. Collaborate with partners who are involved in the planning and implementation of urban restoration projects to develop and implement a consistent multidisciplinary monitoring strategy for evaluating the effectiveness of the restoration effort.	1. With partners, develop integrated tools that provide a more comprehensive quantification of the effects of urbanization on water-quality conditions in urban areas.
2. With partners, apply integrated surface-water and water-quality modeling techniques to urban stream systems to provide better quantification of the effects of urbanization on water-quality conditions.	2. Identify opportunities to collaborate with the USGS Biological Resources Discipline in the areas of aquatic habitat restoration and community structure monitoring.
3. With partners, investigate occurrence and temporal changes in concentrations of emerging contaminants in urban streams.	3. Expand ongoing aquatic habitat monitoring by collaborating with other disciplines to apply remote sensing techniques.
4. With partners, use DNA-based technology to identify sources of bacteria and pathogens in contaminated water resources and understand their fate.	4. With partners, develop a statewide, long-term sediment-monitoring network.
5. With partners, expand the ongoing long-term multidisciplinary monitoring of trends at Gills Creek in Columbia.	5. With partners, evaluate water-, aquatic community, and sediment-quality conditions prior to, during, and after dam removal and stream restoration efforts.
6. With partners, target three geographically and geologically distinct urban areas in South Carolina and develop urban gradient studies to document effects of urbanization on aquatic communities.	6. With partners, develop techniques to characterize the hydraulic and ecological effects of channel modifications.
7. With partners, develop tools to predict the effects of urbanization on habitat.	7. With partners, expand ongoing or target new monitoring that provides pertinent data to evaluate the effects of urban sprawl on commercial fisheries in freshwater and saltwater environments.
8. With partners, investigate links between sediment contamination, water quality, and aquatic community structure.	
9. Expand urban water-quality programs to include reconstructed water-quality trends based on sediment chemistry in reservoirs.	
10. Collaborate with the USGS Biological Resources Discipline in evaluating sublethal effects of sediment-bound contaminants on aquatic organisms.	

Priority issue 5—Applied ecosystem research	
Tactical actions	**Strategic actions**
1. With partners, investigate potential DNA-based approaches to identifying sources of bacteria and pathogens in fecal-contaminated waters.	1. With partners, evaluate the sources, fates, and biological effects of contaminated sediments in ecologically sensitive areas.
2. With partners, develop a quality-assured approach to using wastewater indicators, pharmaceutical compounds, and endocrine disrupters to understand the sources and fate of effluent.	2. With partners, expand the long-term, statewide network of real-time water-quality stations.
3. With partners, develop a regional monitoring strategy to evaluate the cost and benefits of various BMPs.	3. Investigate the fate of ground-water contaminants at ground-water and surface-water interfaces.
4. With partners, develop a regionally applicable monitoring strategy for the application of phytoattenuation processes to restore affected sites.	
5. With partners, develop a regionally applicable ecosystem-based approach for evaluating the fate of mercury in surface-water bodies in South Carolina.	

Table 3. Additional requirements needed for meeting priority science issues in South Carolina, 2004–2009

All priority issues

Additional personnel will be needed only if several studies identified as tactical or strategic actions come to fruition within a 1- to 2-year period. An assessment of available and needed personnel will be done before pursuing development of the investigations. Specialized skills are required to conduct some of the investigations; thus, any personnel assessment should include available and needed skills and feasibility of training available personnel.

Priority issue 1—Data collection, integration, and analysis

The data, information, and equipment needed to address most of the tactical and strategic actions listed above currently exist within the District. However, additional skills are needed to upgrade the navigability of the District web pages and to develop databases of District data-collection activities.

Priority issue 2—Hydrologic and hydraulic hazards

Some of the data, information, and equipment needed to address most of the tactical and strategic actions listed above already exist within the District. However, the following steps need to be taken to complete the actions:

- Train selected members of current staff in the use of rainfall-runoff modeling tools.
- Increase the number of personnel who are proficient in GIS technology.

Priority issue 3—Sustainable water resources in piedmont and coastal environments

Some of the data, information, and equipment needed to address most of the tactical and strategic actions listed above already exist within the District. However, the following step needs to be taken to complete the actions:

- Train District personnel in statistical analysis of hydrologic data and GIS.

Priority issue 4—Urban effects on human and aquatic health

Some of the data, information, and equipment needed to address most of the tactical and strategic actions listed above already exist within the District. However, the following steps need to be taken to complete the actions:

- Increase the number of District personnel proficient in ArcView GIS data analysis.
- Develop and enhance District expertise in hydrologic and water-quality models (such as SPARROW, AGNPS, or BASINS).
- Increase the number of District personnel who are trained in the USGS protocols for water-quality sampling.
- Increase the number of District personnel who are proficient in hydrologic surface-water modeling.

Priority issue 5—Applied ecosystem research

Some of the data, information, and equipment needed to address most of the tactical and strategic actions listed above already exist within the District. However, additional personnel will be needed if several of the above investigations are funded. If water-quality parameters were added at all streamflow-gaging sites, additional training of technicians for data interpretation purposes would be required.