REPORT ON GROUND-WATER CONDITIONS IN THE LOW COUNTRY AREA, SOUTH CAROLINA

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A Capacity Use Investigation

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ABSTRACT

The Low Country Capacity Use Investigation was initiated by the S. C. Water Resources Commission (SCWRC) in 1973 at the request of legislative and local officials in the four-county area. As required by the S. C. Ground Water Use Act of 1969, the SCWRC must report on ground-water problems in a capacity use study area. The results of a technical ground-water investigation, made by the U. S. Geological Survey (WRD) in cooperation with the SCWRC, are contained in SCWRC Report Number 9 entitled, "The Ground-Water Resources of Beaufort, Colleton, Hampton, and Jasper Counties, South Carolina". Therefore, this report and SCWRC Report Number 9 are submitted to fulfill the requirement of the Act, and to make the findings of the investigation available to the public.

Ground water is the most important source of water supplies in the Low Country area. Six major aquifer systems have been identified. From the surface downward, these are: (1) the Hawthorn-Recent, (2) the Tertiary Limestone, (3) the Black Mingo, (4) the Peedee, (5) the Black Creek, and (6) the Tuscaloosa Aquifer Systems. Approximately 50 million gallons per day (Mgd) of ground water are withdrawn daily from these aquifer systems. The largest withdrawals, approximately 35 Mgd, are from the Tertiary Limestone Aquifer. In the adjacent Savannah area, approximately 75 Mgd to 90 Mgd of ground water are being pumped from this aquifer system for industrial and municipal water supplies.

There are several major ground-water problems that are occurring now in the Low Country area, and other problems that are likely to become major problems unless a comprehensive management program is initiated. Documented problems include:

(1) Regional water-level declines (loss of artesian pressure) throughout large areas of the Low Country and adjacent counties in Georgia.

(2) Salt-water contamination of the Tertiary Limestone Aquifer in the coastal area, primarily in Beaufort County.

(3) Local well interference, where water levels have been lowered below some pump intakes.

(4) Interaquifer transfer, resulting in artesian pressure losses and(or) water quality impairment.

(5) Inadequate requirements relating to well location, spacing, construction, and abandonment.

(6) No requirements for proper water-use, well-construction, and hydraulic data reporting.

Potential problems include:

(1) Subsidence of the land surface (compaction subsidence) caused by excessive, concentrated ground-water withdrawals,

(2) Local dewatering of the Tertiary Limestone Aquifer,

(3) Land-surface subsidence and collapse, if certain conditions are created by improperly-planned well location and spacing, or by dewatering operations, and

(4) Ground-water pollution of aquifers within the Hawthorn-Recent and in the Tertiary Limestone Aquifer Systems.

There are several administrative problems that have a bearing on an effective ground-water management program. These are:

(1) Technical data acquisition and technology transfer.

(2) Uncoordinated water resources development, and

(3) Economics and financing of ground-water management.

An assessment of these technical and administrative problems indicates that:

- The major technical problems are related to ground-water withdrawals from the Tertiary Limestone Aquifer.
- Many of the problems are interrelated, and the solution of one problem would permit the solution of another problem.
- There is no local, state, or federal regulation which is capable of providing appropriate remedies for all of these ground-water problems.
- A ground-water management program is urgently needed that will provide for the proper development of the ground-water resources, and aid in eliminating some of the current problems.
- *The uses of ground water in the Low Country area have developed to a degree which requires coordination and regulation. Therefore, it is recommended that the Low Country area, which includes all of Beaufort, Jasper, Colleton, and Hampton Counties and Edisto Island in Charleston County, be declared a capacity use area.*

If the Low Country area is declared a capacity use area, the SCWRC would have the authority to promulgate regulations concerning the drilling of wells and the withdrawal of ground water in the capacity use area. The following ground-water management methods are needed to protect the aquifers and ground-water users in the Low Country area.

1. *Coordinated water-supply planning.*

The major problem in the Low Country is uncoordinated pumpage, a water-supply management problem. In the past, ground-water development activities have been undertaken without proper consideration of existing ground-water withdrawals, both on a local and on a regional scale. Ground-water withdrawals from the Tertiary Limestone Aquifer in the Low Country area and the adjacent Savannah area now exceed a daily average of 110 Mgd. Throughout the Low Country area as a whole, greater ground-water withdrawals from this aquifer can be made. However, a comprehensive ground-water management program is needed to insure that the proper planning precedes additional pumpage from this important aquifer. This program must consider existing and future water-supply needs of both the Low Country and the adjacent Savannah area. Therefore, it is recommended that officials in South Carolina and Georgia establish a formal Interstate Ground Water Committee. With the proper coordination of ground-water management programs, existing water-supply problems could be realistically addressed. More importantly, emerging or possible future water-supply problems could be addressed before the problems become serious.

2. *Regulations to limit ground-water withdrawals in areas where the supply is limited or where the movement of poor-quality water is degrading a fresh-water aquifer.*

In some areas, it will become necessary to limit the quantity of ground water withdrawn from the Tertiary Limestone Aquifer in order to protect the aquifer from salt-water contamination. Currently, the most critical area is in southwestern Beaufort County where salt water is slowly moving into this aquifer. With the proper management of this aquifer, greater quantities of ground water can be withdrawn without immediate danger to fresh water. However, it is especially important that additional ground-water withdrawals be carefully planned, and that wells be properly designed and constructed.

3. *Regulations related to well spacing, well construction and abandonment.*

The proper location and construction of wells, and proper well-abandonment procedures are ground-water management methods, or "tools", that can be successfully employed in preventing excessive water-level declines, inter-aquifer transfer, salt-water contamination, and other problems outlined in this report.

4. *Regulations related to proper testing of aquifers during well-construction operations, and the proper reporting of this information.*

Certain types of information must be collected prior to, during, and after well-construction operations in order to insure the proper development (utilization) of ground-water resources. Prior to issuing a water use permit, the SCWRC would evaluate the effects of a proposed ground-water withdrawal in order to avoid or minimize adverse effects on the aquifer or existing users.

5. *Best Practical Management of Ground-Water Systems.*

In order to protect existing ground-water users, measures should be instituted that would provide for the best practical management of a ground-water system. Such measures would include careful consideration and evaluation of well placement, proper well spacing, and the establishment of "optimum practical" pumping rates and pumping water levels.

6. *Water Conservation and Alternative Water-Source Selection.*

Water users and prospective water users would be required to use the water of lowest quality available that is suitable, or can feasibly be made suitable, for a particular purpose. If necessary, water users would be required to utilize water-conservation measures where necessary to protect an aquifer or other water users. The selection of these water-management measures would be made on the basis of the best available technical information.

7. *Proper Ground-Water Monitoring.*

One of the most important ground-water management "tools" is the continual collection of ground-water data, including water levels, water quality, geophysical and well-construction data, and water-use information. Without these technical data, a ground-water management program can not be effective. Accordingly, it is recommended that the Regional Office of the SCWRC be maintained to collect and evaluate these data on a continuing basis. These data will insure that the proper technical assistance can be rendered to existing and prospective ground-water users.

Although ground-water problems are emphasized in this report, this report should not be used to suggest that ground water is an undependable resource. To the contrary, the ground-water resources of the area can sustain much greater development. Artesian aquifers in the Black Mingo, Black Creek, and Tuscaloosa Aquifer Systems are capable of supplying large quantities of good-quality water in much of Hampton and Colleton Counties, and possibly in northern Jasper and Beaufort Counties. The Tertiary Limestone Aquifer is also capable of supplying much greater quantities of water, providing wells are properly located and constructed.

The S. C. Ground Water Use Act of 1969 must be regarded as a ground-water management "tool" which can be utilized to insure the proper development and management of ground-water resources. If many of the ground-water management measures outlined in this report are not initiated, and ground-water problems become critical, certain management options may not be available over the long term.

INTRODUCTION

LOW COUNTRY CAPACITY USE INVESTIGATION

The Low Country area as defined for this study lies in the southwestern Lower Costal Plain and composes the four southernmost counties in South Carolina, namely Beaufort, Colleton, Hampton, and Jasper Counties (fig. 1). The population of the Low Country area was 106,521 in 1970 and is projected to increase by more than 24,000 between 1980 and 1990. Agriculture, timber and several U. S. military installations are the primary sources of income and employment, although industrial development is beginning to play an important role. The chief areas of urban development and growth are located in the towns of Beaufort, Port Royal, Walterboro, and on Hilton Head Island. However, with the completion of Interstate 95, opportunities for economic growth in other areas such as Yemassee, Ridgeland, and Hardeeville are promising. In addition, the extensive wetlands beaches, sea islands and other recreational attractions provide excellent benefits from tourism.

Ground water is the major source of water supply in the Low Country area, and supplies 100 percent of the drinking water needs of residents in Colleton, Hampton and Jasper Counties and of many residents in Beaufort County. The majority of this ground water is obtained from the Tertiary Limestone (principal artesian) Aquifer which generally occurs at a depth of less than 150 feet below land surface throughout most of the area. Problems associated with the development of this aquifer are well known to most of the residents of the Low Country area, particularly those living in coastal Beaufort County. In 1972, the local legislative delegation and leaders of county governments of the four counties requested the S.C. Water Resources Commission (SCWRC) to conduct a capacity use investigation of the four-county area.

The S. C. Ground Water Use Act of 1969 (49-5-10 et. seq., 1976 S. C. Code of Laws) provides for the establishment of capacity use areas where necessary to protect the public interest and rights of ground-water users and to protect the ground-water resources within a declared capacity use area. A *capacity use area* is defined in the Act as one where the SCWRC has found that the aggregate uses of ground water in or affecting that area (1) have developed or threaten to develop to a degree which requires coordination and regulation or (2) exceed or threaten to exceed or threaten to impair the renewal or replenishment of water.

Prior to the establishment of a capacity use area, the Act requires that the SCWRC, at the request of a county, municipality or other subdivision of State government, conduct a ground-water capacity use investigation to determine the need and extent of regulation. After requests for an investigation were made by local authorities, the SCWRC initiated the Low Country Capacity Use Investigation in 1973. Because of their well-recognized expertise in ground-water hydrology, the Water Resources Division, U. S. Geological Survey (USGS), was requested to participate in and provide a project leader for a technical investigation designed to evaluate the ground-water resources of

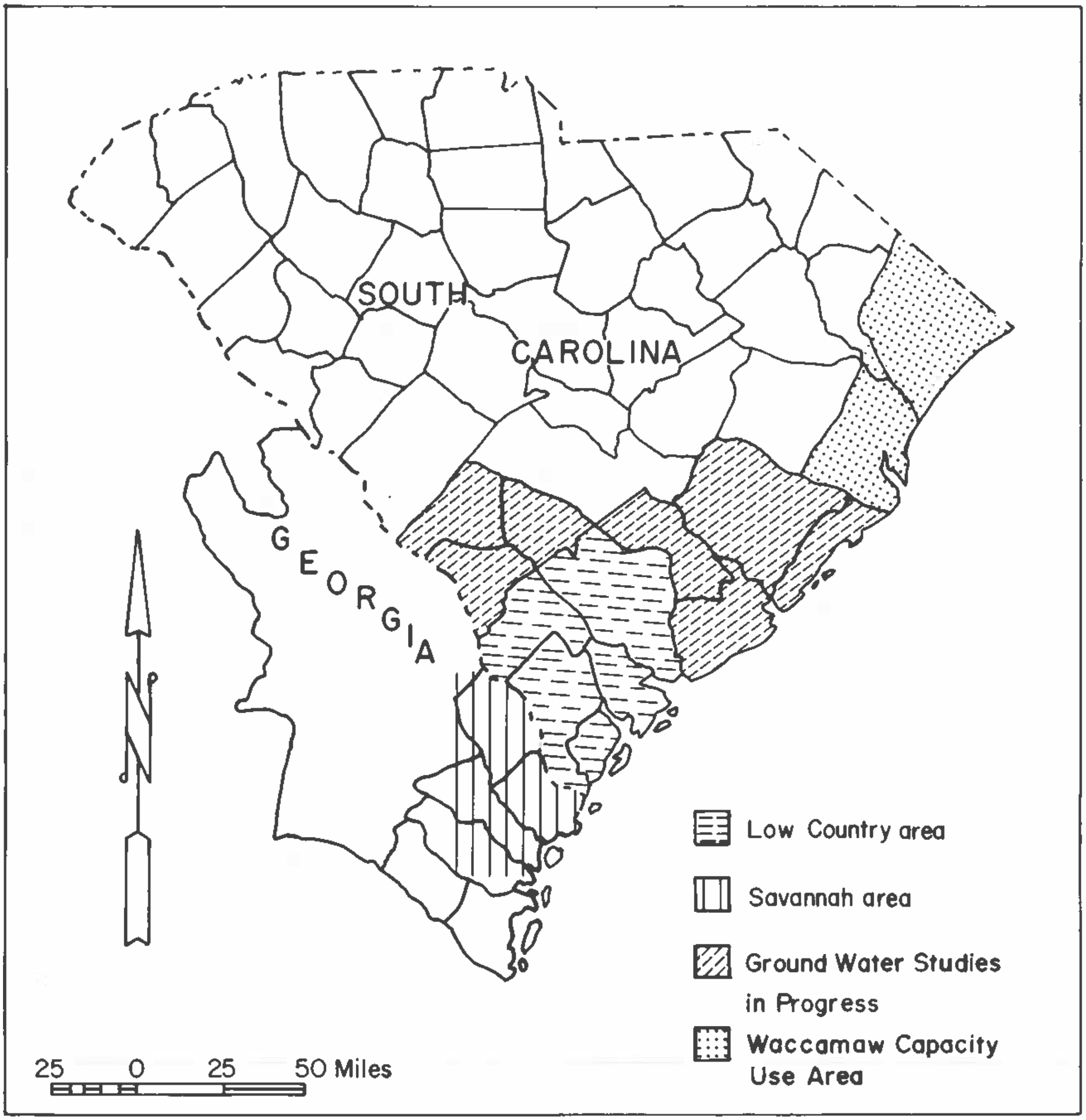

FIGURE I. MAP SHOWING LOCATION OF THE LOW COUNTRY AND ADJACENT STUDY AREAS.

the area. This cooperative first phase of the capacity use investigation extended over a period of four years, from 1973 to October, 1977. The results of the first phase of the investigation are contained in SCWRC Report No. 9, entitled, "The Ground-Water Resources of Beaufort, Colleton, Hampton, and Jasper Counties, South Carolina" by Larry R. Hayes.

PURPOSE AND SCOPE OF THIS REPORT

Phase II of the capacity use investigation began in October 1977 when the SCWRC assumed project leadership and USGS participation ended. The main purpose of phase II was the preparation of this report, the responsibility of the Geology-Hydrology Division of the SCWRC. This report is submitted in accordance with Section 49-5-40(c)(2) of the S. C. Ground Water Act of 1969 which specifies that the report shall: (1) include the Executive Director's findings and recommendations as to the water use problems of the area involving ground water; (2) specify whether effective measures can be employed limited to ground water, and whether timely action by any agency or person may preclude the need for additional regulation at that time; and (3) include recommended boundaries for any capacity use area that may be proposed.

This report summarizes the findings of phase I of the Low Country Capacity Use Investigation, information collected since the completion of phase I, and previous and on-going investigations pertaining to the ground-water resources of the Savannah-Low Country area. In preparing this report, we have made extensive use of the phase I report, SCWRC Report No. 9. Both during phase I of the investigation and since completion of Report No. 9, we have benefitted and borrowed freely from technical opinions expressed by Mr. Larry R. Hayes and other USGS hydrologists (hopefully giving proper credit for their ideas and opinions). In addition, we have sought the professional opinions of engineers, hydrologists, and others who are working or have worked in the Low Country area, and adjacent areas of South Carolina and Georgia. In addition, particularly informative discussions and conferences were held with state officials in the Southeast that are responsible for ground-water management in their states.

The South Carolina Ground Water Use Act requires that copies of the findings of a capacity use investigation be made available to the public. Therefore, SCWRC Report No. 9 and this report are submitted to fulfill that requirement. Recognizing the diverse backgrounds of the citizens for whom this report is intended, we have attempted to present technical ground-water concepts for easier understanding by the non-technical reader. In short, we have sought to make the report 'readable' and useful to the lay public. There are, however, many concepts in ground-water hydrology that are not easily generalized without risking misinterpretation or without lengthy discussion. Rather than lengthy discussion or risking misinterpretation, we have chosen in some cases to simply reference SCWRC Report No. 9 or other technical documents for the reader interested in a more indepth analysis.

The basis of ground-water hydrology is physical geology--the physical description and analysis of the 'container'--the rocks or sediments through which ground water is stored and moves. Therefore, ground-water hydrologists and geologists (stratigraphers) share a basic common interest. This common interest has produced a number of published and unpublished documents that pertain either directly or indirectly to the ground-water resources of the Low Country and adjacent areas. We believe that we have conducted a thorough review of this literature. The most pertinent documents are reviewed in this report and are listed in "Selected References". We realize that this is not a comprehensive bibliography, especially in regard to geological literature. However, we have listed those references that we feel are pertinent to the purposes of this report.

The Geology-Hydrology Division of the SCWRC is responsible for the mapping and evaluation of all aquifer systems (i.e., hydrogeologic units) in the State. We 'map' aquifers on the basis of lithologic (rock type), geophysical, and hydrologic (water-bearing and water-quality) characteristics. We name these aquifer systems by utilizing the names of certain geologic formations used by geologists. However, there are considerable differences of opinion among geologists concerning the terminology and boundaries of certain geologic formations in the S. C. Coastal Plain. Thus, the geologic terminology used by the Geology-Hydrology Division follows terminology accepted by some geologists but not other geologists. The terminology used in this report is not necessarily the same as that currently in use by the Geologic Division of the USGS or by the S. C. Geological Survey (SCGS).

Some readers may believe that more basic data should have been included in this report. However, this report is not a technical ground-water report; and we feel that the inclusion of such data in this report would be unnecessarily duplicative of that presented in SCWRC Report No. 9. Many existing well schedules (well-report forms) or bits and pieces of data have been reviewed and revised; and many wells have been inventoried (scheduled) during this investigation. These data are on file and are available for inspection in the SCWRC Main Office in Columbia and the SCWRC Regional Office in Beaufort. Original copies of much of the data collected during phase I of the study are on file, and also available for inspection at the District Office of the USGS in Columbia. Cuttings (geologic samples) obtained from test holes have been (or will be) transferred to the Subsurface Samples Repository of the S. C. Geological Survey in Columbia when construction of this facility is completed. Throughout both phases of the Low Country study, we have made all basic data and much interpretive data available to all persons requesting it.

We must emphasize one important factor concerning the purpose of this report. It is a report prepared and submitted as required by a State law. As such, we are obligated by that law to discuss and evaluate the severity of problems with the ground-water resources and evaluate ground-water management options. Unfortunately, such 'problem-oriented' reports have too often been erroneously utilized to show that ground water is an 'undependable resource', that aquifers are 'drying up' and that surface water has many advantages over ground water as a water-supply source. The use of these reports for such purposes is often misleading. To the contrary, properly developed and managed ground-water supplies have many advantages over properly developed and managed surface-water supplies. We strongly believe that a ground-water management program is urgently needed in the Low Country area. However, with proper management and development, the ground-water resources of this area as a whole can sustain much greater utilization.

The responsibility of capacity use and ground-water resource programs of the SCWRC has been delegated by the Executive Director to the Chief Hydrologist of the Geology-Hydrology Division. Because of the importance of South Carolina's ground-water resources, and the implications of the S. C. Ground Water Use Act, this responsibility is not taken lightly. While we have relied on the data collected and opinions expressed by others, the Chief Hydrologist takes full responsibility for the conclusions and opinions expressed in this report. We have attempted to present a straightforward and honest appraisal of the ground-water problems in the area with the data available to us.

SUMMARY OF WATER-SUPPLY PROBLEMS AND GROUND-WATER INVESTIGATIONS

The Tertiary Limestone Aquifer System is the most economical source of good quality ground water in most of Florida and in large parts of the Atlantic Coastal Plain in Georgia and South Carolina. In many localities, it is the only locally available source of fresh water. For many years, the increasing and locally heavy demands on the aquifer have created problems involving water-level declines and salt-water contamination, and have raised questions concerning the quantity of water available from this aquifer system.

Since the early 1900's, many ground-water investigations (primarily in Florida) have been conducted to evaluate and provide the technical data needed to properly develop and manage this important aquifer system. Most of these investigations have been conducted by the USGS in cooperation with state and various local agencies. Systematic investigation of the Tertiary Limestone Aquifer System in Georgia and Southwestern South Carolina came about largely because industrial, irrigation, municipal, and domestic water users have relied heavily on this aquifer to meet their demands for water supply.

Systematic evaluation of this aquifer system in the Savannah-Low Country area has been periodically intensive, but rather sporadic since the late 1930's. We feel it is pertinent to provide a summary of (1) the history of ground-water problems in the Low Country and adjacent Savannah area, (2) the results of previous technical investigations, and (3) the concerns of local officials over the lack of ground-water management in the area. Our conclusions concerning these problems, investigations, and concerns are expressed in following sections of this report.

Perhaps the first systematic ground-water investigation of the Tertiary Limestone Aquifer in the Savannah-Low Country area was begun in 1938 by the USGS in cooperation with the State of Georgia. A report on this investigation entitled, *"Artesian Water in Southeastern Georgia"* by M. A. Warren was published in two volumes (Warren, 1944a; 1944b). The study area primarily involved 12 counties in the Georgia Coastal Plain, although some information was provided on Beaufort and Jasper Counties, South Carolina. This study was initiated because concern had developed over declining water levels in the Tertiary Limestone Aquifer resulting from a pumpage increase of approximately 40 Mgd (million gallons per day) in six coastal counties of Georgia during the period 1928 to 1938. Water-level declines were particularly noticeable in Chatham County where an estimated 42 Mgd were being pumped from the aquifer in the vicinity of Savannah in 1943. Warren prepared three potentiometric (water-level) maps of the Tertiary Limestone Aquifer which showed (1) the estimated potentiometric surface prior to 1880 when very little ground water was being pumped from the aquifer, (2) the measured potentiometric surface in 1943 with a pumpage of 42 Mgd in the vicinity of Savannah, and (3) the predicted potentiometric surface if pumpage in the vicinity of Savannah increased to 60 Mgd. Because these were the first potentiometric maps constructed for the Savannah area, they have provided important historical data for subsequent studies. Warren discussed the impact of water-level declines resulting from pumpage and the relationship of salt-water contamination and water-level declines. He believed that salt-water channels in the Port Royal Sound area of Beaufort County, S. C. were probably the primary source of the salty water in the Tertiary Limestone Aquifer underlying Parris Island. Warren noted that chlorides in this aquifer increased with depth and suggested that low permeability in the lower portions of the aquifer had prevented the complete 'flushing' of this salty sea water by fresh-water discharge. Because data were insufficient to accurately assess the problem of salt-water contamination, Warren concluded that the water levels and quality of water in the aquifer should be carefully monitored.

In the early 1940's, when Warren was conducting his study, authorities in South Carolina were also concerned with the impact of heavy pumpage in the Savannah area and in Beaufort County and the need for a better water supply for military and municipal requirements in the Beaufort, S. C. area.

A potable water supply had always been a problem for the Marine Corps Recruit Depot (MCRD) at Parris Island. Since 1903, the military had abandoned several wells on Parris Island because of increasing chloride concentrations in the water. By 1919, a well field that supplied water to the MCRD had been located north of Parris Island near the town of Port Royal. However, this well field near Port Royal was reportedly abandoned in 1927 because of bacterial contamination and increasing chlorides. A second well field (the Jericho Well Field) was then located at Jericho Point. However, pumping was eventually reduced in a few wells in this well field, partially as a measure to maintain sufficient fresh-water head between a third well field at Burton and salty surface-water bodies, and because of some increases in chloride content, particularly noticeable during World War II. Afer World War II, pumpage at the Jericho Well Field was discontinued, and water was supplied to Parris Island from two wells located about 5.5 miles north of Parris Island near Burton (Burton Well Field). Although the two wells at Burton had shown no signs of chloride contamination, the military was concerned that additional ground-water withdrawals throughout the area, particularly for irrigation, would also degrade the quality of water in these wells. In addition to the extensive salting of wells on Parris Island and MCRD well fields on Port Royal Island, chlorides were increasing in several wells supplying water to the town of Beaufort. Therefore, in 1944, the Bureau of Yards and Docks, Department of the Navy, requested the USGS to conduct a ground-water investigation in the Beaufort area and make water-supply recommendations. The results of this reconnaissance study were released in a 1944 report entitled, *"Ground Water in the Beaufort Area, South Carolina"* by M. J. Mundorff. This study provided the first potentiometric map of the Tertiary Limestone Aquifer in the Beaufort area. The map indicated that the aquifer was probably in hydraulic connection with salt-water channels in the vicinity of Port Royal Sound; thus, the aquifer was vulnerable to salt-water contamination. This fact was further substantiated after observations by Mundorff showed that Battery Creek was the likely source of chlorides which necessitated a reduction of pumping at the Jericho Well Field. In addition, he discussed the condition of wells withdrawing water from the Tertiary Limestone Aquifer at Beaufort, Burton, and the Naval Air Station and concluded that water-level declines should be limited to only a few feet if salt-water contamination was to be avoided. He recommended that wells should be drilled as far as possible from salt-water channels, that water levels and water quality should be monitored, and that any well showing signs of increasing chlorides should be abandoned.

Although Mundorff had concluded that the ground-water supply from the Tertiary Limestone Aquifer in the immediate Beaufort area was limited, the extent to which the supply was limited had not been assessed. Therefore, in 1948, David A. Kendall with the Bureau of Yards and Docks, Department of the Navy, prepared a report entitled, *"Comprehensive Plan for the Development of an Adequate Water Supply for the Marine Corps Recruit Depot, Parris Island, South Carolina"*. The report summarized the status of the existing ground-water supply serving Parris Island; and Kendall estimated the present and future water-use requirements and proposed alternatives for improving the water system to attain the 'maximum safe yield'. Kendall made several recommendations regarding the construction of new wells and modifications of the existing water system that would approximately double the ground-water supply serving Parris Island. However, it was concluded that because salt-water contamination of the ground-water supply was influenced by water-level declines and since no controls on pumping existed, it was impossible to control water levels. Therefore, Kendall believed that a surface-water supply would eventually be necessary, and he recommended that a project be undertaken to study the feasibility of obtaining water from the Combahee River.

Additional support for the Combahee River project came when Barber, Keels & Associates, Inc., prepared a water-supply report for the Beaufort County Water Authority in 1954. This report, along with a supplemental report released in 1955 by B. P. Barber and Associates (formerly Barber, Keels & Associates, Inc.), contained data on the chemical quality and availability of surface and ground water in the Beaufort area and estimates of water requirements for the major water users. After evaluating these data, B. P. Barber & Associates agreed with Kendall's conclusion that ground-water supplies on Port Royal Island were inadequate to meet future demands, particularly during war time. Therefore, the Combahee River was recommended as the best alternative and information was given on the feasibility of utilizing the river as a source of water supply.

In 1956, at the request of the Department of the Navy, the USGS prepared a report entitled *"Memorandum Report on the Geology and Ground Water of the Parris Island Area, South Carolina"* by George E. Siple. Although Siple made reference to other aquifers in the area, he focused mainly on the Tertiary Limestone Aquifer. A number of water-level measurements were made and automatic water-level recorders were installed on key wells in the Tertiary Limestone Aquifer, and Siple compared pumpage with chloride concentrations in certain wells. He explained several ways that the Tertiary Limestone Aquifer could become contaminated with salt water; and he suggested that undrained depressions (sinks) occurring throughout the area could be the result of breaks in the confining bed, thereby providing an avenue by which the aquifer could become contaminated. Siple indicated that the influence of tides and discrepancies regarding previous measuring points prevented him from accurately determining if there had been a progressive water-level decline, particularly at the Burton Well Field. He suggested that the apparent decline was from one to four feet in an area of southern Hampton and Jasper Counties and eastern Beaufort County. Several estimates were made regarding the total supply of ground water available to Parris Island and Siple proposed, as had Mundorff (1944), that the deeper aquifers which contained mineralized water at Parris Island may yield fresh water northwest of Burton. He also pointed out that because there was a hydraulic connection between the Tertiary Limestone Aquifer and salt-water bodies, future wells withdrawing water from the aquifer should be located farther inland and that a monitoring program should be continued. Siple recommended that the most favorable locations for future wells were northwest of Burton, west of the Broad River, and north of Spring Island. However, he noted that the increasing demand on the Tertiary Limestone Aquifer for agricultural irrigation would diminish the net supply of ground water available for use by military installations.

In 1956, it appeared that the Combahee River was the best alternative water source capable of supplying additional water to the Beaufort area. However, during that year, Hazen and Sawyer Engineers submitted a report to the Bureau of Yards and Docks, Department of the Navy, entitled, *"Water Supply in the Vicinity of Beaufort, South Carolina"*. Hazen and Sawyer provided cost estimates comparing the Combahee River project with a well field west of the Broad River, and concluded that the Combahee River project was costly and unnecessary. They pointed out deficiencies in the Combahee River as a water source, such as extremely low flow during droughts. Hazen and Sawyer's interpretation of data provided by the USGS showed that the Combahee River could be used only 90 percent of the time unless reservoirs were constructed. Hazen and Sawyer agreed with B. P. Barber & Associates' conclusion that the ground-water supplies on Port Royal Island were inadequate to meet future requirements. However, Hazen and Sawyer believed that a well field west of the Broad River would meet future requirements and would be more economical than the Combahee River project.

Within the same year (1956), B. P. Barber & Associates prepared a supplemental report in which they defended their conclusion that the Combahee River was the best alternative water source. Financial estimates prepared for the report showed the Combahee River project to be only slightly higher in cost than a well field west of the Broad River. B. P. Barber & Associates disagreed with Hazen and Sawyer's interpretation of records pertaining to streamflow and chlorides which indicated that the Combahee River would not have sufficient flow 100 percent of the time. B. P. Barber also emphasized that because no control existed on ground-water pumpage, a well field west of the Broad River would be endangered by the quantity of water pumped in Savannah and by pumpage for local irrigation. Therefore, the Combahee River was still recommended by B. P. Barber as the most reliable source of water to supply the Beaufort area.

Another 1956 report was prepared by Major Allen C. Bowen, (U.S. Marine Corps) on the water supply for Parris Island, in which he favored the Combahee River project over the well field west of the Broad River. He reasoned that the increasing demand for large irrigation wells throughout the area and the resulting competition for ground water would act to steadily downgrade the Parris Island water supply should it continue to be obtained from wells. He requested that no further funds be expended by the Navy in connection with a proposed well field. Bowen recommended the Beaufort County Water Authority as the best agency to undertake the Combahee River Development project, and recommended that the water requirements of the MCRD could be met by purchasing water from the Beaufort County Water Authority.

In 1957, Hazen and Sawyer Engineers prepared a supplemental report that offered additional support for a well field west of the Broad River in Jasper County. However, earlier in 1957, an Act was passed by the S. C. General Assembly that prohibited the transfer of more than 5,000 gpd of well water beyond the boundaries of Jasper County (Section 70-421, 422, 1962 S. C. Code of Laws). Therefore, this Act, in effect, prohibited the construction of a well field west of the Broad River. Consequently, Hazen and Sawyer concluded that if the proposed well field west of the Broad River could not be constructed, then the Savannah River would be a better water source than the Combahee River. Hazen and Sawyer summarized the feasibility of a project to supply the Beaufort area with surface water from the Savannah River.

In 1960, the USGS submitted a report to the U.S. Navy entitled, *"Geology and Ground-Water Conditions in the Beaufort Area, South Carolina"* by George E. Siple. This report provided information on the ground-water resources in much of the Low Country area with an emphasis on the Tertiary

Limestone Aquifer in the Beaufort area. Siple provided numerous well records, water-quality analyses, a cross-section showing the depth and thickness of the geologic formations, and a 1959 potentiometric map of the Tertiary Limestone Aquifer. The potentiometric map, when compared to the one constructed by Mundorff in 1944, showed how the heavy pumpage in Savannah was affecting water levels in Beaufort and Jasper Counties. In addition, Siple's map showed a cone of depression created by ground-water withdrawals at the Burton Well Field and also showed several areas of abnormally high water levels, particularly near the Marine Corps Auxilliary Air Station (MCAAS). Siple suggested that these high water levels were caused by local recharge occurring from a shallow water-table aquifer through breaks in the confining bed. Along with these areas of local recharge, the primary recharge area for the Tertiary Limestone Aquifer was interpreted to be approximately 30 to 40 miles northwest of Beaufort. In addition, Siple discussed the problem of salt-water contamination and noted that it was not as extensive as previously thought. However, he suggested that if ground-water development in certain areas continued, the problem would worsen. He supported Hazen and Sawyer's conclusion which coincided with those he had made earlier (1956), that if new well fields were located, including one west of the Broad River, the water needs of the civilian and military population could be met for many years without fear of salt-water contamination.

Further development of the ground-water supplies for the military and for municipal requirements of Beaufort and Port Royal never materialized. Instead, federal assistance made possible plans to withdraw surface water from the Savannah River 18 miles to the southwest. Completion of the Savannah River project in 1964 ended the quest for an adequate ground-water supply for military establishments and municipalities in the Beaufort area. The existing wells at the Burton Well Field, MCAAS, Port Royal, and Beaufort, were phased out of operation and maintained only as a standby system. This left the available ground-water supplies to other water users.

In Savannah, ground-water pumpage had been steadily increasing and continually declining water levels were still causing concern that the supply might be depleted or that salt water might be encroaching from the Beaufort area. Therefore, in 1954 the USGS, in cooperation with the State of Georgia, began a ground-water investigation of the Tertiary Limestone Aquifer in the Savannah area. The purposes of this investigation were to study the extent of salt-water contamination of the aquifer, and where salt water was present, to determine its vertical and lateral position, and to trace its movement. During this investigation several short reports were released (Warren, 1955; Herrick and Wait, 1955; Counts, 1958; Counts and Donsky, 1959; Counts, 1960). The final report entitled, *"Salt-Water Encroachment, Geology and Ground-Water Resources of Savannah Area, Georgia and South Carolina"*, by Harlan B. Counts and Ellis Donsky was published in 1963. Data for this investigation were obtained from test drilling, geophysical logging, water-quality analyses, water-use inventories, and aquifer tests. Interpretation of these data provided an evaluation of the geology, well yields and hydraulic properties, quality of water, and salt-water contamination of the Tertiary Limestone Aquifer. Counts and Donsky observed that since the first wells at Savannah were drilled in the late 19th century, there had been little change in the chemical quality of water withdrawn from the upper portion of the aquifer in the immediate Savannah area, even though salt water was present in the lower portion of the aquifer. However, in the Beaufort area of South Carolina, Counts and Donsky noted that salt water, present in both the lower and parts of the upper portions of aquifer, was slowly moving toward Savannah. They reasoned that as the salt water moved toward the center of pumpage at Savannah, large portions of the Tertiary Limestone Aquifer underlying Beaufort and Jasper Counties would eventually become contaminated. Although the rate of the salt-water movement was uncertain, Counts and Donsky presented evidence that further water-level declines resulting from increased pumpage in Savannah would hasten the inland movement of salt water. It was recommended that additional ground-water needs for the Savannah area be met by locating well fields 15 to 20 miles northwest, west, and southwest of Savannah so as to avoid excessive water-level declines and salt-water encroachment.

In 1964, as part of a continuing cooperative program with local governments, the USGS published the results of another ground-water investigation pertaining to the Savannah area by M. J. McCollum and Harlan B. Counts entitled, *"Relation of Salt-Water Encroachment to the Major Aquifer Zones, Savannah Area, Georgia and South Carolina"*. Emphasis during this investigation was placed on delineating the different water-bearing (permeable) zones within the Tertiary Limestone Aquifer and the rate of salt-water movement in each zone. These zones were defined primarily by current-meter tests conducted on eight test wells located in the Savannah to Hilton Head Island area. These tests revealed that in the vicinity of Savannah, the Tertiary Limestone Aquifer consisted of five major permeable zones (and several minor ones) separated by relatively impermeable zones. They traced four of these permeable zones onto Hilton Head Island, but only two zones were present at the north end of Hilton Head Island. Results of current-meter tests indicated that 70 percent of the water yielded from an individual well came from the two uppermost permeable zones. Chemical analyses of ground water in these zones showed that chloride concentrations increased with depth. These facts supported Warren's (1944) theory that low permeabilities in the lower portions of the aquifer prevented ancient sea water from being completely flushed from the aquifer. McCollum and Counts concluded that although the rate of movement varied in each zone, salty water was moving toward Savannah from the Beaufort area in all five zones. However, they noted that salt water in the lower zones of the aquifer was closer to Savannah; therefore, even though the movement of ground water in the lower zones was slower, increases in chloride concentration in the immediate Savannah area would probably occur first in the lower zones of the aquifer underlying Savannah. Recommendations by McCollum and Counts were similar to those made by Counts and Donsky (1963) in that future wells in the Savannah area should be located 15 to 20 miles west of the city.

A second report was published by McCollum (1964) entitled, *"Salt-Water Movement in the Principal Artesian Aquifer of the Savannah Area, Georgia and South Carolina"*. McCollum presented data showing slight increases in the chloride concentration of water in the lower zones of the aquifer underlying Savannah. However, he suggested that the threat of salt-water contamination of the Tertiary Limestone Aquifer in the immediate vicinity of Savannah was minimized because only 20 percent of the water flowing toward Savannah was coming from the contaminated area (Beaufort area). McCollum recommended that periodic sampling of the permeable zones be continued.

During the late 1960's, proposed phosphate mining in Chatham County, Georgia and industrial development in Beaufort County, South Carolina led to requests for permits to dredge in several channels and marshes. The material (confining bed) to be dredged is a relatively impermeable, clayey, phosphatic sand or limestone that acts as a barrier between salty water in the sea and tidal estuaries and fresh water in the Tertiary Limestone Aquifer.

Proposed phosphate mining in eastern Chatham County resulted in several reports concerning the complex technical questions. As part of a larger study, R. E. Carver (1968b) reported the results of a test drilling and geophysical logging study of the confining beds overlying the Tertiary Limestone Aquifer in the proposed mining area and concluded that mining operations were probably feasible if certain environmental safeguards were followed.

In a later report by the Georgia Department of Mines, Mining and Geology, authored by James Furlow (1969) entitled, *"Stratigraphy and Economic Geology of the Eastern Chatham County Phosphate Deposit"*, Furlow discussed the economic geology of the phosphate deposits and calculated the amount of salt-water leakage that would be caused by reducing the thickness of the confining beds overlying the Tertiary Limestone Aquifer. Permeability values were obtained from 40 cores taken from the confining bed in the proposed mining areas. Based on the analyses of the vertical permeability values, thicknesses of the confining material, and water-level data, Furlow calculated the amount of downward leakage of ground water into the Tertiary Limestone Aquifer. He concluded that the increase of salt-water leakage into the Tertiary Limestone Aquifer would not significantly affect the water quality in the City of Savannah's wells.

In contrast was a report published in 1970 by the USGS entitled, *"Notes on the Position of a Phosphate Zone and its Relation to Ground Water in Coastal Georgia"* by R. L. Wait. Wait discussed the lithology and position of phosphate beds occurring in the Hawthorn Formation (confining bed) and other sediments overlying the Tertiary Limestone Aquifer. Seemingly unaware of Furlow's investigation and conclusions, Wait commented that if the confining bed were deeply cut or breached, sea water would move downward into the Tertiary Limestone Aquifer and contaminate the fresh-water supply.

In South Carolina, similar problems were arising because the Port Royal Sound area was being considered for industrial development which would require dredging to deepen existing shipping channels in some areas--primarily in the Beaufort River. Much controversy arose surrounding the possible adverse environmental impact that the dredging would have on the Tertiary Limestone Aquifer. At the request of Governor Robert McNair, the SCWRC, in connection with other state and federal agencies, conducted a study to assess the environmental impact of industrial development on the Port Royal Sound area. The findings of this study were published in 1972 by the SCWRC in a report entitled, *"Port Royal Sound Environmental Study"*.

One objective of this study was to evaluate the effect of dredging on ground water in the Tertiary Limestone Aquifer. The evaluation included a seismic survey of sediments underlying the channels in the Port Royal Sound area along with 19 test holes drilled adjacent to the channels. Lithologic descriptions of samples obtained from the test drilling were prepared by Colquhoun (1972) to determine the nature and relationship of the upper confining beds to the Tertiary Limestone Aquifer. Duncan (1972) correlated these descriptions with the profiles obtained from the seismic study which supported conclusions of Mundorff (1944) and Warren (1944) that the aquifer was in contact or in close contact with the bottom of several navigation channels. These investigations and recommendations of a technical committee led to the conclusion that:

> "No further dredging should be allowed in the Beaufort River unless reliable investigations can demonstrate that additional dredging to deepen the shipping channel can be conducted without jeopardizing the ground water resource. Seismic surveys indicate that the aquifer is extremely shallow and may already have been breached in portions of the river" (SCWRC, 1972).

This conclusion was based primarily on the physical characteristics and relative position of the confining beds and their relationship to the aquifer. A detailed ground-water study of the Tertiary Limestone Aquifer had not been included in the investigation. Consequently, members of a technical committee recommended that a ground-water investigation be conducted to provide answers to the dredging question and to provide information needed for the management of the ground-water resources. The committee recommended that the investigation be conducted under the provisions of the South Carolina Ground Water Use Act of 1969.

Shortly after completion of the Port Royal Sound Study, local officials made a formal request to conduct the Low Country Capacity Use Investigation. The results of the cooperative phase I of the Low Country Capacity Use Investigation conducted from 1973-1978, are contained in SCWRC Report No. 9, entitled, *"The Ground-Water Resources of Beaufort, Colleton, Hampton, and Jasper Counties, South Carolina"*, by Larry R. Hayes of the USGS. The report by Hayes emphasizes the hydrogeology of the Tertiary Limestone Aquifer and provides an up-to-date evaluation of this aquifer system. Since Hayes' report is so extensively quoted throughout this report, it will not be thoroughly reviewed here.

In 1970 the USGS, in cooperation with the City of Savannah, Chatham County, and the State of Georgia, began preparing a digital model of the Tertiary Limestone Aquifer in the Savannah area. Some results of this model were published in 1976 in a report entitled, *"Digital Model Analysis of the Principal Artesian Aquifer, Savannah, Georgia Area"* by H. B. Counts and R. E. Krause. The model is used to project the change in water levels brought about by a redistribution of pumpage, an increase or decrease in the rate of pumpage, or a combination of all three. Counts and Krause calibrated the model using Warren's 1880 potentiometric map of the original potentiometric surface prior to pumpage; and they verified the model by comparing computed water levels with actual water-level measurements made in 1956, 1960, and 1970. Verification of this model indicated a reasonably good match between computed and measured water levels. Counts and Krause presented three computed maps showing the projected change in water levels that would occur from 1970 to the year 2000 by adding to the 1970 pumpage (1) 10 Mgd at theoretical sites on Hilton Head Island, (2) 10 Mgd at Hutchinson Island, Georgia, and (3) 6 Mgd at Montieth, Georgia. Two other projections were also illustrated showing the projected water-level change caused by (1) transferring 10 Mgd of the 1970 pumpage from Savannah to Bloomingdale, 10 miles to the west, and (2) decreasing the 1970 pumpage 20 Mgd at the center of the cone of depression in Savannah.

In the preparation of this report we have been extremely fortunate to have had continual contact with several of the state and federal hydrologists who have authored technical ground-water reports on the Savannah and Low Country areas. Obviously, we have had continual personal contact with Larry R. Hayes. Other USGS hydrologists consulted include Harlan Counts and Richard Krause with the USGS in Atlanta. George Siple (USGS, retired), now a ground-water consultant living in Columbia, South Carolina, and Donald Duncan, with the SCDHEC, were sources of information.

METHODS OF INVESTIGATION

The technical methods and procedures used to obtain ground-water data during phase I of the Low Country Capacity Use Investigation were summarized by Hayes (1979) in SCWRC Report No. 9. However, we would like to summarize and re-emphasize certain methods that have a direct bearing on some of the ground-water management problems discussed in this report, and on certain conclusions and recommendations made herein. It is particularly important for the reader to understand how ground-water investigations are conducted in order for them to appreciate the importance and magnitude of proper ground-water investigations.

GROUND-WATER INVESTIGATIONS

Although no specific guidelines are given in the South Carolina Ground Water Use Act as to how a capacity use investigation should be made, there are nine factors listed in Section 49-5-60(h) of the Act that, for all practical purposes, require a minimum of what we term a planning or management-level knowledge.

The Geology-Hydrology Division classifies ground-water "knowledge" into four categories or "levels" progressing from lesser to greater detail as (1) Field Data, (2) Reconnaissance, (3) Planning, and (4) Management levels of knowledge. These levels of ground-water knowledge are achieved by conducting ground-water studies that range from general (reconnaissance level) to more detailed (planning-and management-level) studies. In a specific area (a county, for example) a planning-level knowledge may exist for one particular aquifer, but the knowledge of other aquifer systems may be at less than planning-level.

As shown in the preceding section, several of the previous ground-water studies were either conducted only in a relatively small area (centered on the Beaufort area); were somewhat general in scope (mainly qualitative, as opposed to quantitative); or were conducted many years ago. Therefore, knowledge of the Tertiary Limestone Aquifer in the Low Country area was at less than reconnaissance-level prior to the Low Country Study. Knowledge of other aquifer systems in the Low Country area was at less than Field Data level because there were few data available on wells that had been completed in these aquifers.

The geologic framework (the ground-water container) of an area is by and large a static (unchanging) condition. However, hydrogeologic conditions are not static. Water levels, ground-water flow patterns, ground-water use, and water quality are elements of dynamic, continually changing ground-water systems. Therefore, ground-water knowledge must be continually updated and refined if we are going to be able to predict changes in ground-water conditions and prevent or solve ground-water problems.

HYDROGEOLOGIC DATA COLLECTION

In the Low Country, as in any area, ground-water knowledge must come from the collection and analysis of borehole (i.e., subsurface) data obtained from water wells or from test wells drilled for the purpose of obtaining certain ground-water data. The "lifeblood" of any ground-water study is the information that can be obtained from the subsurface; some of this information can be of a "general" nature, but the "true lifeblood" is accurate, truly representative information. Much of this information must come from test holes or water wells that existed prior to a study. If a well is in use (has pump installed), often the only data that can be obtained is a chemical or biological analysis of the water from the well.

If the exact depth of the well, type of well construction, depth of casing, and other factors are not known, the water sample may reveal little useful data--except to let the well owner know the quality of water he is drinking (which is, of course, important to know).

During the Low Country study, subsurface hydrogeologic information was obtained from the following sources:

(1) Published ground-water reports and file data from various federal (primarily USGS) and state (primarily SCWRC) agencies--The published reports are listed in "Selected References" and file data have been recorded on Well Report Forms (SCWRC Form GW-1). The types of hydrogeologic data available on wells and test holes are summarized in appendix table 1. These basic data are available for inspection in the Beaufort Regional Office and the Main Office of the SCWRC in Columbia.

(2) Borehole data from mineral exploration or stratigraphic test holes--These data were obtained from industries or the S. C. Geological Survey. While providing extremely useful geologic information, few of these holes provide useful hydrologic data. Most were drilled to obtain geologic samples, and then abandoned; and most penetrate only a few feet into the Tertiary Limestone Aquifer.

(3) Data from shallow foundation exploration holes--These data were obtained from various consultants, the U. S. Department of Agriculture, Soil Conservation Service, and the S. C. Department of Highways and Public Transportation. Most of these test holes are drilled; geologic samples are obtained for laboratory tests; then the holes are abandoned.

(4) Inventorying (scheduling) of existing water wells by contacting well owners, well-drilling contractors, consultants, and others--In addition to providing useful hydrogeologic information to the SCWRC, many requests for technical assistance are received and processed as a result of these contacts. Unfortunately, many well owners do not have any well construction information on their well and, in some cases, the depth is not known.

(5) Information obtained from wells drilled during the study--from well-drilling contractors, well owners, or consultants--In some cases a well-drilling contractor would save drill cuttings (geologic samples) from recently-drilled wells, or would allow project personnel to collect samples and obtain a geophysical log. While the majority of well owners and drilling contractors are extremely cooperative, sometimes we are not notified until after drilling operations, after casing and pump have been installed in the well. Thus, at least one-half of the potentially usable information from such wells is lost. Some of the most useful information during a ground-water study is obtained in cooperation with various consultants and well-drilling contractors who request technical assistance during the project. Considerable time is spent on such technical assistance requests during a ground-water investigation because much of

the best hydrogeologic information is obtained in this manner. In South Carolina, unlike most states, most of this type of information is not required by State law, except in designated capacity use areas.

(6) Information from unused, abandoned wells--Many small diameter and some large-diameter (6 inches and larger) abandoned wells were located during the project, and with permission from the well owner, gamma-ray and caliper logs were obtained. The gamma-ray log provides certain information from a cased hole, and these logs were extremely useful for the study.

(7) Shallow seismic profiles in Port Royal Sound--Shallow seismic refraction profiles conducted by a commercial geophysical company for the Port Royal Sound Study were available, as well as the interpretations of Duncan (1972).

(8) Borehole geophysical data--In addition to gamma-ray and caliper logs, other geophysical logs were obtained on some wells that were being constructed. Electrical-resistivity ("electric") and spontaneous potential (SP) logs must be obtained prior to the installation of casing in a well. Consequently, notification of a new well often occurred too late to obtain these logs. It must be pointed out that only one geophysical logger (owned and operated by the USGS) was available during the study, and this logger had to cover the entire State in support of other USGS or SCWRC-USGS cooperative ground-water studies. Usually, many wells are being simultaneously completed in the Low Country and other areas of the State. Obviously, only one well can be logged at a time; consequently, much critically needed data are being lost daily in South Carolina. Most of this information is lost forever; even if at some future date, the pump could be removed from such a well, several types of logs cannot be run in a cased well.

(9) Drillers' logs--Few well drillers in the Low Country keep written records of the types and thicknesses of geological strata penetrated during drilling operations. A driller's log of a well can sometimes be used to interpret the subsurface geology between two wells where more data are available, if the distance is not too great between wells.

TEST-DRILLING PROJECT

When all existing borehole data were collected and evaluated, they were inadequate to provide the kinds of hydrogeologic data needed to properly evaluate even the Tertiary Limestone Aquifer in the Low Country area. Therefore, it was necessary to drill test holes which could provide (1) geologic samples, (2) points for obtaining geophysical logs, (3) hydraulic data (from current-meter or pumping tests), and (4) water-quality data.

Thirty-two project test holes were drilled during the study. Twenty five of these were drilled by commercial well-drilling companies; and seven were drilled by the junior author in cooperation with the S. C. Geological Survey (SCGS). Four special-purpose test wells at the Port Royal Clay Company (three into the Tertiary Limestone Aquifer, and one into the Hawthorn Formation) were cooperatively financed by the S. C. State Ports Authority, SCWRC, and USGS. One special-project test well was completed by a commercial contractor at Beaufort, financed by the City of Beaufort, the SCWRC, and the USGS. The location of these test holes are shown in figure 2, and hydrogeologic information on these test holes is summarized in appendix table 1.

Funding was available to complete most of these test wells only into the Tertiary Limestone Aquifer. In order to reduce costs, compromises had to be made: The number and depth of test holes had to be limited; four-inch plastic casing was used in most test wells; and casing length had to be limited to a depth of less than 200 feet. Current-meter tests were run in certain test holes to determine the position and thicknesses of water-bearing (permeable) zones in the borehole. Point water samples (multi-depth) were obtained with a borehole water sampler at certain depths in some wells to get representative water-quality analyses of a specific water-bearing zone.

In the 1950's, the USGS installed three multi-aquifer test-well stations in Beaufort County--one on Daufuskie Island (Bft-304) and two on Hilton Head Island (Bft-101, -315). The quality of ground water (chlorides) has been continuously monitored from these wells since the 1950's by the USGS, Georgia District.

During the latter stages of the investigation (1977-78), the SCDHEC constructed test wells into shallow aquifers. Some of these wells were located adjacent to SCWRC test wells in order to provide data on potentiometric head relationships between shallow aquifers and the underlying Tertiary Limestone Aquifer. These also constitute multi-aquifer stations because hydrologic information is obtained on more than one aquifer at the same location.

WELL-NUMBERING SYSTEM

As previously mentioned, basic hydrogeologic data obtained on water wells, springs, or test holes are recorded on a Well-Report Form (SCWRC Form GW-1) and every well, spring, or test hole is assigned a permanent well number that is unique to that particular well, spring, or test hole. In addition to providing a unique number for reference, each well number is a location key to the well. The SCWRC well location grid system is based on latitude-longitude coordinates. These grids for the Low Country area are shown on figure 2. Each 5-minute latitude-longitude grid is

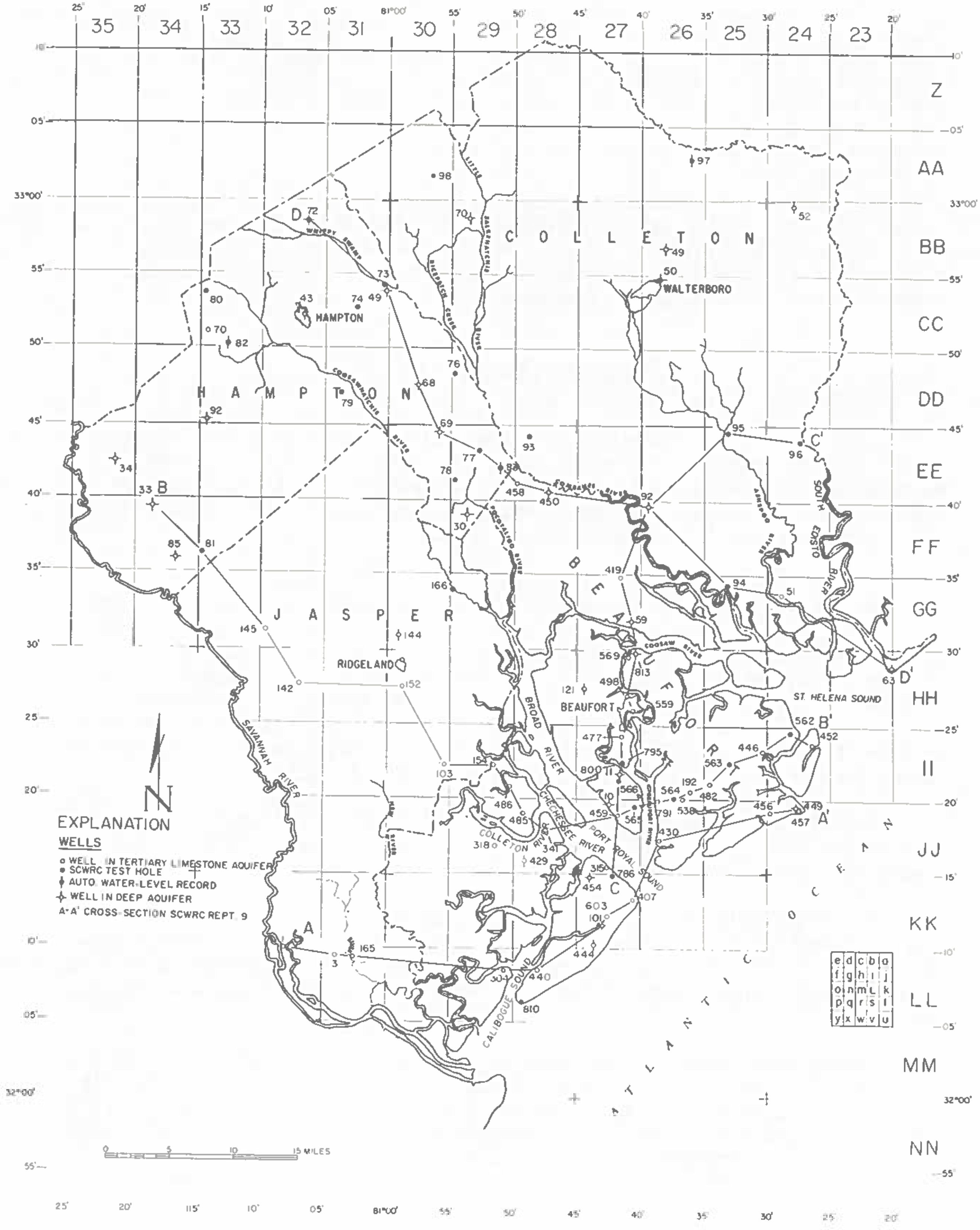

FIGURE 2. WELL LOCATION MAP, LOW COUNTRY AREA.

further subdivided into 1-minute grids, each assigned a small letter. Each well or test hole inventoried in each 1-minute grid is numbered consecutively. For example, SCWRC Well No 27KK-b1, refers to well number one in Grid 27KK-b. All ground-water files are now keyed to this well locator system, which facilitates ease in answering ground-water availability requests received by the SCWRC.

As a cross-reference, USGS well numbers as they are assigned by that agency are also listed on each GW-1 Form. The USGS well-numbering system is also based on latitude-longitude coordinates and each well is assigned a county prefix and a number, for example Bft-60. Well Bft-60 is the sixtieth well inventoried in Beaufort County.

ACKNOWLEDGEMENTS

During a lengthy investigation there are so many individuals and organizations that deserve recognition for their contributions that it becomes impossible to give proper acknowledgement. At the risk of an omission, we would like to thank certain organizations and individuals for their assistance on behalf of the SCWRC.

Much of the credit for initiating the investigation should go to the local legislative delegation and local government officials who long ago recognized the importance and need for ground-water management. Most notable assistance in this regard was provided by Representative J. Wilton Graves and Senator James M. Waddell (Beaufort), former Representative Wilson Tyson (Colleton-Hampton), former Lt. Governor William Brantley Harvey, Jr., former Senator James P. Harrelson (Colleton), Representative Harriet H. Keyserling (Beaufort), Representative L. Martin Sauls (Jasper-Beaufort) and Representative Peden B. McLeod (Colleton).

Special appreciation is extended to the Coastal Plains Regional Commission (CPRC) for financial support. Without this assistance, a comprehensive ground-water study would have been impossible.

Mr. John Stallings, former District Chief, U. S. Geological Survey and his staff were instrumental in the investigation from its inception. Mr. Rodney Cherry, District Chief, and his staff have continued to provide wide-ranging support for technical water-resources investigations in South Carolina.

During both phases of the investigation there were many local officials, water superintendents, water-works managers, and individuals who provide information, support and encouragement for the study. Many well-drilling contractors and consulting engineers provided access to their files, and allowed project personnel to collect geologic samples and water-quality data from wells. During the test-drilling project, several County and

S. C. Department of Highways and Public Transportation officials provided assistance in locating test-drilling sites on County or State rights-of-way. Several private citizens also provided sites on their property. All of these individuals have our gratitude.

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SUMMARY OF WATER RESOURCES

AQUIFER SYSTEMS

GENERAL

In the Low Country area, ground water occurs in a thick sequence of sedimentary rocks that can be subdivided into six major aquifer systems on the basis of similar hydrogeologic properties (fig. 3). In descending order (youngest to oldest) these are the Hawthorn-Recent, Tertiary Limestone (principal artesian), Black Mingo, Peedee, Black Creek, and Tuscaloosa Aquifer Systems. Several of these aquifer systems are generally equivalent, in whole or in part, to geologic formations that have been named and described by geologists in South Carolina and other parts of the Southeastern United States. However, as indicated earlier in this report, there are some terminology differences that should be explained.

The term 'aquifer system', as utilized by the SCWRC, refers to a succession of strata that have similar hydrogeologic (water-bearing and water-quality) characteristics. Thus, an aquifer system is a generally defined 'hydrogeologic unit'. An aquifer system, in some cases, may not be strictly equivalent to a formally named geologic formation, especially if that geologic formation is named or delineated on the basis of age.

An aquifer system normally contains many different strata or beds of different lithology (rock type). Thus, each of the aquifer systems in the Low Country area is composed of both confining beds (such as clay or marl) that do not readily yield ground water, and aquifers (such as limestone or sand) that do yield ground water to wells. Where hydrogeologic data are sufficient, a particular aquifer system can be more accurately subdivided into more detailed hydrogeologic units on the basis of lithologic, geophysical, water-bearing and water-quality (hydrologic) characteristics.

Currently, little information is available on the hydrologic properties of deeper aquifer systems in the Low Country area. Therefore, lithologic and geophysical data have been used to delineate the general boundaries of these aquifer systems. As mentioned in the 'Introduction', and as explained more fully in this section, the names applied to several aquifer systems correspond to the names of geologic formations in South Carolina.

The thickness and stratigraphic positions of aquifer systems in the area are presented in figure 3, a generalized cross section along a line from the town of Hampton to Fripp Island. This cross section indicates the coastward dip and general thickening of the sediments from northwest to southeast across the Low Country area. Although detailed hydrogeologic

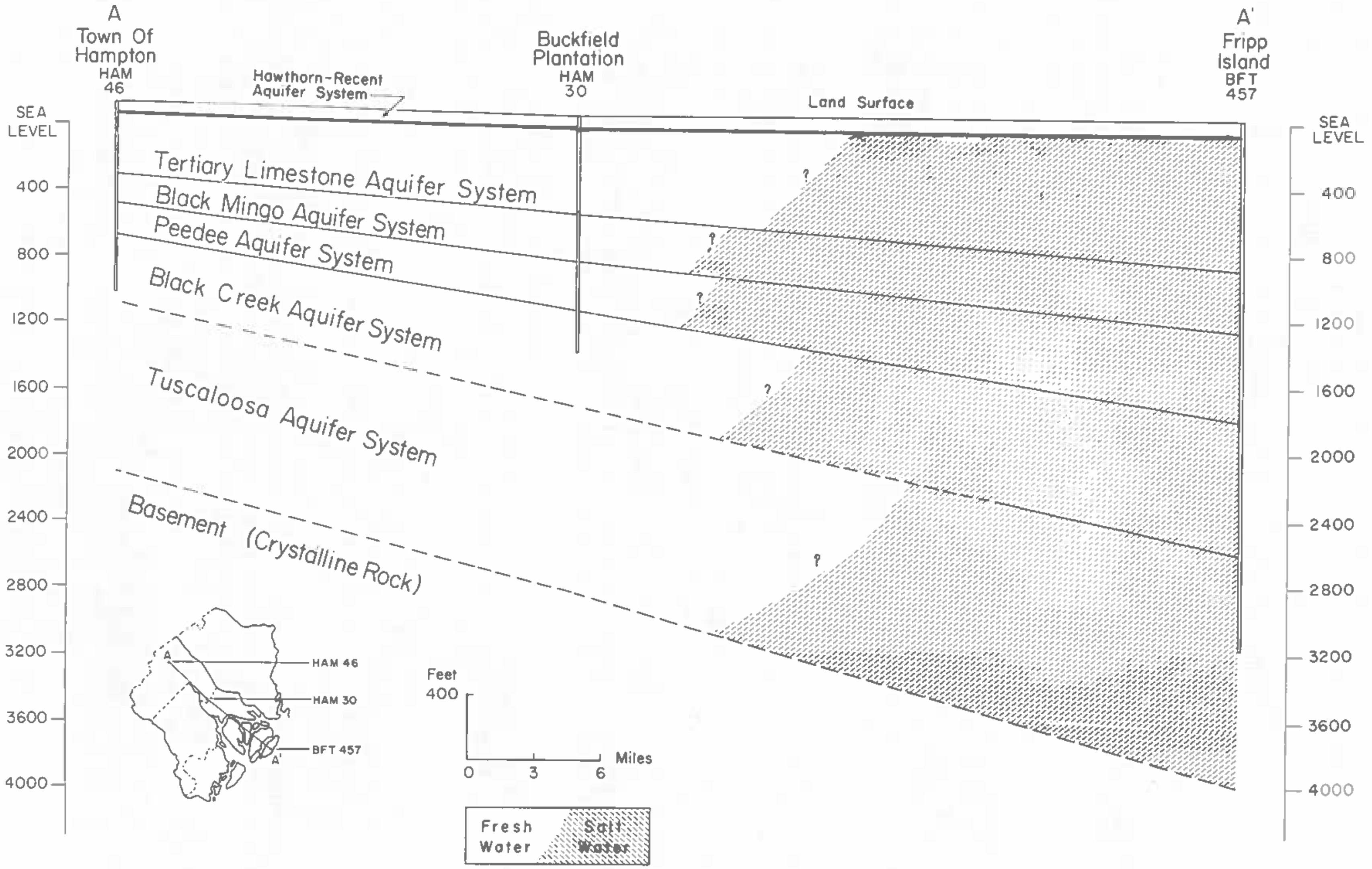


FIGURE 3. GENERALIZED HYDROGEOLOGIC CROSS-SECTION OF THE LOW COUNTRY AREA.

units in each aquifer system are not delineated in this cross section, the generalized positions of fresh and mineralized ground water in the aquifer systems are shown. The distribution of fresh and mineralized ground water in these deeper aquifer systems has an important bearing on overall ground-water availability and management in the Low Country area. However, because so little information is available on wells or test holes that have penetrated below the Tertiary Limestone Aquifer, the thickness, lithology, and hydrologic properties of the deeper aquifer systems are not well known in the Low Country.

The Tertiary Limestone Aquifer, the most important source of fresh ground water in the Low Country area and adjacent areas in Georgia, occurs at shallow depths (25-1,000 feet) throughout this coastal area. Wells drilled into this aquifer are called 'open-hole' or 'open-end' wells in reference to their method of construction. These wells do not contain screens. Screens are required in wells completed opposite deeper sand aquifers and are sometimes required in shallow sand aquifers within the Hawthorn-Recent Aquifer System.

Ground water in the Tertiary Limestone Aquifer and underlying aquifer systems occurs under artesian (confined) conditions and 'water levels' in the aquifers are defined by the height that water rises in tightly-cased wells completed in the aquifer. A line connecting points of equal pressure is the piezometric or potentiometric (pressure) surface, and is determined by measuring the water level in observation wells. In a few areas, ground water in the uppermost part of the Tertiary Limestone Aquifer and overlying shallow aquifers in the Hawthorn-Recent Aquifer System occurs under water-table (unconfined) conditions where water levels in wells is at atmospheric pressure.

The Tertiary Limestone Aquifer supplies over 80 percent of the ground water pumped from wells in the Low Country area. The remaining 20 percent is supplied from wells completed in aquifers of the Black Mingo, Black Creek, Tuscaloosa, and Hawthorn-Recent Aquifer Systems. As can be seen in figure 3, wells must be drilled deeper in the southern or southeastern part of the area in order to penetrate artesian aquifers. In addition to the greater cost of these deeper wells, mineralized ground water occurs in these deeper aquifers in coastal Beaufort County and possibly in southern Jasper and southern Colleton Counties. Shallow wells in the Hawthorn-Recent Aquifer System can be economically constructed. These shallow aquifers have been utilized in the past to supply drinking water to many rural-domestic (single household) users, but these shallow aquifers are not widely utilized as a source of water supplies at the present time.

In this report, frequent reference is made to certain water-quality terms such as 'salt water', 'fresh water', 'saline water', 'good quality', and 'mineralized water'. There are different technical connotations for several of these terms. For example, the term 'fresh water', utilized by the USGS, refers to water containing less than 1,000 mg/L total dissolved solids. However, in this report, the terms are used in a general sense as follows:

'Fresh water' refers to water containing 'relatively low' concentrations of dissolved solids (less than 500 mg/L) and chlorides (less than 250 mg/L). 'Salt water' refers to water containing greater than 500 mg/L dissolved solids. The term 'saline water', for the purpose of this report, is equivalent to the term 'salt water'. 'Mineralized water' is used in reference to water that generally contains excessive concentrations of dissolved solids (greater than 500 mg/L), but that may not necessarily contain high concentrations of chloride. For example, ground water from several deep artesian aquifer systems contain in excess of 1,000 mg/L total dissolved solids (i.e., 'high mineral concentrations'), but contains relatively low (less than 100 mg/L) chloride concentrations. 'Good quality water' refers to water that meets state and federal drinking-water standards. It must be remembered, however, that 'mineralized water' may not be 'poor quality water' for many uses, even for drinking-water supplies, if it is mixed properly with water of higher quality.

Because of its obvious importance in the Low Country, the hydrogeology of the Tertiary Limestone Aquifer has been emphasized during the Low Country Capacity Use Study. However, ground water from other aquifer systems or fresh water from surface-water sources are important and may become more important in the future. Therefore, the present utilization from these other sources is briefly summarized in this section; and the estimated future potential is discussed in as much detail as available data would allow.

TUSCALOOSA AQUIFER SYSTEM

The Tuscaloosa Aquifer System, the lowermost (oldest) of the Cretaceous aquifer systems in South Carolina, includes rocks between crystalline 'basement' rocks and the Black Creek Aquifer System (fig. 3). The major geologic formation in this aquifer system is the Tuscaloosa Formation, which is referred to by some geologists in the Carolinas as the Middendorf Formation. Preference for the term 'Tuscaloosa' is based primarily on the fact that the term is commonly used by ground-water hydrologists and geologists and is a more familiar term to engineers, well-drilling contractors, and the general public.

Although not known precisely, the thickness of the Tuscaloosa Aquifer System in the Low Country is estimated to range from approximately 600 feet in northeastern Colleton County to more than 1,200 feet in the Savannah, Georgia area. The thickness of this aquifer system in the deepest well drilled in the Low Country (Bft-10) is approximately 850 feet.

The Tuscaloosa Aquifer System is the major source of ground water in the Upper Coastal Plain of South Carolina and has been tapped by some wells in the Lower Coastal Plain. Many large-capacity wells withdraw ground water from this aquifer system in the Upper Coastal Plain northwest of the

Low Country area in Aiken, Barnwell, and northern Allendale Counties (Siple, 1967a). The term 'Tuscaloosa' is so widely known by engineers, well-drilling contractors, and others that many believe that any well in the Coastal Plain that yields 1,000 gpm must be completed in the 'Tuscaloosa'. However, in the Lower Coastal Plain, this aquifer system is not presently tapped as a major source of ground-water supplies.

Several wells or test holes have penetrated the entire thickness of this aquifer system in nearby Dorchester and Charleston Counties. However, in the Low Country area, the entire thickness of the Tuscaloosa Aquifer System has not been penetrated (i.e., no test hole to basement rocks), and only six wells are known to have screens opposite Tuscaloosa aquifers. Four of these wells are located in coastal Beaufort County--two on Parris Island (Bft-10, -11), well Bft-454 on Hilton Head Island, and well Bft-457 on Fripp Island. The other two wells are located in Walterboro (Col-49, -50). These six wells are also partially screened in the Black Creek Aquifer System, and each of these wells penetrate only the upper part of the Tuscaloosa Aquifer System (see fig. 3, for example).

Although more detailed descriptions of rocks in the Tuscaloosa Aquifer System exist, they are basically fine-to coarse-grained sands with some gravel, interbedded and (or) alternating with beds of clay. In general, the sands of the Tuscaloosa Aquifer System are somewhat coarser than those in the overlying Black Creek Aquifer System and are arkosic (i.e., contain feldspar). The clays of the Tuscaloosa are somewhat lighter in color than clays in overlying aquifer systems, with red and purple colors generally recognized as indicative of the non-marine depositional history of the Tuscaloosa Formation.

In the northern part of the Low Country area, data from two wells Col-49, -50) indicate that sand aquifers in the Tuscaloosa Aquifer System yield considerable quantities of good-quality water at Walterboro. Each of these two wells has a natural artesian flow of over 1,000 gpm. The pressure head in these wells at land surface (about 90 feet above msl) is about 30 psi (pounds per square inch), which is equivalent to 160 feet of head above msl (Hayes, 1979, p. 25). North of the Low Country area near the city of Orangeburg, sand aquifers in the Tuscaloosa are capable of yielding large quantities of fresh water to wells (Siple, 1975). In northern Allendale County and in Barnwell County, Tuscaloosa aquifers are extremely permeable and yield large quantities of good-quality ground water to properly-constructed, large-diameter wells (Siple, 1967a). Therefore, reasonable interpretation of a currently limited amount of data suggests that at least in northern Colleton and Hampton Counties the Tuscaloosa will probably yield large quantities of fresh water to properly constructed wells. However, the Tuscaloosa Aquifer System has not been tapped to any extent in these counties because of the availability of ample supplies of ground water in overlying aquifers.

To the south in Beaufort County, there have been two known attempts at developing drinking water from Tuscaloosa aquifers. These two deep wells were drilled at Parris Island in 1939 in an attempt to develop supplemental drinking-water supplies for the MCRD. Well Bft-11 (Parris Island No. 1), drilled initially to a total depth of 2,830 feet, was completed in March 1940 with screens in the interval from 2,500 to 2,700 feet in the Black Creek and in upper Tuscaloosa sand aquifers. Water from this well contains low chlorides (10 mg/L), but contains 1,030 mg/L dissolved solids and high concentrations of fluoride (4.1 mg/L), sodium (412 mg/L) and bicarbonate (1,000 mg/L). This well was used for supplemental water supply at the MCRD during and after World War II. Well Bft-10 (Parris Island No. 2), completed in April 1941, was drilled to a total depth of 3,455 feet (the deepest water well test hole in South Carolina). During the drilling operations in 1939, water samples were taken at various depths, and the well was finally screened in Black Creek and Tuscaloosa aquifers. Ground water from this well contains excessive concentrations of sodium (550 mg/L), bicarbonate (1,250 mg/L), fluoride (6.0 mg/L), and dissolved solids (1,310 mg/L) and has a temperature of 39° C (101.4° F). The well has been used in the past to supply water to a swimming pool near the Rifle Range. Both of these deep wells at Parris Island have natural artesian flows of about 75 gpm; and shut-in pressures of about 50 psi, which is equivalent to 125 feet of water at sea level (Hayes, 1979, p. 25).

At Fripp Island, the Tertiary Limestone Aquifer contains very salty ground water that is unacceptable for most uses, including commercial irrigation. In order to develop higher quality water for commerical irrigation, well Bft-457 was drilled and was completed in the interval from 2,410 to 2,730 feet below land surface in the Black Creek and Tuscaloosa Aquifer Systems (see fig. 3). Ground water from these deep aquifers at Fripp Island is of much better quality than that in the overlying Tertiary Limestone Aquifer, and well Bft-457 is now used for commercial (golf-course) irrigation.

At Hilton Head Island, well Bft-454 was drilled into and completed in the Black Creek and Tuscaloosa Aquifer Systems in 1974 for the purpose of obtaining warm mineralized ground water for recreational use at a proposed health resort. The well was successfully completed, but plans for the resort never materialized and the well is currently not utilized. Ground water from this well is warm and contains high concentrations of sodium (480 mg/L), bicarbonate (1,130 mg/L), fluoride (4.3 mg/L) and dissolved solids (1,160 mg/L).

No wells or test holes are known to have penetrated the Tuscaloosa Aquifer System in Jasper County; therefore, the hydrogeologic properties of this aquifer system remain unknown in this county.

Information on a deep test well drilled in 1975 at the Savannah Airport and completed in the Tuscaloosa Aquifer System is provided in a consulting report by Thomas and Hutton Engineers (1976). Ground water from Tuscaloosa aquifers in this well is warm (119° F), and contains excessive concentrations of fluoride, sodium, bicarbonate, total dissolved solids, and iron. According to Thomas and Hutton, the best water quality in this well occurs in the interval from 3,090 to 3,220 feet. They report that ground water in the sand at 2,570 feet (Black Creek Aquifer System) is very high in chlorides and total dissolved solids.

Possible future development of ground water from the Tuscaloosa Aquifer System in the Low Country area can be summarized as follows:

(1) The known occurrence of good-quality ground water in the Tuscaloosa Aquifer System at Walterboro suggests good to excellent potential for developing additional high-capacity wells in possibly the northern two-thirds of Colleton County. Chances are good that ground water of usable quality (but possibly high in some chemical constituents) can be developed from Tuscaloosa aquifers in southern Colleton County.

(2) In Hampton County, the occurrence of large quantities of good-quality ground water from the Black Creek Aquifer System suggests an excellent chance that similar quantities and quality of ground water can also be developed from underlying Tuscaloosa aquifers in northern and probably southern Hampton County.

(3) If it can be shown that adequate quantities of good-quality ground water can be developed from the Tuscaloosa Aquifer System in southern Hampton County, this would suggest favorable chances for doing the same at least in northern Jasper County (possibly as far south as Ridgeland) and possibly northern Beaufort County.

(4) Information from the four deep wells in coastal Beaufort County indicates that Tuscaloosa Aquifers have high potentiometric heads, but may possibly have low hydraulic conductivities (permeabilities). Ground water from these wells contains excessive concentrations of some chemical constituents, and the water would have to be mixed with higher quality water to meet drinking-water standards. The successful completion and utilization of one well at Fripp Island for commercial irrigation is an indication that additional Tuscaloosa wells could be drilled in other areas for this purpose. However, the cost of drilling and completion of a deep Tuscaloosa well in coastal Beaufort County (in excess of $200,000) is not encouraging.

(5) The availability of sufficient quantities of good-quality ground water from overlying aquifers in Hampton and Colleton Counties will tend to discourage the drilling and completion of deeper, more expensive wells in the Tuscaloosa Aquifer System. If developed in the forseeable future, this aquifer system will likely be developed by large-diameter wells drilled for industrial or municipal use or possibly for large-scale irrigation.

The Tuscaloosa Aquifer System represents a tremendous source of available fresh ground-water supplies in the northern and northwestern Low Country area, a resource that is essentially undeveloped at this time. Although ground water from the Tuscaloosa Aquifer System in the southern Low County area contains some excessive mineral constituents, this aquifer system also represents a valuable resource. Potentially, ground water from the Tuscaloosa Aquifer System could be mixed with ground water from the Tertiary Limestone Aquifer to yield a water quality acceptable for many uses, even including drinking-water supplies. This procedure was used at the MCRD at Parris Island during and for a time after World War II. Ground water from Well Bft-11 was used as a supplemental water supply, and for other public-supply uses. In addition, if economic and environmental incentives become sufficiently favorable and if technical feasibility could be shown, it is possible that ground water from Tuscaloosa aquifers in the coastal area could be utilized in 'repressuring' the Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer in some areas.

It is entirely possible that ground water pumped from the Tuscaloosa Aquifer System at Hilton Head Island could be used alone or, certainly if mixed with ground water from the Tertiary Limestone Aquifer, for commercial irrigation. This technique would be expensive, but the potential benefits of reducing pumpage from the Tertiary Limestone Aquifer could be substantial.

BLACK CREEK AQUIFER SYSTEM

The Black Creek Aquifer System is one of the major aquifer systems in the S. C. Coastal Plain and has been tapped by several hundred wells. Aquifers within this aquifer system supply ground water to many wells in the southeastern Lower Coastal Plain, especially in Horry and Georgetown Counties. However, in the southwestern Lower Coastal Plain, this aquifer system occurs at greater depths and has been penetrated by less than 25 widely-spaced wells and test holes. Therefore, much less is known about the hydrogeology of this aquifer system in southwestern South Carolina. Sediments in the Black Creek Aquifer System dip to the south or southwest in the Lower Coastal Plain and are somewhat thicker in downdip wells (see fig. 3). The subsurface geology of this aquifer system is complicated in the Upper Coastal Plain (and probably in the Lower Coastal Plain) because the Black Creek Formation 'interfingers' and is in part equivalent in age to the overlying Peedee Formation and the underlying Tuscaloosa Formation. Thus, as has been generally recognized by geologists for many years, there is no clear, well-defined lithologic separation between these three Upper Cretaceous geologic formations in some areas.

The Black Creek Aquifer System has been completely penetrated by only a few wells in the Low Country; therefore, the hydrogeologic properties of this aquifer system are not well known in this area. In the Clubhouse Cross Roads Core Hole No. 1 in western Dorchester County, the Black Creek Aquifer System consists of approximately 500 feet of shell-rich limestones, dark carbonaceous clays, and clean, light-colored sands (Gohn and others, 1977). In the two municipal wells at Walterboro (Col-49, -50), the Black Creek Aquifer System consists of about 350 feet of fine to medium sands; silty, calcareous clays; and hard layers of calcareous, shell-bearing fine sand (Hayes, 1979). Downdip in Beaufort County in wells Bft-10, -11, -454, and -457, rocks of the Black Creek Aquifer System consist of approximately 700 to 800 feet of dark gray to black and greenish clay, sandy clay; and gray to white phosphatic, glauconitic, fine sand interbedded with dark-gray and greenish red clay containing nodules of pyrite and marcasite (see McLean, 1960; Hayes, 1979).

Regionally, there is one hydrologic characteristic of the Black Creek Aquifer System that generally differentiates it from overlying and underlying aquifer systems--the occurrence of high, often excessive concentrations of fluoride and its sodium bicarbonate-type ground water. For the past six years, the SCWRC and USGS have been cooperatively studying the occurrence, distribution, and geochemistry of fluoride and other chemical constituents in the Black Creek Aquifer System and other aquifer systems in the Lower Coastal Plain in order to more accurately define the vertical and lateral limits of fluoride-bearing aquifers. These studies were initiated because excessive concentrations of fluoride is one of the most troublesome problems facing municipalities and other public suppliers of drinking water. Two reports of this cooperative research contain more detailed information on the occurrence and geochemistry of fluoride in the Black Creek Aquifer System in Horry and Georgetown Counties (Zack, 1977; 1979).

In Hampton County, several large capacity wells tap the Black Creek Aquifer System. These wells produce large quantities (over 1,000 gpm per well) of good quality water with low concentrations of fluoride.

In Colleton County, the two municipal wells at Walterboro (Col-49, -50) yield large quantities of excellent quality ground water with low fluoride concentrations. These two wells withdraw ground water partly from sand aquifers in the underlying Tuscaloosa Aquifer System (see Hayes, 1979). Therefore, the water-quality characteristics of individual Black Creek or Tuscaloosa aquifers in these two wells are not known. Ground water from these wells has such an excellent water quality that ground water from both aquifer systems is likely of good quality.

In the southern part of the Low Country in Beaufort County, hydrologic information on Black Creek aquifers is rather meagre. A drill-stem test conducted during the drilling of well Bft-10 in 1939 at Parris Island indicated that ground water in the interval 1,850-1,900 feet in the Black Creek Aquifer System contained 925 ppm chloride (Siple, 1956). A water sample from a Black Creek aquifer in well Bft-457 at Fripp Island contained 1,100 mg/L of chloride (Hayes, 1979, p. 25). Therefore, as indicated schematically in figure 3, fresh water in the Black Creek Aquifer System becomes more mineralized toward the south or southwest. However, data are not presently available to delineate the boundary between fresh and mineralized water in this aquifer system. These analyses indicate that the quality of ground water in lowermost Black Creek and upper Tuscaloosa aquifers is better than in shallower Black Creek aquifers.

In areas immediately adjacent to the Low Country area, the Black Creek Aquifer System supplies large quantities of good quality ground water to properly-constructed wells. In Allendale County, several large-diameter irrigation and municipal wells withdraw water from this aquifer system. Several of these wells yield in excess of 1,000 gpm of good-quality water. In Orangeburg County, Siple (1975) reported that coarse and fine to medium sands within the Black Creek Formation and underlying Ellenton Formation (which he suggested was a part of the Black Creek Formation) probably have relatively high permeabilities, although no specific hydraulic data were available to Siple.

The data available indicate that the Black Creek Aquifer System yields large quantities of good quality ground water in Colleton and Hampton Counties and will possibly do so in much of northern Jasper County and northern Beaufort County. However, several attempts at obtaining large quantities of good-quality drinking water from this aquifer system in coastal Beaufort County have not been successful, and prospects of doing so are not promising. The high cost of deep, large-diameter wells and uncertainty of obtaining good-quality ground water from this aquifer system in coastal Beaufort and Colleton Counties and in southern Jasper County would tend to discourage attempts at developing Black Creek aquifers in these areas. The availability of ground water from shallower aquifers makes shallower wells more economical.

In areas where the Black Creek Aquifer System contains or is believed to contain good-quality water, the prospects for future development will probably be from wells drilled for industrial or municipal use, or for large-scale irrigation. Costs would generally be prohibitive for the majority of smaller ground-water users. As with the underlying Tuscaloosa Aquifer System, the Black Creek Aquifer System represents a tremendously valuable resource in the Low Country area, a ground-water resource that for practical purposes is currently undeveloped.

PEEDEE AQUIFER SYSTEM

The Peedee Aquifer System is the uppermost (youngest) of the Cretaceous aquifer systems in South Carolina, and is currently not a major source of large ground-water supplies in the Low Country area. As in other areas of the S. C. Lower Coastal Plain, sands within this aquifer system are relatively thin and fine grained, and are thus not conducive to the development of large well yields. These thin, fine-grained aquifers are generally not screened, and wells are generally extended deeper and completed in Black Creek aquifers.

Strata composing the Peedee Aquifer System in the southwestern Lower Coastal Plain consist of dark-colored clays; fine-to medium-grained sands, and impure, shell-bearing clayey limestones. As has been recognized by several geologists, strata in the Peedee Formation are so lithologically similar to the overlying Black Mingo Formation in the subsurface that there is no clear distinction between these two geologic formations. Thus, in many areas, the lithologic and (or) geophysical separation of the Peedee from the overlying Black Mingo and from the underlying Black Creek Aquifer System is currently subject to considerable individual interpretation.

In the Low Country area, the general lithology and thickness of beds in the Peedee Aquifer System are known from the six deep wells discussed previously and several other widely-spaced wells, mainly in Hampton County. Although this aquifer system occurs at shallower depths and is penetrated by more wells and test holes than penetrate deeper aquifers, specific borehole data on these wells and test holes (many of which were drilled many years ago) are not now easily obtained or are simply not available. Therefore, the current hydrogeologic evaluation of this aquifer system must be made from the interpretation of the few available geophysical and lithologic logs.

The hydrogeology of the Peedee Aquifer System in the Low Country area was summarized briefly by Hayes (1979, p.27). He concluded that rocks in this aquifer system do not appear to be of significant value as aquifers in the Low Country area. Some wells in the northwestern part of the Low Country area in Colleton and Hampton Counties may obtain some water from the Peedee Aquifer System, but specific data on these wells are unavailable. Siple (1975) suggested that several wells in Orangeburg County were withdrawing water from this aquifer system which indicates that Peedee aquifers may have some potential in nearby Colleton County.

In coastal Beaufort County, data from geophysical and drillers' logs of four wells (Bft-10, -11, -454, -457) indicate that strata in the Peedee Aquifer System consist primarily of fine-grained sediments such as clay or clayey, impure limestone that most likely function as confining beds rather than as aquifers. Although specific water-quality data are lacking, Peedee aquifers probably contain mineralized ground water in coastal Beaufort County (fig.3) and in southern Colleton and Jasper Counties.

In Beaufort County, where the overlying Tertiary Limestone Aquifer contains mineralized water, the occurrence of fresh water in the Peedee or overlying Black Mingo Aquifer Systems could be of significant importance to some water users. Siple (1960b) reported that two wells at Coosaw Plantation (Bft-59, -60) were reported as being 1,500 feet deep, which would indicate that they were drilled into the Peedee Aquifer System. Siple noted that the quality of water from these wells was similar to that found elsewhere in the Peedee aquifer north of the Low Country area. Therefore, an attempt was made during the Capacity Use Study to obtain geophysical and well-construction data from these wells, but the exact source of ground water from these wells could not be precisely determined. Thus, the occurrence of fresh water in Peedee aquifers in northern Beaufort County remains to be proven.

Prediction of the future ground-water development potential of the Peedee Aquifer System in the Low Country area is currently hampered by the lack of specific hydrogeologic information on Peedee aquifers. However, reasonable, but cautious, interpretation of the limited data available indicates that: (1) Peedee aquifers are thin, fine grained and probably contain mineralized ground water in coastal Beaufort County, and possibly in southern Jasper and Colleton Counties; (2) Peedee aquifers, if developed, will probably be developed with underlying and overlying aquifer systems in areas where these aquifer systems contain fresh water--in Hampton and northern Colleton Counties; (3) Peedee aquifers, if developed, will probably be in wells drilled for municipal or industrial use; and (4) The utmost care in screen selection and well construction will be required to obtain the optimum development from these thin and fine-grained Peedee aquifers.

BLACK MINGO AQUIFER SYSTEM

The Black Mingo Aquifer System includes all rocks between the underlying Peedee Aquifer System and the overlying Tertiary Limestone Aquifer System (fig. 3). This aquifer system includes the Black Mingo Formation of Paleocene (Midway) and Early Eocene (Wilcox) age, and other strata of Paleocene and Wilcox age that have been previously described in the Low Country or adjacent areas by several geologists. Therefore, the Black Mingo Aquifer System includes strata in the interval referred to as the Black Mingo Formation by Hayes (1979), and is equivalent to the Clayton Formation and rocks of Wilcox age in the Savannah area that were described by Counts and Donsky (1963).

In the Low Country area, hydrogeologic information from wells or test holes that penetrate rocks of the Black Mingo Aquifer System is available from several rather widely spaced holes. The deep wells in Beaufort County discussed previously (Bft-10, -11, -454, -457) penetrated the entire thickness of this aquifer system. Wells at Walterboro (Col-49, -50) and several other wells in Colleton and Hampton Counties (Ham-30, -46, -72, -92) have also penetrated the entire thickness of this aquifer system. Some hydrogeologic data are also available on several wells drilled into or through the Black Mingo Aquifer System in adjacent Dorchester and Charleston Counties, South Carolina, and in Chatham County, Georgia.

In deep wells in coastal Beaufort County, the Black Mingo Aquifer System consists primarily of dark clays overlain by impure limestone that contains thin chert beds. To the northwest in Hampton and Colleton Counties, the Black Mingo Formation as described by Hayes (1979) consists of green-gray clay; phosphatic, glauconitic, fossiliferous limestone; fine to medium light-gray sand; and shell fragments. In the Clubhouse Crossroads Core Hole No. 1, the Black Mingo Aquifer System occurs at a depth of 410-800 feet and consists of gray-green silty or sandy clays; muddy sands; and thinly interbedded sands and clays and shelly limestones.

Because of its shallower depth in Hampton and Colleton Counties, the Black Mingo Aquifer System has been penetrated by more wells than have penetrated deeper aquifer systems. Hayes (1979) reported that approximately 25 wells open to the Black Mingo Formation in Hampton and Colleton Counties have natural artesian flows of 50 to 250 gpm per well of good-quality water, with artesian pressures ranging from 25 to 30 psi at land surface. Water quality analyses from three wells in Hampton County (Ham-34, -49, -85; see fig. 8) and one well in Colleton County (Col-70) indicate that this aquifer system contains good-quality water at these locations (see Fig. 2 for locations).

In Beaufort and Jasper Counties, Black Mingo aquifers are not known to be tapped by wells; thus, the water-bearing properties and chemical quality of ground water in the Black Mingo Aquifer System are not known in these counties. Both Siple (1960b) and Hayes (1979) suggested that in Beaufort County, rocks equivalent to the Black Mingo are unlikely to yield significant quantities of fresh water; and Hayes indicated that the lack of deep wells in Jasper County prevents an adequate appraisal of the potential of this aquifer system.

Limited hydrogeologic data are available on the Black Mingo Aquifer System in areas adjacent to the Low Country. In Orangeburg County, Siple (1975) suggested that Lower Tertiary sand and limestone aquifers may supply moderate yields to wells. In adjacent Dorchester and Charleston Counties, the Black Mingo occurs at shallower depths and is generally developed in conjunction with the overlying Tertiary Limestone Aquifer. In adjacent counties in Georgia, there are apparently little hydrogeologic data available on Lower Tertiary rocks. Counts and Donsky (1963) discussed only one well that penetrated rocks of Midway age (the Clayton Formation) and rocks of Wilcox age in Chatham County (well Cha-357). In this well the Clayton Formation contained 21,400 ppm of dissolved solids; therefore, Counts and Donsky believed that the overlying Wilcox sediments would also contain highly mineralized water.

The present and future development potential of the Black Mingo Aquifer System is largely unknown at this time. From the lithologic and geophysical data available, it appears that the fine-grained rocks in the Black Mingo Aquifer System would tend to function more as confining beds in coastal Beaufort County. Therefore, from the data available at this time, it would appear that the Black Mingo Aquifer System cannot be relied upon to relieve the draft on the Tertiary Limestone Aquifer in the coastal area where it is most needed. Available information indicates that the greatest potential will continue to be in Hampton and Colleton Counties where aquifers in the system can be tapped by wells less than 1,000 feet deep.

At least several test wells need to be completed in the Black Mingo Aquifer System in Jasper County, at least as far south as Ridgeland, in order to determine the quantity and quality of ground water available from this aquifer system. If test wells indicate that Black Mingo aquifers contain sufficient quantities of fresh water, properly-constructed Black Mingo wells might relieve some of the draft on the Tertiary Limestone Aquifer.

TERTIARY LIMESTONE AQUIFER

EXTENT AND UTILIZATION

The Tertiary Limestone Aquifer as it is referred to in South Carolina by the SCWRC, extends continuously from South Carolina into Florida. Depending on the locality, this aquifer system has been variously referred to as the principal artesian aquifer, Floridan aquifer, Ocala aquifer, principal limestone aquifer, Santee aquifer, and more recently as the Southeastern limestone aquifer. Since it is not everywhere the 'principal' aquifer, nor is it necessarily 'artesian', several of the above names are probably more appropriate. The term Tertiary Limestone Aquifer is preferred by the Geology-Hydrology Division of the SCWRC over the term principal artesian aquifer; however, the two terms are considered synonymous and are used interchangeably in this report.

The Tertiary Limestone Aquifer occupies a large geographical area in the S. C. Coastal Plain (fig. 4) and supplies ground water to hundreds of wells. In the central Coastal Plain in parts of Orangeburg, Dorchester, Berkeley, and southwestern Georgetown and Williamsburg Counties, this aquifer occurs at or near land surface and is tapped by many small-diameter wells less than 100 feet deep. In many locations throughout its 'updip' extent in the central Coastal Plain, ground water in the aquifer occurs largely under unconfined conditions, although artesian (confined) conditions are common. Toward the south and southeast (in southern Berkeley, Charleston, and Dorchester Counties) the aquifer is capped by confining beds of the Cooper Marl and artesian conditions predominate. In the Low Country, the aquifer system again occurs near land surface in the Beaufort area, and confining beds vary from esentially zero to more than 150 feet in thickness. Ground water occurs mainly under artesian conditions, but locally, confining beds are thin or absent and unconfined conditions occur.

For several reasons the Tertiary Limestone Aquifer is the most important source of ground water in the Low County area. Wells generally less than 250 feet deep tap this aquifer system throughout the area. Simple well construction means that wells can be constructed at much less cost than screened wells; and in much of the area, this aquifer system is the only source of good-quality ground water. It is conservatively estimated that over 4,000 wells tap this aquifer in the Low Country area, and that this aquifer system probably supplies over 80 percent of the ground water used in this area.

There have been many studies conducted on the Tertiary Limestone Aquifer in the Southeast, particularly in Florida and Georgia. However, in South Carolina, the hydrogeologic properties of this aquifer system have not been as well defined. When the Low Country study began in 1973, there had never been a comprehensive, sufficiently-funded investigation of this aquifer system in the Low Country area. In the Savannah area, the USGS had completed several local or regional reconnaissance investigations in

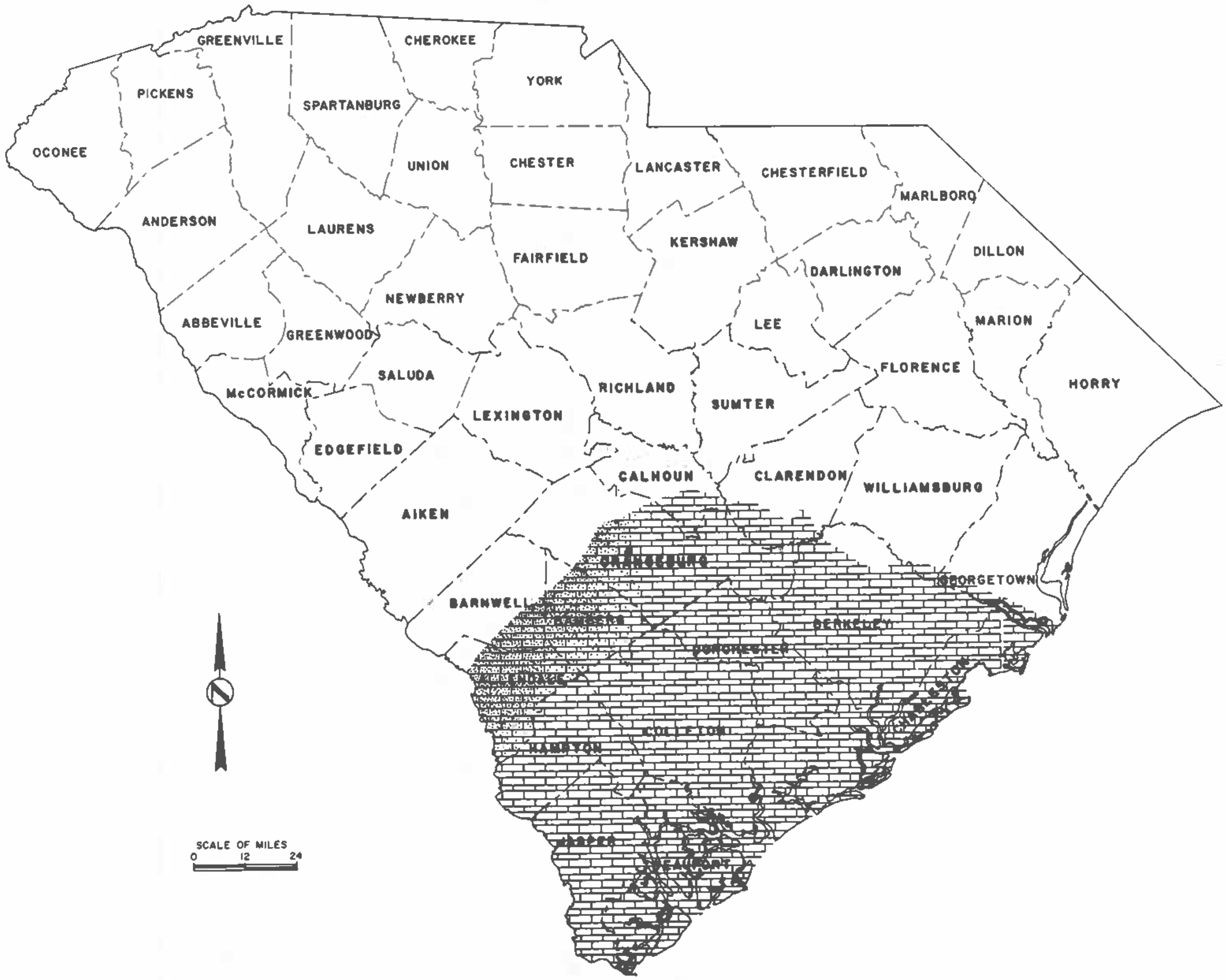


FIGURE 4. DISTRIBUTION OF THE TERTIARY LIMESTONE AQUIFER IN THE SOUTH CAROLINA COASTAL PLAIN.

the late 1930's and 1940's. More comprehensive investigations were conducted by the USGS in the 1950's and early 1960's that concentrated on the Savannah area, although the reports did include some information on the aquifer primarily in southern Jasper and western Beaufort Counties (Counts and Donsky, 1963; McCollum and Counts, 1964). In the Beaufort area of South Carolina, the USGS had completed several short-term investigations for the U. S. Navy in 1944 (Mundorff), and in the late 1950's (Siple, 1956, 1960b). A hydrogeologic investigation (Duncan, 1972; Colquhoun, 1972) conducted in the immediate Port Royal area as part of the Port Royal Sound Environmental Study in the early 1970's concentrated on the physical characteristics of the confining beds overlying the Tertiary Limestone Aquifer.

Despite the many test holes and water wells that had been drilled into the Tertiary Limestone Aquifer in the Low Country area (mostly concentrated in the Beaufort area), these existing data points were not sufficient to satisfactorily 'map' the subsurface distribution of this aquifer throughout the Low Country area. Therefore, as reviewed earlier, the project test holes were drilled into or to the base of this aquifer system in the area to provide additional information (fig. 2, and appendix table 1). Most of these test holes were completed as 4-inch wells, and additional hydrologic data were obtained from the completed wells. These wells were of critical importance in determining the lateral and vertical limits of the aquifer and permeability distribution within the Tertiary Limestone Aquifer.

GENERAL GEOLOGY AND STRUCTURE

Geologic Units

Various geologic formations, or parts of formations, comprise the Tertiary Limestone Aquifer in the S. C. Coastal Plain. In the updip region (fig. 4), the Tertiary Limestone Aquifer is composed almost entirely of the Santee Limestone, although locally the upper part of the Black Mingo Formation could logically be considered part of the aquifer. In the Low Country area, the Tertiary Limestone Aquifer is mainly composed of the Santee Limestone of Claiborne (Middle Eocene) and Jackson (Late Eocene) age, and in some areas a limestone of Oligocene age and a thin limestone of Miocene age in southwestern Beaufort County. The Santee Limestone is considered the downdip and offshore equivalent of the Warley Hill, Congaree, McBean, and Barnwell Formation recognized in the Middle and Upper Coastal Plain (Colquhoun and others, 1969). The Santee Limestone is primarily composed of limestone which varies from relatively 'pure' limestone to impure limestone containing clay or shale, and relatively thick 'marls'. In the Low Country area, the Santee Limestone was subdivided by Hayes (1979, p. 28) into three main lithologic (or geologic) units which are summarized as follows: The *uppermost unit* consists of white, cream-colored, or light-gray fossiliferous limestone and, in places, is composed almost entirely of fossil remains; this unit ranges in thickness from essentially zero to more than 200 feet. The *middle unit* consists of impure, sandy or clayey limestone and ranges from 200 to 600 feet thick. The *lower unit* is an indurated, siliceous, glauconitic, light-gray to creamy-yellow limestone that averages about 30 feet in thickness.

Oligocene limestone overlies the Santee Limestone in some areas (primarily southwestern Beaufort County) and is considered to be part of the Tertiary Limestone Aquifer. In other areas, rocks of Oligocene age may be water-bearing and thus part of the aquifer, or non-water-bearing and thus part of the overlying confining beds. These rocks of Oligocene age have either been unnamed (Counts and Donsky, 1963), referred to as the Cooper Marl (Hayes, 1969), or considered part (or the equivalent) of the Santee Limestone as suggested by Comer (1973), among others.

A thin (5 to 15 feet thick) Lower Miocene limestone, called the Tampa Limestone by Counts and Donsky (1963), and the 'Tampa Limestone equivalent' in eastern Chatham County by Furlow (1969), overlies Oligocene rocks in southwestern Beaufort County and southern Jasper County. Depending on location, this thin limestone has been considered part of the Tertiary Limestone Aquifer or either part of the overlying confining beds (Siple, 1960b; Counts and Donsky, 1963). This thin limestone is hydrogeologically important for several reasons. Counts and Donsky (1963, p. 28-29) noted that wells open to the Tampa Limestone have a noticeably high content of hydrogen sulfide which imparts a rotten egg odor to the water. Thus, if a driller does not extend casing through this unit, the well may yield ground water with a higher than normal odor of hydrogen sulfide. Secondly, as pointed out by Furlow (1969) and by Hayes (1979), this unit (composed of phosphatic sand, sandy marl, or sandy clay in eastern Chatham County and southwestern Beaufort County) occurs just above the Oligocene-Miocene boundary and was identified on the basis of gamma-ray log deflections which allows good correlation between wells where lithology alone is insufficient. The base of this thin stratigraphic unit in southwestern Beaufort County was chosen primarily on the basis of gamma-ray log deflections and was included in the Hawthorn Formation by Hayes (1979). In the vicinity of Port Royal, this unit is either absent or is only a few feet thick; and although not mentioned, the Tampa Limestone was apparently considered as part of the overlying Hawthorn Formation by Colquhoun (1972). Northeast of the immediate Beaufort area, this thin limestone unit is apparently absent over the crest of the Beaufort Arch, or the unit is indistinguishable from the Hawthorn Formation. The third fact concerns whether this thin unit is or is part of the 'cap rock' that is part of the confining bed in the Beaufort-Port Royal area. The nature of this 'cap rock' is summarized in a later section of this report.

In this report, as in Hayes' report, the base of the Tertiary Limestone Aquifer is considered as the top of the Black Mingo Aquifer System (fig. 3). However, as pointed out by Counts and Donsky (1963), in reality, the 'effective' base of the Tertiary Limestone Aquifer is determined more by lithologic or hydrogeologic characteristics (i.e., water-bearing or water-quality characteristics) than by geophysical or stratigraphic criteria. As shown later by McCollum and Counts (1964) and Hayes (1979), the Tertiary Limestone Aquifer is composed of several major hydrogeologic units, each of these composed of several aquifers and confining beds.

Geologic Structure

Geologic structure has an important influence on the hydrogeology of the Tertiary Limestone Aquifer in the Low Country area. As pointed out by Siple (1965), the regional structural setting of the aquifer influences the occurrence and extent of salt-water encroachment in this aquifer, the thickness of confining beds or absence of confining beds over the aquifer, and the permeability distribution, particularly in the upper part of the aquifer. Thus, the position of the top of the Tertiary Limestone Aquifer, with respect to msl, has been important in the past geologic history of this aquifer and also is important at the present time.

Prior to the Low Country study, the lack of well control prevented the construction of more than generalized regional structure maps of the top of the limestones comprising the Tertiary Limestone Aquifer. G. E. Siple (1965, fig. 3) prepared a regional structure map of the top of Eocene to Miocene limestone (i.e., the Tertiary Limestone Aquifer) that showed a basin structure in southern Jasper County and one in the Charleston area. He named a structural high in central Beaufort County the 'Burton high', a feature later named the Beaufort Arch (Heron and Johnson, 1966). McCollum and Counts (1964, plate 1) constructed a generalized structure map of the top of the Tertiary Limestone Aquifer in the Savannah area which showed the regional trend or slope of the top of the aquifer.

A structure map of the top of the Tertiary Limestone Aquifer in the Low Country area was prepared from information obtained from several hundred water wells and test holes (fig. 5). This map indicates that the upper surface of the aquifer has a regional dip (or slope) generally toward the southeast, but this surface is highly irregular with structural 'highs' and 'lows' interrupting the regional dip. The greatest control in preparing the map is in Beaufort County where the greatest number of geophysical logs and test-hole data are available.

The most conspicuous and hydrogeologically important structural feature in the Low Country is the Beaufort Arch, a structural high with a northeast-trending axis in central Beaufort County (fig. 5). Over the axis of the Beaufort Arch, the top of the Tertiary Limestone Aquifer ranges from about 40 to 20 feet below msl and locally is close to land surface--less than 20 feet below msl (figs. 6 and 7). This shallow depth means that in the Beaufort area, tidal rivers and estuaries (e.g., the Coosaw River) that are more than 20 feet deep actually penetrate the upper surface of the Tertiary Limestone Aquifer. As pointed out by several hydrologists (Siple, 1960b; Duncan, 1972), during Pleistocene time when sea level was much lower than it is at present, the top of the aquifer in the Beaufort area was 'scoured' by rivers flowing into the sea. Thus, Miocene confining beds that were deposited originally over the Eocene limestone composing the aquifer were removed in some areas. In the late 1800's and early 1900's, 'river phosphate' was mined from Miocene deposits in some of these

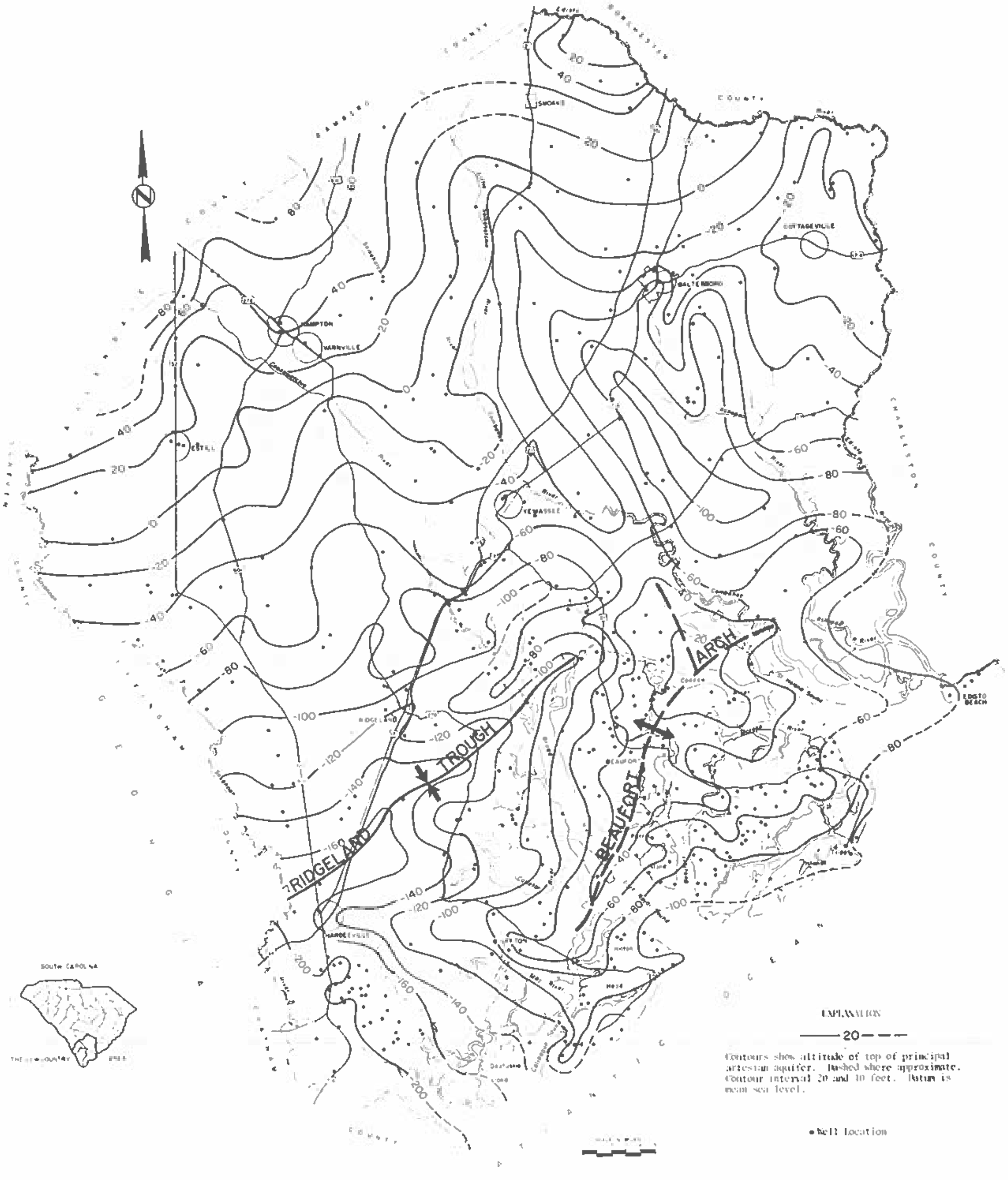


FIGURE 5. STRUCTURE-CONTOUR MAP OF THE TOP OF THE TERTIARY LIMESTONE AQUIFER (AFTER HAYES, 1979).

shallow tidal rivers in the Beaufort area (see Rodgers, 1914). It has also been suggested that dredging in recent times has also been responsible for removing confining beds in the Beaufort River (Siple, 1956; Duncan, 1972). It is presently unknown exactly what effect dredging has had on removing confining beds in the tidal rivers in the Beaufort area. It would now be impossible, in the absence of historical data, to accurately and economically assess the relative effects of dredging and other factors that have contributed to the removal of confining beds overlying the Tertiary Limestone Aquifer in the Beaufort area. The questions concerning the hydraulic function of these confining beds and their relation to salt-water contamination of the Tertiary Limestone Aquifer are discussed in later sections of this report.

A structural low, the Ridgeland Trough, has a northeast-trending axis extending from just northwest of Hardeeville, Jasper County, to the vicinity of Highway 21 in northern Beaufort County (fig. 5). Along the axis of this structural basin, the top of the Tertiary Limestone Aquifer occurs at an elevation of greater than 160 feet below msl, and in southwestern Jasper County the top of the aquifer occurs at an elevation of more than 200 feet below msl.

In reference to ground-water hydrology, these geologic structures are important with respect to the depth of the Tertiary Limestone Aquifer below salty surface-water bodies. They are also important because confining beds overlying the aquifer are thick in structural basins or troughs, and are thin over structural highs. Thus, the structural setting of the Tertiary Limestone Aquifer is important in regard to ground-water development and any ground-water management program that may be initiated in the Low Country area.

HYDROGEOLOGIC UNITS

Ground water in the Tertiary Limestone Aquifer occurs in solutionally-enlarged openings or cavities in the limestone. These openings and thus the hydraulic properties of the aquifer system vary considerably both in lateral (horizontal) and vertical directions. In general, ground water occurs in a series of broadly-defined water-bearing (permeable) 'zones' that have been traced throughout the Low Country area with the aid of geophysical and mechanical logs (primarily gamma-ray and caliper logs), and information from test holes and many water wells (Hayes, 1979). These zones consist of water-bearing (permeable) zones that serve as aquifers. These permeable zones are separated by less permeable rocks. McCollum and Counts (1964) delineated five major permeable zones in the aquifer at Savannah and traced the four upper permeable zones to test well Bft-304 on Daufuskie Island and well Bft-101 on Hilton Head Island; however, only the two upper zones were present at well Bft-315 on the northern end of Hilton Head Island (fig. 6). As shown in figure 6, the permeable zones in the Tertiary Limestone Aquifer dip toward Savannah, and are parallel to the

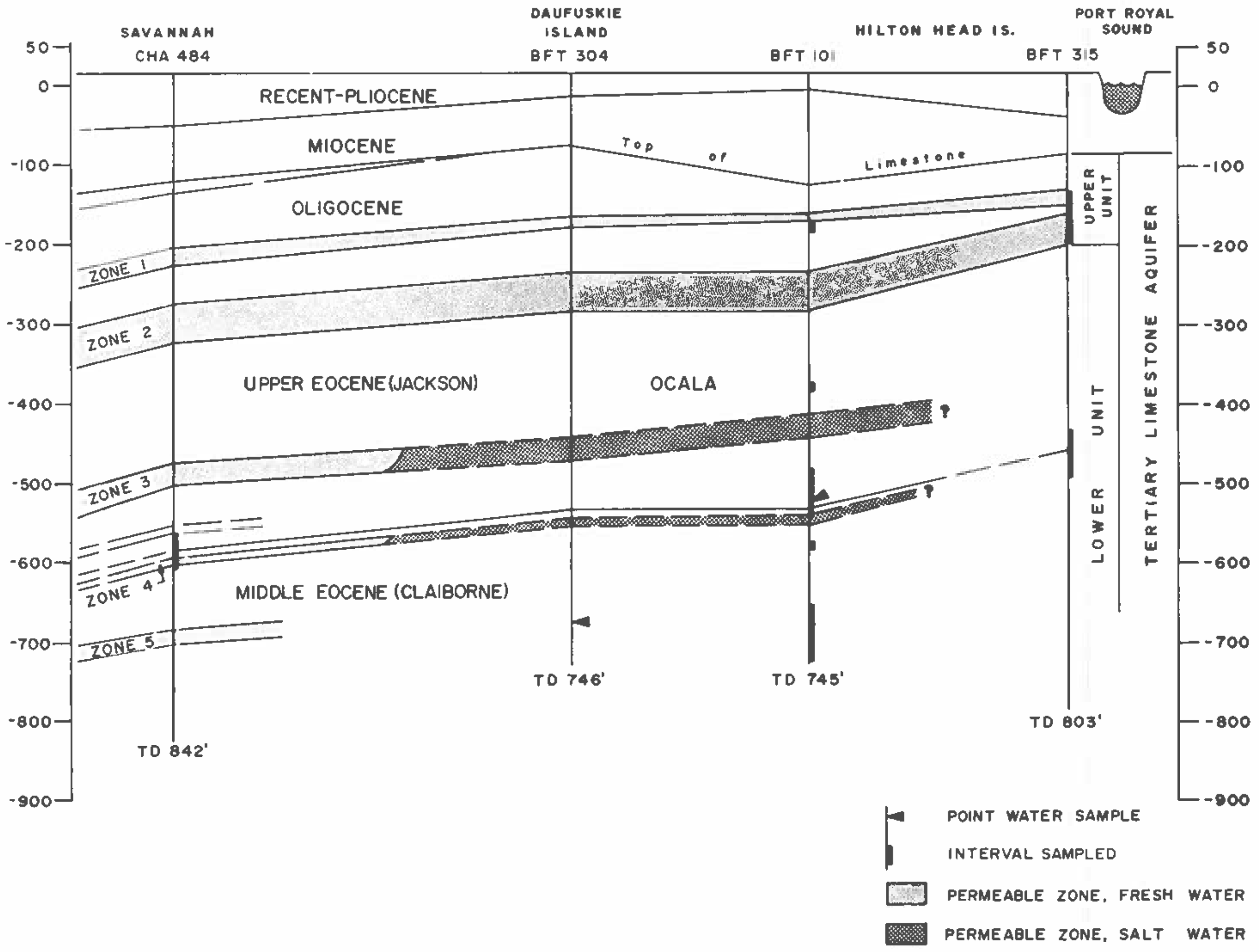


FIGURE 6. HYDROGEOLOGIC CROSS-SECTION OF THE TERTIARY LIMESTONE AQUIFER FROM SAVANNAH TO PORT ROYAL SOUND. (MODIFIED FROM McCOLLUM AND COUNTS, 1964)

geologic unit (or 'formation') boundaries. This parallelism of water-bearing zones and geologic units is important in understanding and 'mapping' hydrogeologic units throughout the Low Country area.

Using information from project test holes, other test holes, and water wells, the Tertiary Limestone Aquifer has been subdivided, for the purposes of this report, into two major hydrogeologic units in the Low Country area (see figs. 7 and 8). The delineation of these hydrogeologic units was based on lithologic, geophysical, and water-bearing (hydrologic) characteristics and current-meter tests run in selected test holes. These data were then correlated with lithologic and geophysical data in wells where current meter data were unavailable. These two hydrogeologic units consist of (1) an *Upper Hydrogeologic Unit* that contains an upper permeable zone delineated by Hayes (1979); and (2) a thick *Lower Hydrogeologic Unit* that is partly water-bearing but has relatively low permeability compared to the Upper Unit. Based on current-meter tests, Hayes (1979) identified a lower permeable zone near the base of the Lower Hydrogeologic Unit that is water-bearing but has a low permeability compared to the upper permeable zone.

The division of the Tertiary Limestone Aquifer into two major hydrogeologic units is done informally for the purpose of this report as an aid in explaining the water-bearing properties, use, and water-quality characteristics of this aquifer system. The division of a limestone aquifer system on the basis of permeable and impermeable 'zones' is a well-accepted practice in limestone hydrology where sufficient hydraulic (permeability) data are available. However, in the case where insufficient data exist (such as in Jasper County where few wells penetrate below the upper part of the Tertiary Limestone Aquifer System), it is rather difficult to discuss 'permeable' zones. Thus, we prefer to call this lower part of the Tertiary Limestone Aquifer the Lower Hydrogeologic Unit.

The Upper Hydrogeologic Unit is composed primarily of the upper part or unit of the Santee Limestone, but it also contains limestones of Oligocene and Miocene age, mainly in southwestern Beaufort County. As pointed out by Hayes, few wells in Jasper County penetrate below the Upper Unit; *thus, the hydrogeologic properties of the Lower Hydrogeologic Unit of the Tertiary Limestone Aquifer are unknown in Jasper County.*

As shown in figures 7 and 8, most of the Tertiary Limestone Aquifer is composed of the Lower Hydrogeologic Unit. Thus, permeable zones (aquifers) constitute a small part of the total thickness of the Tertiary Limestone Aquifer. *Although the Lower Unit is water-bearing in many places, the Upper Unit generally has a greater overall permeability and will yield much greater quantities of ground water to wells.*

According to Hayes (1979), the upper permeable zone is not present in southern Colleton County, and wells withdraw ground water from the Lower Hydrogeologic Unit. Therefore, in figure 7 (which is modified from Hayes' figure 8) we have extended the Upper Hydrogeologic Unit into southern Colleton County, but not the upper permeable zone.

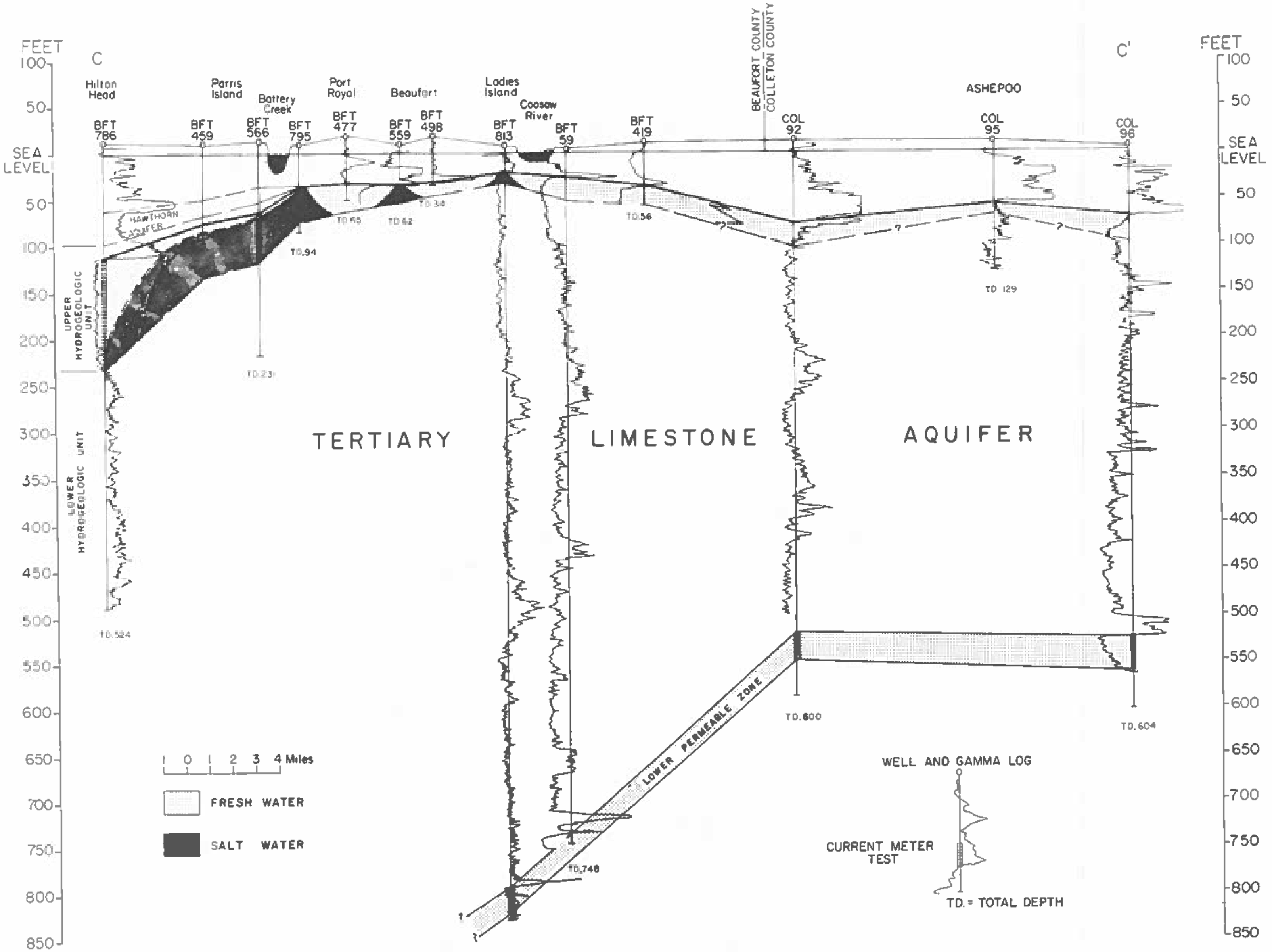


FIGURE 7. HYDROGEOLOGIC CROSS-SECTION OF THE TERTIARY LIMESTONE AQUIFER IN BEAUFORT AND COLLETON COUNTIES (AFTER HAYES, 1979).

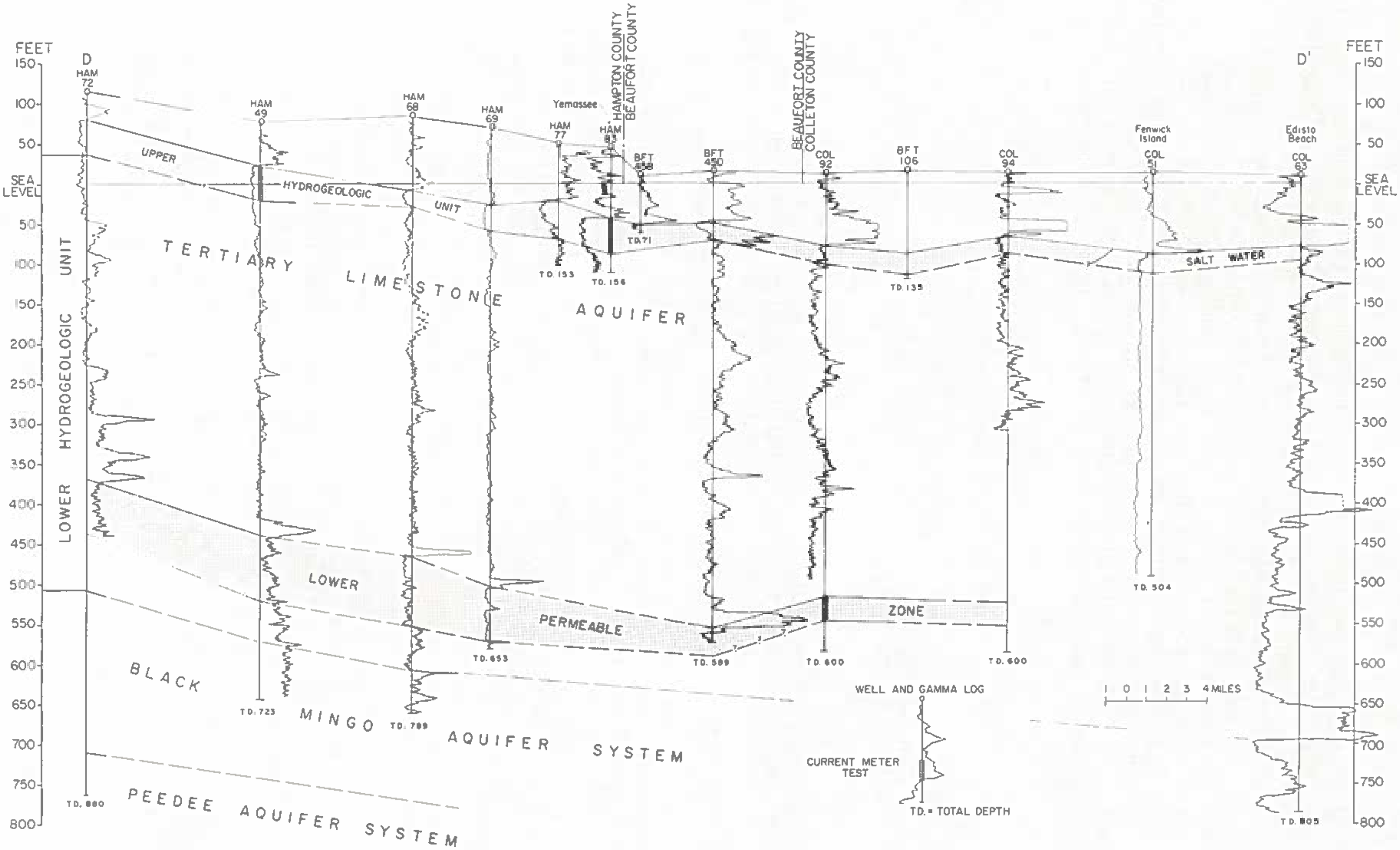


FIGURE 8. HYDROGEOLOGIC CROSS-SECTION OF THE TERTIARY LIMESTONE AQUIFER SHOWING UPPER AND LOWER HYDROGEOLOGIC UNITS (AFTER HAYES, 1979).

In Hampton County, the Lower Hydrogeologic Unit also occupies much of the Tertiary Limestone Aquifer (fig. 8). The Upper and Lower Hydrogeologic Units are generally parallel to lithologic units which all dip toward the southeast in Hampton County. In parts of northern and northwestern Hampton County, the Upper Hydrogeologic Unit is close to land surface (fig. 8), and some recharge probably takes place by downward leakage through overlying confining beds of Pleistocene and Miocene age. In southern Allendale County, some data have been collected which indicate that the Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer is overlain by less than 100 feet of sands, and at some locations there are few or only very thin clays (that would serve as confining beds) overlying the Tertiary Limestone Aquifer.

Upper Hydrogeologic Unit

Distribution and Utilization

The Upper Hydrogeologic Unit is more-or-less equivalent to the two uppermost permeable zones delineated by McCollum and Counts (1964) in southwestern Beaufort County (figs. 6 and 9). Current-meter tests conducted by McCollum and Counts indicated that 70 percent of the ground water yielded by one well in the Savannah area came from the two upper permeable zones (i.e., the Upper Hydrogeologic Unit). Therefore, these two zones supply most of the ground water pumped from the Tertiary Limestone Aquifer in the immediate Savannah area. The Upper Hydrogeologic Unit contains the shallowest and most permeable water-bearing zone (upper permeable zone) in the Tertiary Limestone Aquifer. This upper permeable zone occurs throughout the subsurface of Jasper and Hampton Counties and most of Beaufort County (Hayes, 1979). However, as noted by Hayes, the upper permeable zone 'thins' over the Beaufort Arch and is not present in southern Colleton County (fig. 7).

The Upper Hydrogeologic Unit is tapped by hundreds of wells in the Low Country area, and this unit supplies most of the ground water used from the Tertiary Limestone Aquifer. In Jasper County, this unit supplies practically all of the ground water used from the Tertiary Limestone Aquifer, although there may be some wells that have not been inventoried that withdraw ground water from the Lower Unit. In some areas of the coastal parts of the Low Country, water-bearing zones in the Lower Unit contain salty water (fig. 6) and the Upper Unit is the only source of fresh ground water.

The depths of wells that tap the Upper Unit range from less than 50 feet in the vicinity of the Beaufort Arch, to more than 200 feet in Jasper County (figs. 5 and 7). In many areas, the upper part of the Upper Unit is the most permeable; consequently, many wells, especially small-diameter domestic wells, tap only the upper few feet of this unit.

Hydraulic Properties

It is not possible, nor particularly relevant, in this report to provide more than a very brief review of the principles of ground-water hydraulics, especially as these principles should be applied to carbonate-rock aquifers. The interested reader is referred to a more thorough discussion in SCWRC Report No. 9 which also contains additional literature on this subject.

The hydraulic properties of aquifers are determined primarily by pumping a well at a known discharge and observing water-level decline (drawdown) in the pumping well or in nearby observation wells completed in the same aquifer (or water-bearing zone). An *aquifer test* is one where at least one observation (non-pumping) well is available for measuring drawdown. A single well *pumping test* (sometimes called a 'capacity test' or a 'well performance test') is one where only the pumping well is available for measuring drawdown. A properly conducted aquifer test is one of the most useful tools in ground-water hydrology for appraising the hydraulic (water-bearing) characteristics of an aquifer and hydraulic performance of wells. The single well pumping test, while not as useful in appraising aquifer or well performance, is also an extremely valuable tool for appraising the hydraulics of a well, and in evaluating the hydraulic characteristics of aquifers.

In South Carolina, the value of these tests has not always been recognized by those designing or constructing wells, and certainly not by most well owners. Most persons are simply unaware of the importance of these tests--not just their value to a ground-water hydrologist, but *for the well owner* as a record that can be of extreme importance in appraising initial well performance and its performance over a period of time. Too often, in an attempt to limit well costs, a properly conducted pumping test is omitted. Unfortunately, this is not the place to cut well costs (except perhaps for a well owner needing only several gallons per minute). Therefore, it should not be suprising that the hydraulic properties of the Tertiary Limestone Aquifer (or of any other aquifer) are so poorly known even though many wells have been completed in this aquifer in the Low Country area. *We feel rather strongly that the lack of proper hydraulic testing is a ground-water problem in the Low Country area.*

Most of the available hydraulic data on the Tertiary Limestone Aquifer are for the Upper Unit in coastal Beaufort County. Of the 14 aquifer that have been conducted (or at least the ones with data available to the SCWRC and USGS), twelve of these are in coastal Beaufort County (Seven of these twelve are on Port Royal Island). Of the 59 pumping tests with mathematical data available, only 17 of these tests have been for a period of 8 hours or longer. Thus, conclusions regarding the hydraulic properties of the Upper Unit of the Tertiary Limestone Aquifer throughout the whole Low Country area must be regarded as of a 'reconnaissance' nature at this time. However, reasonable interpretations can be made concerning the hydraulic properties of the Upper Unit when the mathematical data are properly utilized in conjunction with the test drilling, lithologic and drillers' logs, and the digital model developed by Counts and Krause (1976).

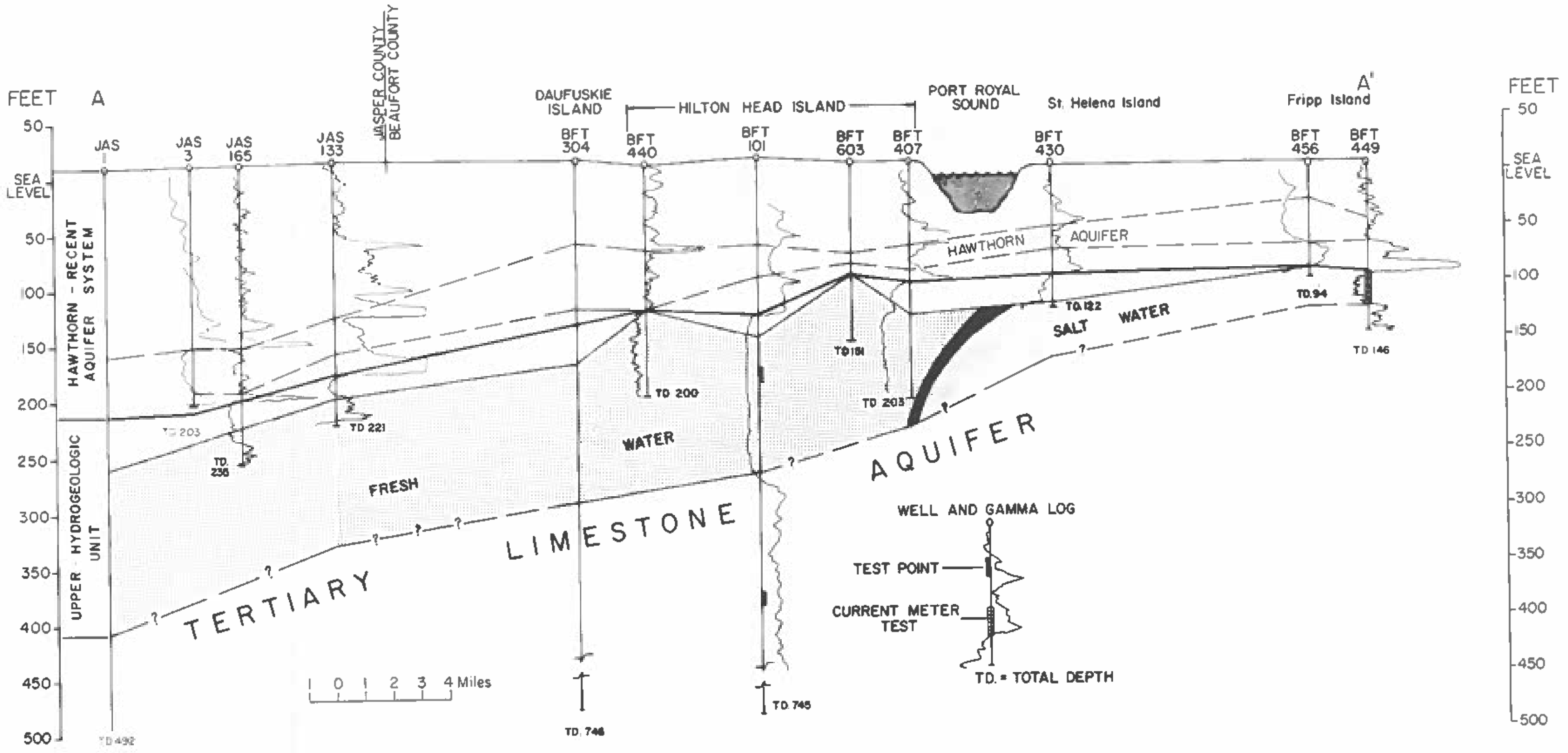


FIGURE 9. HYDROGEOLOGIC CROSS-SECTION OF THE TERTIARY LIMESTONE AQUIFER SHOWING UPPER HYDROGEOLOGIC UNIT (AFTER HAYES, 1979).

As is common with most limestone (i.e., rock) aquifers, the hydraulic properties of the Upper Unit vary considerably in a relatively small area. However, when considered over a fairly large area (several square miles or tens of square miles), the Upper Unit behaves hydraulically as a leaky, diffuse-flow aquifer. This means that certain hydraulic equations and methods can be reasonably applied to the quantitative hydrogeologic evaluation of this hydrogeologic unit. The confining beds overlying the Upper Unit (and possibly confining beds immediately below this unit) are not completely impermeable and they allow a certain amount of vertical groundwater leakage into this unit. Although the amount of leakage is locally small, it can be considerable over a large area (see Hayes, 1979).

As with most sedimentary-rock aquifers, the horizontal permeabilities of the Upper Unit can be reasonably presumed to be much greater than vertical permeabilities. This fact has an important bearing on the movement of ground water and the rate of lateral salt-water movement into and through the Upper Unit. Hayes (1979, fig. 13) showed that the horizontal permeabilities of the Upper Hydrogeologic Unit are locally highly variable; but there is a regular pattern of decreasing permeabilities from southwest to northeast into southern Colleton County where the permeability of the Upper Unit decreases considerably, and the upper permeable zone is absent.

The greatest calculated permeabilities of the Upper Unit are in southwestern Beaufort County (i.e., southwest of the Broad River) where the Upper Unit is several times 'more permeable' than it is northeast of the Broad River on Port Royal Island. These data indicate that for wells with the same pumping rates, drawdown (water-level declines) will be greater in wells located northeast of the Broad River-Port Royal Sound. Therefore, although some wells on Port Royal Island, for example, can be pumped at high rates, it would not necessarily be as 'safe' to do so as it would be southwest of the Broad River. Unfortunately, southwest of the Broad River-Port Royal Sound, the Upper Unit is susceptible to lateral salt-water encroachment, and intrusion. *Therefore, the location of extremely high-capacity wells or well fields, especially in coastal Beaufort County, should be carefully designed and constructed, and properly located.*

In the event that a ground-water management program is initiated for the Low Country area, the design, location, spacing, and construction of large-capacity wells in this area would be carefully evaluated. In addition, greater attention to proper hydraulic testing of new wells would be stressed. Such testing is strongly recommended, even if a capacity use area is not declared.

Ground-Water Quality

As stated elsewhere in this report and as summarized by Hayes (1979), the chemical quality of ground water from the Upper Hydrogeologic Unit is suitable for drinking-water and other uses (except where contaminated by salty water). Except for the occurrence of excessive concentrations of chlorides and other mineral constituents, generally where salt-water contamination is a problem, ground water from the Upper Unit generally meets federal and state primary and secondary drinking-water standards. Uncontaminated ground water from the Upper Unit is a calcium-bicarbonate type ground water that contains low concentrations of chloride (less than 25 mg/L), dissolved solids, fluoride, sodium, iron, and other chemical constituents. As discussed later in this report, water-quality data throughout the Low Country area as a whole are currently at less than reconnaissance-level, as the number of complete chemical analyses is rather limited. Additional water-quality data are now being collected as part of the planning-level ground-water study now in progress.

Lower Hydrogeologic Unit

As previously discussed and as illustrated in figures 7 and 8, much of the Tertiary Limestone Aquifer in the Low Country is composed of the thick Lower Hydrogeologic Unit that in some areas contains a lower permeable zone. Based on current information, the broadly defined Lower Hydrogeologic Unit is comprised of various geologic units of Claiborne (Middle Eocene) age which are considered to be the lower (Claiborne age) parts of the Santee Limestone.

Most project test holes were drilled into the Lower Unit, and geologic samples and geophysical logs were obtained in order to correlate these data to wells where only a gamma-ray log or other type of log was available. These test-hole data were correlated with geophysical information (primarily gamma-ray logs) obtained from existing wells. Therefore, as shown in figures 7 and 8, it was possible to trace the Upper and Lower Units from well to well throughout the area. However, in many existing wells the only borehole data that could be obtained was a gamma-ray log (which can be obtained from a cased well). *Therefore, the hydrogeologic (water-bearing) properties of the Lower Hydrogeologic Unit are poorly known in much of the Low Country.*

Wells that are drilled into the Lower Unit are also usually open to the Upper Unit. Therefore, unless current-meter data are available, it is generally impossible to accurately determine the amount of water supplied to a well from water-bearing zones in each hydrogeologic unit. Similarly, a down-hole water sampler is needed to accurately determine the quality of ground water in each unit. The most accurate hydraulic and water-quality data from aquifers in the Lower Unit are from test wells cased through the Upper Unit and open only to Lower Unit aquifers. Currently, several Lower Unit test wells have been constructed--these located in coastal Beaufort County (fig. 2 and appendix table 1). One multi-aquifer observation well station was constructed on the northeastern end of Hilton Head Island during the Low Country study (fig. 2, wells Bft-786, -788). As previously mentioned, funding or time were not available during the Low Country study to construct at least several more of these multi-aquifer test wells where the data are needed to fully evaluate the hydrogeology of the entire Tertiary Limestone Aquifer. Currently, no test wells have been constructed and no water wells are known that are open only to the lower permeable zone in the Lower Hydrogeologic Unit.

The Lower Hydrogeologic Unit is not a single hydrogeologic unit. It is a thick complex unit that is composed of both aquifers and confining beds. However, the water-bearing zones (aquifers) within the Lower Unit are relatively thin and not as permeable as those in the Upper Unit. Prolific aquifers do not occur in the Lower Unit because these rocks are primarily 'impure' limestone or marl. Therefore, water-bearing solution cavities in this unit are not as thick and laterally extensive as those in the Upper Unit. Consequently, the large well yields that can be obtained from the Upper Unit (especially from the Upper permeable zone) in many areas generally cannot be obtained from the Lower Unit.

Lower Permeable Zone.--Currently the hydrogeologic characteristics of this zone are poorly known. Since no wells are known to be open only to this zone, additional knowledge must be obtained from current-meter and downhole sample tests before reasonable interpretations of the hydrogeology of this zone can be made.

As shown in several multi-zone test wells, aquifers in the Lower Unit contain saline formation water in the coastal parts of the Low Country (see, for example, fig. 6). Chloride and dissolved solids generally increase with depth in these zones; therefore, drilling a well deeper into the Lower Unit of the Tertiary Limestone Aquifer in these areas will not obtain better quality water.

Inland from the coastal area in northern Beaufort County and in Hampton and Colleton Counties, Lower Unit aquifers contain fresh water. However, as previously mentioned, water-quality data on these aquifers are poor, especially in Jasper County. Presumably, fresh water could be obtained from Lower Unit aquifers, at least in northern Jasper County.

In some areas of Hampton and Colleton Counties and possibly in northern Beaufort County, potentiometric head (or 'artesian pressure') of aquifers in the Lower Hydrogeologic Unit is believed to be greater than the potentiometric head of the Upper Unit. This belief is based on the fact that increases in artesian pressure were noted as some test holes penetrated deeper; and the potentiometric head of the Upper Unit has been reduced as a result of ground-water withdrawals. Thus, in some areas, it may be possible to obtain flowing artesian wells by tapping aquifers in the Lower Unit, whereas shallower wells completed in the Upper Unit no longer flow. In some cases, if a well penetrates and is uncased through both the Upper and Lower Units, ground water could flow upward from a Lower Unit aquifer and into the lower-head Upper Unit. This probably would also occur in open-hole wells drilled in much of Jasper County where the potentiometric head of the Upper Unit has been substantially reduced as a result of large ground-water withdrawals from this unit at Savannah (see fig. 14). It must be emphasized that hydraulic data on Lower Unit aquifers is so limited that upward movement of ground water from the Lower Unit is more speculation than documented fact.

Although the potentiometric head and hydraulic data from aquifers in the Lower Unit are admittedly poor, it is possible that head differentials may be sufficiently large to be utilized to some extent in 're-pressurizing' the Upper Unit of the Tertiary Limestone Aquifer, perhaps in southern Jasper County. However, in some areas at least, sufficient head differentials may not exist. This principle of using multi-aquifer recharge wells has been utilized in Florida and in other states (often to dewater an upper aquifer as a convenience more than as a ground-water management tool). *The same principle may prove to be useful in 're-pressurizing' the Upper Unit with ground water from deeper artesian aquifers in the Black Mingo, Black Creek, or Tuscaloosa Aquifer Systems.*

Important factors in determining technical feasibility would be the hydraulic properties and ground-water quality of aquifers in the Upper and Lower Hydrogeologic Units and in lower aquifers. At this time, lack of economic incentive and lack of a ground-water management program are deterrents to the use of this type of ground-water management tool in the Low Country. It is possible, perhaps probable, that environmental incentives may in the future become economic incentives for the use of recharge wells. A 'prime' area for consideration is in southern Jasper County or southwestern Beaufort County in the area most influenced by pumpage at Savannah. Georgia and South Carolina hydrologists should investigate the feasibility of installing a recharge-well system in southwestern Jasper County. Water users in South Carolina have a lot to gain if successful. We would also suggest that the USGS, as part of their regional aquifer system analysis, may want to consider the installation of one or several test wells in southern Jasper County.

FUTURE DEVELOPMENT

The Tertiary Limestone Aquifer is the most important source of ground-water supplies in the Low Country and adjacent counties in the Savannah, Georgia area. The future of this important aquifer system in continuing to supply large quantities of good-quality ground water, especially over the long term, is currently uncertain. In the past, this aquifer system has been developed with little thought to ground-water management.

Over the 'immediate' short term (the next 5 to 10 years or perhaps 20 years), if *new very large* concentrated withdrawals are not made (i.e., maintain the current 'status quo' of ground-water pumpage), then ground-water problems should not be expected to worsen dramatically. However, it is unrealistic to expect that the 'status quo' is going to remain, even over the short term. *It would also be unrealistic and technically incorrect to believe that additional ground-water withdrawals from this aquifer system can not be safely developed. However, there are certain problems associated with the past and present ground-water development from this aquifer system that must be realistically and effectively addressed if this aquifer is going to continue to supply large quantities of good-quality ground water to wells.*

If no ground-water management measures are initiated in the Low Country-Savannah area, and if the aquifer is developed as it has been in the past, the effects of any *improper* development will be seen over the immediate short term (they already have in some areas), and most certainly over the long term. As stated previously in the 'Introduction' and as discussed later in this report, there are certain ground-water management measures and options now available (which may or may not be available 5 to 10 years from now) that can be utilized in solving or at least mitigating additional ground-water development problems.

As reviewed in this section, the Tertiary Limestone Aquifer System is 400-700 feet thick, but the available fresh-water aquifers (permeable zones) within this aquifer system constitute a much smaller thickness. The upper part of this aquifer system, the Upper Hydrogeologic Unit, contains the most prolific aquifers, the best water quality (except where contaminated by salt-water), and is the most heavily pumped part of the Tertiary Limestone Aquifer. *The most crucial short-term and long-term question involves managing the available fresh-water supplies of this Upper Hydrogeologic Unit in the most practical and beneficial manner.*

HAWTHORN-RECENT AQUIFER SYSTEM

The Hawthorn-Recent Aquifer System, for the purpose of this report, includes all sediments of Miocene, Pliocene, Pleistocene, and Holocene (Recent) age that overlie the Tertiary Limestone Aquifer. The thickness and distribution of these sediments are shown in several general cross sections (figs. 7, 8, and 9), and the thickness and lithology are shown in more detailed cross sections (figs. 10, 16, and 17). These sediments include the Middle Miocene Hawthorn Formation, Upper Miocene (?) to Pliocene (?) Duplin Formation, and unnamed sediments of Pleistocene and Holocene age. As previously mentioned, the thin Tampa Limestone unit could also be considered part of the confining beds in southwestern Beaufort County. All of these deposits, for simplicity, are informally referred to as the Hawthorn-Recent Aquifer System in this report.

Much of the information on the geology of the rocks comprising this aquifer system has been collected by geologists interested in stratigraphy or mineral deposits, or by engineers concerned with foundation conditions. During the 1960's many shallow mineral exploration test holes were drilled by mineral companies interested in the phosphate resources in the Hawthorn Formation. Many shallow foundation test holes have been drilled in order to obtain undisturbed soil samples for engineering testing, especially in Beaufort County. *However, despite the many test holes and wells that have been drilled into and through these sediments, little is known about the precise water-bearing properties of these sediments in the Low Country area.* As stated previously, many of the samples are collected, analyzed, then discarded; and the test holes are filled and abandoned. *Thus, much potentially useful hydrogeologic information (particularly concerning permeability) is lost when these samples are discarded and the test holes are abandoned.*

Geologic studies that provide relevant borehole or other data that are useful in the hydrogeologic evaluation of this aquifer system have been conducted by Duncan (1972), Colquhoun (1972), Johnson and Geyer (1965), Heron and Johnson (1966), and Comer (1973). The hydrogeologic complexity of this aquifer system reflects, in part, the geologic complexity of the formations comprising the aquifer system. These geologic formations of Miocene to Holocene age were deposited during periods of geologic time that were strongly influenced by changes in sea level and other factors. Thus, the thickness and character (lithology, structure, sorting, mineralogy, etc.) of these sediments vary considerably from place to place, making geologic interpretation most difficult.

In the Low Country area, the hydrologic properties of sediments overlying the Tertiary Limestone Aquifer have been briefly summarized by Mundorff (1944), Siple (1956, 1960b), Counts and Donsky (1963), Duncan (1972), Colquhoun (1972), and Hayes (1979). These investigators have all discussed the fact that these sediments function both as aquifers and confining beds, and that the particular hydrologic function in a given area varies considerably over short distances. Therefore, closely spaced drilling and detailed hydrologic testing is needed in a relatively small area to accurately determine the hydrogeologic characteristics of the sediments. As shown in several reports, the hydraulic and water-quality characteristics of this aquifer system have an important influence on the hydrogeology of the underlying Tertiary Limestone Aquifer. One of the most important hydrologic functions of beds at the base of this aquifer system is as a confining bed over the Tertiary Limestone Aquifer.

NATURE OF CONFINING BEDS

A *confining bed* is a stratum (or bed) that has a relatively lower hydraulic conductivity (that is, permeability) than a vertically adjacent aquifer. The key phrase in the definition is 'relatively lower hydraulic conductivity'. Actually, no confining bed is completely impermeable because any confining bed has some measurable, finite permeability. The vertical and horizontal permeabilities of confining beds vary from 'barely measurable' (non-leaky) to 'fairly permeable', (but relatively lower than an adjacent aquifer). In some areas a certain bed or stratum may be referred to as a confining bed, but in another area the same bed or stratum (with identical permeabilities) may be an aquifer that is utilized to supply ground water to wells (even though in small amounts) because other strata are even less permeable.

Considerable attention has been focused on the hydrologic characteristics of the confining beds overlying the Tertiary Limestone Aquifer in the Low Country-Savannah area. At least as early as the investigations by Warren (1944) and Mundorff (1944), it has been known that confining beds over the Tertiary Limestone Aquifer at Savannah are relatively thick (over 100 feet) and provide an effective confining bed over the aquifer. However, as shown by Warren's 1880 potentiometric map, ground water in the Tertiary Limestone Aquifer once discharged by upward leakage through thin and relatively permeable confining beds in the Port Royal area. Mundorff's 1944 potentiometric map of this aquifer in the Beaufort area, and his discussions, provided further support that the confining bed over the Tertiary Limestone Aquifer is a leaky confining bed (i.e., not completely impermeable). It was suggested by Siple (1956) that long-time residents of the Beaufort-Port Royal area had reported the existence of fresh-water springs in Port Royal Sound. Additional information indicating the lack of effective confining beds over the Tertiary Limestone Aquifer in the Port Royal area was provided by Counts and Donsky (1963) and McCollum and Counts (1964).

There has been considerable discussion concerning the nature of a 'cap rock' overlying or at the top of the Tertiary Limestone Aquifer. The term 'cap rock', used locally by water-well contractors and others, has been discussed in several publications; and when taken in proper context with other statements should not be confusing. However, it has often been taken out of context. The term 'cap rock' has been used in reference to a hard, phosphatic bed of limestone or calcareous sandstone occurring in the base of the confining beds overlying or at the top of the Tertiary Limestone Aquifer in the Beaufort area (Siple, 1956; Duncan, 1972; and Colquhoun, 1972). The most complete description of this phosphatic 'cap rock' in the Beaufort-Port Royal area was provided by Colquhoun (1972) and Duncan (1972). Their observations were based primarily on analysis of data from holes drilled during the Port Royal Sound Environmental Study (SCWRC, 1972, p. 362-367, geologic logs). Colquhoun (1972, p. 76) stated: "The principal aquifer cap rock is very dense, hard, cherty limestone which is occasionally phosphatic. It is, however, *erratic in occurrence*...and was either absent or its presence was very questionable in Beaufort County holes 3, 5, and 11; and...there is ample evidence from the subsurface drilling that the *principal aquifer within the Santee Limestone and the secondary aquifers of the overlying Hawthorn Formation are interconnected." (Emphasis added.)*

Duncan (1972, p. 93) described the confining beds as: "Typically, the confining beds consist of a gray to olive green silt and sand interbedded with *thin discontinuous lenses* of marl and limestone. These confining beds vary vertically and horizontally in both thickness and character. The base of the confining beds is usually characterized by the occurrence of a very hard but relatively thin layer which is generally referred to as the 'cap' rock and is essentially composed of indurated limestone and phosphate. This layer, or cap rock, *when present, in sufficient thickness, along with the overlying sediments,* provide a very effective barrier to the vertical movement of water into and out of the underlying principal artesian aquifer." *(Emphasis added.)*

Since completion of the Port Royal Sound Study, one might get the impression that this thin (usually less than one to about three feet thick) 'cap rock' unit is 'the' confining bed; occurs without 'disruption' throughout the Beaufort area; is 'brittle'; and, if 'fractured' would result in rather wholesale introduction of salt water from estuaries into the Tertiary Limestone Aquifer. However, even in the immediate Port Royal area, early investigations by the USGS and Duncan and Colquhoun showed that this 'cap rock' is not everywhere present and is only part of the confining bed (which also consists of silt and sand, and lenses of marl and limestone) overlying the Tertiary Limestone Aquifer. *Therefore, it has been documented that confining beds over the Tertiary Limestone Aquifer are leaky and are not a completely 'impermeable protective cap' throughout the whole Low Country, especially in the Beaufort area.*

During the Low Country study, additional data were collected on the nature of the confining beds overlying the Tertiary Limestone Aquifer. The sources of these data were primarily from project test holes, various logs of engineering, stratigraphic or mineral exploration holes, drillers' logs of water wells, geophysical logs, and various foundation engineering reports. Rather than a lengthy discussion, and at the risk of overly simplifying a very technical concept, we prefer to summarize the data as follows:

(1) Hydraulic data from several aquifer tests and interpretation of potentiometric and all test-drilling data indicate that, as previously believed by Warren, Mundorff, and later hydrologists, the confining beds in the Beaufort area and in other areas vary considerably in thickness and character. These confining beds appear to be relatively impermeable in places (mainly clay, marl or hard limestone) and relatively permeable in other places (in some areas consisting mostly of sand). They are also absent in places--thus the Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer is not everywhere separated from overlying salty surface water by an effective confining bed. The variation in physical character of the confining bed is shown in figure 10 and in several more detailed cross sections in this report.

(2) In the immediate Beaufort-Port Royal area, particularly in the Beaufort River and Battery Creek, data from several test holes indicate the partial absence of confining beds thus confirming observations by Colquhoun (1972) and Duncan (1972) that confining beds and the 'cap rock' are thin, discontinuous, and erratic in occurrence (fig. 10; see also figs. 16 and 17).

(3) Sediment-filled 'sinks' in coastal Beaufort County, as believed by Siple (1956), apparently do represent breaks in the confining beds (even in the 'cap rock') in places. They are, however, apparently plugged by fine-grained material in some places. Thus, the 'sinks' do provide avenues for recharge (by leakage) to the underlying Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer.

(4) Sediments within the Hawthorn-Recent Aquifer System 'thin' over the Beaufort Arch (fig. 7) in Beaufort County, and overlying water-table aquifers are in hydraulic connection with the Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer.

(5) In the immediate Beaufort area, there are many places where the 'cap rock' was apparently removed by natural erosion during Pleistocene time, and by phosphate mining activities in the late 1800's and early 1900's and later by various dredging activities (see figs. 16 and 17). *Therefore,*

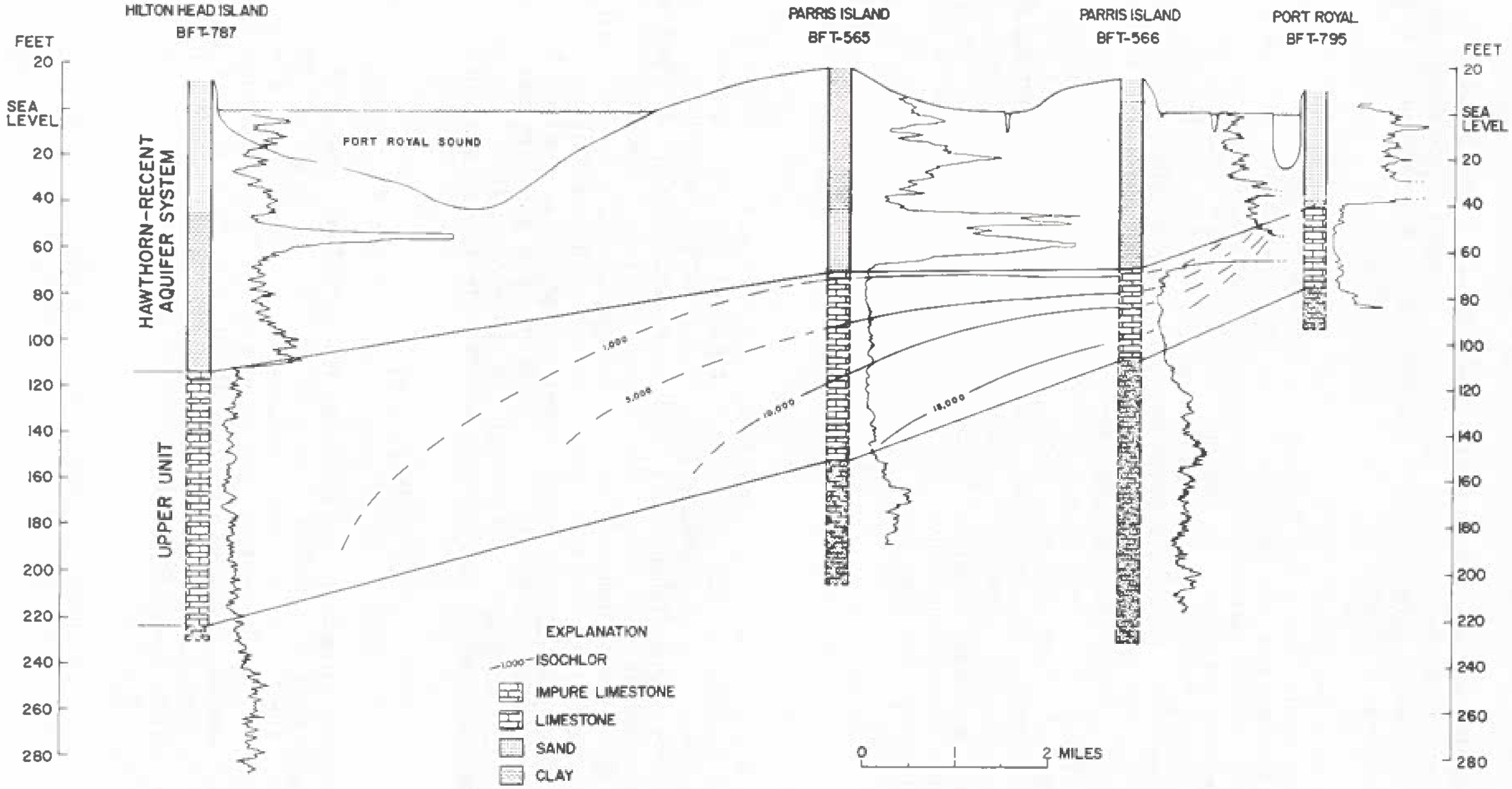


FIGURE 10. HYDROGEOLOGIC CROSS-SECTION OF THE TERTIARY LIMESTONE AQUIFER AND CONFINING BEDS, HILTON HEAD ISLAND TO PORT ROYAL.

there are undoubtedly many areas where ground water in the Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer is in direct contact with salt water, or perhaps separated by several to as much as 10 feet or more of silt, clay, or sand.

(6) *As reviewed later in this report, a leaky, discontinuous, and in places non-existent 'confining bed' cannot completely prevent downward salt-water movement from the Beaufort River, Battery Creek, and other salt-water streams in the coastal area into the Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer.* It has not done so in the past and will not do so in the future if sufficient hydraulic gradients exist. The physical character (lithology, thickness, vertical permeability) of the overlying confining beds is only one of two principle factors preventing salt water from entering the Upper Unit. *The second and most important factor is the potentiometric head of the Upper Unit which is discussed under 'Salt-Water Contamination'.* These factors were discussed long ago by Warren (1944), Mundorff (1944), and since that time by several USGS hydrologists. If the confining beds overlying the Tertiary Limestone Aquifer were 'completely impermeable', the ground-water flow lines on Warren's 1880 potentiometric map of the Tertiary Limestone Aquifer might not have 'pointed' toward the Parris Island-St. Helena Island area; but they did.

SHALLOW AQUIFERS

The thickness of sediments overlying the Tertiary Limestone Aquifer ranges from essentially zero (in several tidal rivers) to approximately 150 feet in southwestern Jasper County (fig. 9). In the Low Country area, shallow aquifers occur within these sediments primarily in the Hawthorn Formation and sediments of Pleistocene age (see figs. 7, 9, and 10). In some areas, the Duplin Formation may contain aquifers, but they tend to be thin and laterally discontinuous; thus, beds within the Duplin Formation tend to act as confining beds rather than as aquifers. Shallow aquifers in the Hawthorn Formation and Pleistocene sediments also are relatively thin and laterally discontinuous. Over much of the area, wells less than 25 to about 100 feet deep would tap shallow aquifers in these sediments.

Hawthorn Formation

The Hawthorn Formation overlies the Tertiary Limestone Aquifer in much of the southern part of the Low Country area, but is absent in other areas. Where present, the Hawthorn Formation consists of phosphatic, clayey sand, and sandy clay; sandy dolomitic limestone; and highly phosphatic, dolomitic, sandy, clayey limestone (Hayes, 1979). In addition to its function as the upper confining bed of the Tertiary Limestone Aquifer, in some areas of Beaufort and Jasper Counties the Hawthorn Formation contains water-bearing sediments (figs. 7 and 8).

In the Port Royal area, Colquhoun (1972, p. 76) found that the Hawthorn consists of (1) dark to light greenish, micaceous silty clays, often with chert and phosphate pebbles, (2) well-sorted medium to coarse, feldspathic, micaceous sands and (3) silty, clayey, bioclastic (shell-bearing) lime muds. He believed that the sands marked a 'secondary' aquifer within the region, but that these sands were limited in extent and erratic in occurrence.

Hayes (1979, p. 30) found that the middle section of the Hawthorn Formation in Jasper and southwestern Beaufort Counties was a fairly persistent, sandy, dolomitic limestone which he termed the Hawthorn aquifer (figs. 7 and 8). He believed that this aquifer would yield 50 to 200 gpm of fairly good-quality water to single wells. As defined by Hayes, the thickness of the Hawthorn aquifer ranges from zero in parts of the Low Country area to about 50 feet in southern Jasper County and in western Beaufort County. He presented chemical analyses of ground water from five wells that tap the Hawthorn aquifer in Beaufort County. The wells range from 37 to 130 feet deep.

The Hawthorn Formation thickens toward the southwest, and in the immediate Savannah area, aquifers in the Hawthorn supply ground water to hundreds of wells, although the yields are small because of low permeabilities and poor recharge (Counts and Donsky, 1963, p. 30). Counts and Donsky stated that the quality of water from Hawthorn aquifers varies locally, and the most noticeable property of the water is the odor of hydrogen sulfide gas. However, in eastern Chatham County, Georgia, the Hawthorn is a 'clayey marl' and acts primarily as a confining bed (see Furlow, 1969, plate 1).

Duplin Formation and Pleistocene Sediments

The Duplin Formation and overlying sediments of Pleistocene age occur discontinuously throughout the Low Country area, and their combined thickness rarely exceeds 100 feet. Thin, laterally discontinuous sand or shell-bearing sand aquifers occur in these shallow sediments, but little is known concerning the hydrologic characteristics of these aquifers.

In the Beaufort, South Carolina area, Siple (1960, p. 42-44) discussed the general geology and hydrologic properties of these sediments and probably summarized it best: "The water-bearing characteristics of these rocks have not been tested adequately, mainly because (1) in the inland areas they are tapped only by domestic wells and (2) in the vicinity of brackish or salty surface waters they are subject to lateral encroachment by brackish or salty water." Hayes (1979, p. 30) stated that the water-bearing characteristics of Pliocene to Holocene deposits are not well known, but that many shallow domestic wells obtain water from these deposits, particularly in Jasper County where the deposits are thickest.

The hydrologic properties of the Duplin Formation and shallower Pleistocene sediments in the Savannah area were briefly summarized by Counts and Donsky (1963, p. 31-35). Little specific hydrogeologic data were provided, and their discussion reflects the lack of data that were available to them on these sediments. Furlow (1969, plate 1) provided a generalized geologic cross section of Oligocene to Holocene sediments in eastern Chatham County, but did not discuss their hydrologic properties. From the lithologic logs presented in Furlow's plate 1, it would appear that the Duplin Formation in eastern Chatham County would function more as a confining bed than as an aquifer.

Where shallow aquifers are close to land surface, especially where water-table conditions prevail, these shallow aquifers are vulnerable to contamination from above. In the coastal Low Country area, the SCDHEC has been studying the hydrologic properties of shallow sediments in regard to the effects of waste-disposal practices on ground-water quality. Although the SCDHEC study is incomplete at this time, preliminary data suggest that shallow aquifers in some areas do contain fresh water, and in other areas extremely shallow sands are vulnerable to contamination from some waste-disposal practices (SCDHEC, 1978). The location of shallow-aquifer observation wells at sites adjacent to SCWRC observation wells promises to provide information on the relationship of shallow aquifers to the underlying Tertiary Limestone Aquifer.

Based on the limited hydraulic and water-quality information now available, the present and future potential of these shallow aquifers in the Hawthorn-Recent Aquifer System as sources of fresh ground water in the Low Country area cannot be determined with certainty. It is reasonable to assume that where these deposits are thickest, they will probably continue to be utilized for rural domestic supplies. However, in most areas, wells can be drilled into the underlying Tertiary Limestone Aquifer at the same or only slightly greater cost. *In some areas where the Tertiary Limestone Aquifer contains salty water, such as on Edisto Island, these shallower aquifers are an extremely valuable source of ground water.* Therefore, it would be judicious management to protect the quantity and quality of ground water in these shallow aquifers, particularly in areas where shallow aquifers are in hydraulic connection with the underlying Tertiary Limestone Aquifer, such as the area near Beaufort. *Utmost care should be exercised in protecting these areas from potential sources of contamination.*

In the immediate Savannah area, the Hawthorn Formation and overlying sediments of Miocene to Pleistocene age are as much as 400 feet thick. In some areas, sand or limestone aquifers in these sediments may have a combined thickness of 50 to 100 feet. Counts and Donsky (1963, p. 92) recommended a study of these shallow aquifers, including a test-drilling and aquifer-testing program, to aid in development of water supplies from these aquifers. They believed that such development would aid in relieving the draft (pumpage) on the Tertiary Limestone Aquifer in the Savannah area. The USGS has never conducted such a study and there are no immediate plans to conduct such a study by Georgia officials (David E. Swanson, verbal communication., 1979).

WATER USE

LOW COUNTRY

Water use can be functionally divided into many categories depending on how water is ultimately used, distributed, or withdrawn. Of primary importance in this investigation is *withdrawal use* rather than *non-withdrawal* (in-stream) *use*. Withdrawal uses include all uses where water is withdrawn or pumped, and conveyed to a point of ultimate use; these include public supplies, rural-domestic (single-household) supplies, irrigation, many types of industrial use, recreational use, and some forms of water use for fish and wildlife propagation. Water that is 'withdrawn' from flowing artesian wells is considered a withdrawal 'use', even though the water may not actually be put to a beneficial use.

The SCWRC is responsible for obtaining water-use data in South Carolina, and water-use reports are published at regular intervals. *Accurate water-use figures are difficult to calculate or estimate because most water users, except some municipal and industrial users, do not normally keep records of the amounts of water withdrawn or used.* The SCWRC is now in the process of upgrading its water-use program that produced the first Statewide water-use inventory in 1970, and the municipal and industrial water-use report in 1975 (Duke, 1977).

Ground water is the principle source of water supplies in the Low Country area and furnishes 100 percent of the drinking-water supplies for residents of Jasper, Hampton, and Colleton Counties, and for most of the residents of Beaufort County. The only significant withdrawal use of surface water is by the Beaufort-Jasper Water Authority that diverts approximately 5 to 8 Mgd of water from the Savannah River via a canal to the Beaufort area (fig. 11). Because of an inadequate supply of fresh surface water, Beaufort County must rely on the interbasin transfer of water from the Savannah River Basin into the Combahee River Basin. This lack of an adequate supply of fresh surface water was one factor responsible for Beaufort County's total reliance on ground-water supplies until completion of the Beaufort-Jasper Water Authority Canal in 1965. Similarly, the City of Charleston also depends on the interbasin transfer of surface water from the Edisto River into the Ashley or Cooper River Basins.

During phase I of the Low Country Capacity Use Study, a thorough water-use inventory could not be conducted because of priorities in technical data collection. However, most of the large public-supply (municipal and water district), industrial, and irrigation uses were inventoried. Because of the importance of the Tertiary Limestone Aquifer, emphasis was placed on inventorying pumpage from this aquifer in Beaufort County. During phase II, preliminary estimates of ground-water withdrawals were refined and additional data were collected on existing and newly constructed wells.

FIGURE 11. HYDROLOGIC MAP OF THE ACE AND LOWER SAVANNAH RIVER BASINS, SOUTH CAROLINA.

In the Low Country, few records of ground-water use are made by users and the pumpage from only a few wells is metered. Therefore, ground-water-use estimates are mainly based on known pump capacity and reported duration of pumpage. A preliminary water-use estimate made by SCWRC and USGS personnel during phase I of the capacity use study and reported in SCWRC Report No. 9, indicated that in December 1976 the estimated average daily ground-water *use* amounted to approximately 20 Mgd for public supply, rural-domestic, industrial, and irrigation uses. Currently (1978 estimates) in the Low Country area, the largest average daily *withdrawals* of ground water (35 Mgd) are from the Tertiary Limestone Aquifer. The largest withdrawals (25 Mgd) are in Beaufort County where this aquifer is extensively utilized for many small public drinking-water supplies, for a number of industrial establishments, for both commercial and agricultural irrigation, and for many rural-domestic supplies. Most of these withdrawals are from the Upper Hydrogeologic Unit in coastal Beaufort County south of the Coosaw River. It is estimated that over 50 percent (10-15 Mgd) of the estimated average daily pumpage of 25 Mgd from this aquifer in Beaufort County is for commercial and agricultural irrigation. Since irrigation is a seasonal water use, there is a considerable difference between amounts pumped during peak-use and low-use periods; and water-use estimates based on average daily pumpage (averaged over annual period) are subject to considerable error. It is estimated that approximately 5 Mgd of ground water is withdrawn (not including flowing artesian wells) from this aquifer in the remainder of the Low Country for various uses. Water users in Jasper County depend almost entirely on fresh water from the Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer. Water users in Hampton and Colleton Counties also depend to a large extent on the Tertiary Limestone Aquifer for water supplies.

In Hampton and Colleton Counties, it is estimated that a daily average of approximately 5 Mgd of ground water is pumped, and an unknown quantity of ground water flows from artesian wells. These flowing wells have not been completely inventoried, but withdrawals could easily exceed the quantity of ground water pumped (5 Mgd) in Hampton and Colleton Counties. Some of the larger municipal and industrial wells in these two counties withdraw ground water from the Black Creek or the Black Mingo Aquifer Systems. Hayes (1979) reported that data had been collected on 25 flowing artesian wells that flowed from 50 to 250 gpm per well, apparently from the Black Mingo Aquifer System. Thus, for only 25 wells alone, from 1,250 to 6,250 gpm of ground water is withdrawn from the Black Mingo Aquifer System. Undoubtedly, the water from these wells is not needed for year-round use and many wells could be valved off when not needed.

In summary, the known estimated average daily ground-water withdrawals from all aquifers in the Low Country is approximately 40 Mgd. In addition, an unknown quantity of ground water (probably 10 Mgd) is withdrawn through flowing artesian wells, some not used at all or used only part of the year. At this time, data are too limited to accurately assess the quantity of ground water withdrawn through these flowing wells; and in most cases the aquifer tapped by the wells is not known for certain. *Thus, it is estimated* *that the quantity of ground-water withdrawn from pumping wells and flowing artesian wells averages about 50 Mgd.* However, during certain irrigation periods, withdrawals could be as high as 70 Mgd. Currently, the greatest quantity of ground water (35 Mgd) is pumped from the Tertiary Limestone Aquifer. Approximately 75 percent (25 Mgd) of this pumpage is in Beaufort County.

SAVANNAH AREA

In the Savannah area, municipal and industrial pumpage estimates from the Tertiary Limestone Aquifer have been made by the USGS, Georgia District. A thorough water-use summary of municipal and industrial pumpage from the Tertiary Limestone Aquifer in the immediate Savannah area for the period 1885 - 1958 was provided by Counts and Donsky (1963). In 1970, water users in the immediate Savannah area were withdrawing approximately 75 Mgd from the Tertiary Limestone Aquifer (Counts and Krause, 1976). However, since 1970 there has not been a water-use inventory conducted in the Savannah area (Harlan B. Counts, verbal communication, June, 1976). As noted previously, much of this pumpage is from the Upper Hydrogeologic Unit.

As part of Georgia's Water Use Act, the Georgia Environmental Protection Division (EPD) requires a permit for each water user withdrawing in excess of 100,000 gpd of surface or ground water. The permit requires that each water user submit a water-use report at six-month intervals accounting for the monthly pumpage, along with the method used to obtain the figure. Georgia officials report that as of June 1979, twenty-one ground water users in the Savannah area have been permitted; and, based on peak daily demands, these 21 water users are permitted to withdraw a maximum of 90 Mgd from the Tertiary Limestone Aquifer. According to Georgia officials, because of the water-level declines resulting from the present pumpage in the vicinity of Savannah, the EPD is not issuing any new permits for ground-water withdrawals in the immediate vicinity of Savannah. Their present policy is to maintain the existing status of withdrawals; and using the computer model developed by the USGS to predict water levels in the Tertiary Limestone Aquifer in the Savannah area, the EPD has plans to develop a water-resource management program for the Savannah-Chatham County area (John Fernstrom, written communication, June, 1979).

WATER-USE PROBLEMS

GENERAL

The S. C. Ground Water Use Act requires that the SCWRC investigate and report on all water-use problems in a capacity use study area. Since several ground-water reports have documented the technical problems, lengthy discussion is not necessary here. However, the Act requires that the SCWRC evaluate the severity of these problems under present and foreseeable future conditions. Therefore, it is necessary to at least briefly review the technical literature to provide 'continuity' in the discussion from problem to solution.

In this report, we discuss certain 'technical problems' and 'administrative problems' that are not unique to the Low Country area. We have been able to only briefly review the technical problems here, several of which are as complex as any in the field of ground-water hydrology. Ultimate solution of these problems presents a challenging job of providing technical answers, and will require a better job of solving the administrative problems.

In the Low Country-Savannah area, ground-water problems are closely linked to the manner in which the ground-water resources have been developed. No one deliberately sets out to create ground-water problems or adversely affect other ground-water users. For many years in the Low Country area, the results of ground-water investigations and technology were not readily available to water users, well-drilling contractors, consultants, and others when they needed the information. Consequently, many mistakes have been 'honest ones', born out of the many misconceptions concerning the occurrence, movement, and availability of ground-water.

Several of the ground-water problems are serious and their solution will require a positive water-management program; however, they are not 'unsolvable'. Too often, the attitude becomes one of complacency toward the solution of a ground-water problem--especially when economic factors are involved. In many areas of the Southeast, the 'solution' of a ground-water problem has been to abandon wells and turn to a supply of surface water. However, as has been shown in several consulting reports, surface-water supplies are not economically available to the entire Low Country area.

PUMPAGE AND WATER-LEVEL DECLINES

GENERAL

The fluctuations of water levels within an aquifer are best understood from records of water-level observation wells (hydrographs) through time and the analyses of potentiometric or pressure-surface (i.e., "water-level") maps. A potentiometric map is a graphic representation of the imaginary surface to which water will rise in tightly cased wells completed in a single aquifer. The map can be used to show directions of ground-water movement, hydraulic gradients, areas and amounts of recharge and discharge, and to show progressive effects of pumpage.

Prior to an aquifer being developed, the potentiometric surface represents a natural state of dynamic equilibrium, or steady state, in which that volume of water being naturally replenished (recharge), balances that volume of water released from storage (discharge). Withdrawal of ground water through wells is an artificial discharge which disrupts the natural balance of the system. As a result, water levels decline because of a loss of ground water from storage, and water-level stabilization must be achieved by a reduction in natural discharge (perhaps flowing artesian wells cease flowing), an increase in recharge, or both. If an adjustment is not possible, ground water will be mined from storage, and rather than stabilize, water levels will continue to decline.

True understanding of the relationship between pumpage and water-level declines requires accurate water-use and water-level data and information on hydraulic characteristics of aquifers and confining beds. Because water-level declines vary inversely with the distance from the pumping center, a potentiometric surface reflecting a pumping center will resemble a funnel, referred to as a cone of depression, being deepest in the center and shallower outward from the center. The essential factors controlling the size, shape, and depth of the cone of depression are related to location of pumping centers, rate and duration of pumpage, and hydrologic characteristics of the aquifer and confining beds. The effects of small pumping centers sparsely located or adjacent to larger ones may be obscured, although their effects will eventually become visible in regional water-level declines.

As discussed in the summary on water resources, ground-water withdrawals from aquifers other than the Tertiary Limestone Aquifer are currently very small. Thus, ground-water withdrawals from aquifers below the Tertiary Limestone Aquifer have been insufficient to have caused significant water-level declines. Therefore, the following discussions are restricted to the effects and possible effects of water-level declines of the Tertiary Limestone Aquifer.

In the Savannah-Low Country area, water levels in wells tapping the Tertiary Limestone Aquifer have been monitored either continuously or periodically by the USGS in cooperation with state and local governments for many years. These monitoring activities have made it possible to construct potentiometric (water-level) maps that show progressive effects of pumpage on water levels in the Tertiary Limestone Aquifer. Water-level monitoring in the Savannah, Georgia area has been more complete, because of long-term records and the location of a USGS field office in Savannah. Prior to the Low Country Study, however, water-level monitoring in the Low Country area had been rather sporadic. Therefore, during the Low Country Study, a series of observation wells were established, some equipped with continuous automatic water-level recorders (see fig. 2); and water levels in many other observation wells were manually measured.

Prior to the year 1880, before intensive ground-water withdrawals from the Tertiary Limestone Aquifer began, the original potentiometric surface of this aquifer throughout the coastal portion of the Savannah-Low Country area ranged from 10 to 35 feet above msl as shown by the map constructed by M. A. Warren in 1944. Since 1880, as a result of increasing demand for ground water, water levels have declined in response to increased ground-water withdrawals.

Figure 12 is a regional potentiometric map of the Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer in the Savannah-Low Country area for December 1976. This map was prepared from water-level data in Georgia supplied by Harlan Counts and from water-level data collected during the Low Country Capacity Use Investigation. This map indicates that the large volume of water discharged through wells in the immediate vicinity of Savannah (approximately 75 Mgd) has lowered water levels in the aquifer to approximately 150 feet below msl. These ground-water withdrawals have caused significant water-level declines in large areas of Georgia and the Low Country.

Ground-water withdrawals in the Low Country area also contribute to water-level declines. For example, as shown in a detailed potentiometric map of Hilton Head Island (Hayes, 1979, fig. 25), pumpage at Hilton Head Island causes local water-level declines that are superimposed on regional declines.

Several other points should be emphasized from figure 12. *Flow lines on the map indicate that ground water discharges northeast of the Coosaw River in southern Colleton County.* In a large area northeast of Port Royal Sound, water levels in the Tertiary Limestone Aquifer range from about sea level to about +5 feet msl. Since the influence of tides on water levels can be as high as 5 to 6 feet, these tidal influences must be accurately 'filtered out' in order to construct accurate potentiometric maps. Thus, management decisions are going to depend on very accurate water-level maps because water-level declines of only a few feet in some areas are going to be critical.

An effective ground-water management program is also going to require accurate delineation of water levels in the Tertiary Limestone Aquifer both in northern Hampton and Colleton Counties and in Allendale and Bamberg Counties. These monitoring efforts are underway by the SCWRC at the present time in connection with a planning-level ground-water study.

FIGURE 13. MAP SHOWING TOTAL WATER-LEVEL DECLINE IN THE TERTIARY LIMESTONE AQUIFER, 1880-1976 (AFTER HAYES, 1979).

area, have a fairly high vertical permeability. Hayes (1979) concurred with Siple and estimated the amount of vertical leakage to the Upper Hydrogeologic Unit in the vicinity of the MCAAS to be about 4 Mgd. Information from recently completed test wells in the vicinity of the MCAAS indicates that sediments overlying the Tertiary Limestone Aquifer consist primarily of sand with little or no clays that could serve as "effective" confining beds; therefore, recharge rates may be slightly greater than previously estimated. Local recharge to the aquifer probably takes place in many other parts of the Low Country, but additional work will be needed to evaluate the amount of vertical leakage in these areas. Thus, based on current data and pumping conditions, recharge in the outcrop area and recharge by leakage amounts to approximately 55 Mgd in the Low Country area.

The USGS has suggested that in the Savannah to Port Royal Sound area the amount of natural recharge to the Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer has been exceeded by ground-water withdrawals. Or to be more precise, the expansion of the Savannah cone of depression toward Port Royal Sound has been "stabilized" by an increase in artifical recharge--the recharge being the southwestward movement of salty water present in the aquifer beneath Port Royal Sound. M. A. Warren (1944) suggested that 25 Mgd was the maximum amount of ground water that could be withdrawn from the Tertiary Limestone Aquifer at Savannah without allowing salt-water encroachment from the Port Royal Sound area. *McCollum and Counts (1964) revised Warren's estimate and suggested that this figure might be increased to approximately 40 Mgd.* Ground-water pumpage at Savannah is now in the range of 75 to 90 Mgd (1970 estimates), and pumpage on Hilton Head Island alone probably approximates 5 to 10 Mgd. As shown in figure 13, the potentiometric surface of the Upper Hydrogeologic Unit is at msl (zero contour) along a line that parallels the Broad River-Port Royal Sound. The USGS has suggested that the stabilization of this msl (zero) contour indicates that increased pumpage at Savannah and southwestern Beaufort County will be met by salt-water movement rather than by additional reduction in water levels. Calculations of the rates of vertical downward leakage (reviewed in discussion of vertical leakage) indicate that the downward leakage is insufficient to cause this stabilization of the zero water-level contour.

These facts indicate that increases in the present rate of pumpage from the Tertiary Limestone Aquifer at Savannah and southwestern Beaufort County (and Hilton Head Island) will result primarily in increasing the hydraulic gradient and, thus, the rate of lateral salt-water encroachment in the Upper Hydrogeologic Unit of the aquifer. It should be noted that the stabilization of water levels in an observation well located southwest of Port Royal Sound (Bft-459--see fig. 2) could give one a somewhat false 'sense of security'. If salt water in the Upper Hydrogeologic Unit is moving toward Savannah, then water levels in well Bft-459 should be *expected* to stabilize; indeed, decline will occur only when ground-water withdrawals *increase* significantly. The initial effects of this increase would be noticeable, but the effects will be seen only ever so slightly in this observation well (unless, of course, a large pumping center is located fairly close to this observation well).

Throughout the Low Country-Savannah area, ground-water withdrawals from the Tertiary Limestone Aquifer will result in some reduction in yield of other wells completed in the aquifer. It has been shown that pumpage at Savannah has some effect on declining artesian pressures as far away as Brunswick, Georgia (and vice versa) (Wait and Gregg, 1973). Therefore, additional pumpage from the aquifer anywhere in the Low Country-Savannah area will have some effect on the potentiometric surface (i.e., water levels) in other wells, even though pumping centers may be widely spaced. Of course, the effect on water users will not be as severe in some areas as in others.

In the Low Country area the greatest water-level decline in wells completed in the Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer has occurred primarily in southwestern Jasper and Beaufort Counties (see fig. 13). The area of greatest water-level decline is currently a somewhat sparsely populated rural area of Jasper County where many wells are also completed in the overlying Hawthorn-Recent Aquifer System. Many once-flowing artesian wells tapping the Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer no longer flow, a situation that has existed for many years. The loss of artesian pressure has been aggravating to some well owners who have lost their flowing wells, and to them, their loss is a problem. *However, for the most part, these water-level declines have apparently not caused severe quantity problems for water users in this area. In the area near Walterboro where water levels have declined approximately 20 to 30 feet since the early 1900's, the effects of these water-level declines have probably not been 'serious' for water users or on the ground-water resources of the Tertiary Limestone Aquifer.*

As shown on the potentiometric map (fig. 12), northeast of the Coosaw River, ground water discharges in the vicinity of St. Helena Sound. Thus (again generalizing a technical concept), it would not be an accurate evaluation to suggest that ground-water pumpage from the Tertiary Limestone Aquifer in the entire Low Country area exceeds the natural recharge to the aquifer. That is, the 'safe yield' of the aquifer system has not been exceeded.

As quoted in a short and beautifully written synopsis of 'safe yield', by S. W. Lohman (1972, p. 61-62), the late H. E. Thomas (1951, p. 261) stated:

> "Safe yield. This term, originated by hydrologists, may well prove to be awkward for them because of the variety of interpretations possible. Safe yield is an Alice-in-Wonderland term which means whatever its user chooses."

Lohman (1972) provided a rather simplified, but appropriate, definition of safe yield, namely:

> "The amount of ground water one can withdraw without getting into trouble. 'Withdraw' may mean from flowing or pumped wells, and it may mean continuously, as for many industrial or municipal supplies, or seasonally,

> as for irrigation. 'Trouble' may mean anything under the sun, such as (1) running out of water, (2) drawing in salt water, or other undesirable water, (3) getting shot, or shot at, by an irate nearby well owner or land owner, (4) getting sued by a less irate neighbor, or (5) getting sued for depleting the flow of a nearby stream for which the water rights have been appropriated."

Quoting further from Lohman's paper:

> "To determine whether or not a desired quantity and quality of water can be withdrawn from a given ground-water reservoir generally requires an adequate knowledge of the geologic framework and its plumbing system plus the application of philosophy, common sense, and knowledge of the proposed type of development that owners or managers have in mind. As problems become more and more complex, however, such as those involving large investments in land and wells, withdrawal of water from both streams and wells that tap a common source, or conflicts in water rights, then the solution may require highly detailed study."

The comments of Thomas and Lohman emphasize that the concept of 'safe yield', regardless of which definition one chooses, is the very basis of ground-water management. Whether we like the term or not is really irrelevant; at some point in time the hydrologist is invariably called upon to attach a number so that someone can decide how much ground water can be withdrawn without getting someone (or an aquifer) into trouble. Obviously, as stated by Lohman, 'trouble" can mean almost anything and it is not easily defined, especially when so many water users depend upon the Tertiary Limestone Aquifer as a source of water supply. We could not agree more with Thomas that the term 'safe yield' is awkward for hydrologists, and is dependent on many factors. Obviously, the 'safe yield' of an aquifer changes with time; what is considered 'safe' now may not be considered safe at a future time.

We believe the statements by Thomas and Lohman can be appropriately applied to the regional water-level decline problems associated with the Tertiary Limestone Aquifer in the Savannah-Low Country area. If we (the hydrologists) must attach a number to safe yield, then this number must be arrived at by application of the proper hydrogeologic data, very liberal application of common sense, knowledge of proposed development, and other factors.

The technical data indicate that the Tertiary Limestone Aquifer is not 'running out of water'. However, water-level declines have been a problem for some water users; and are contributing to salt-water contamination of the aquifer. In addition, uncoordinated pumpage and lack of a ground-water management program is of concern to water users in the Low Country area that have large investments in their wells and water-supply *systems. Therefore, even though additional pumpage from the Tertiary Limestone Aquifer is possible throughout the Low Country-Savannah area as a whole, it is apparent that the 'safe yield' of the aquifer has, in effect, been exceeded as far as some water users are concerned.*

LOCAL INTERFERENCE

Although not all pumping centers are as large as the one at Savannah, as previously mentioned, pumpage from the Tertiary Limestone Aquifer has a widespread effect on water levels. Consequently, if an additional quantity of water is pumped from an exisiting or newly constructed well, some decline in water levels or reduction in yield will take place at all other nearby wells completed in the aquifer. As mentioned earlier, the extent and rate of water-level declines are in part controlled by the hydrologic characteristics of the aquifer, which vary considerably from one locality to another. Therefore, local well interference problems may occur that are superimposed on the regional water-level declines shown in figure 13.

In the Low Country area, local interference problems have occurred in the towns of Hampton and Lobeco (Beaufort County) and in other areas. For example, when one well in the Burton Well Field, formally operated by the MCRD, was pumped at 1,400 gpm, nearby wells were reportedly 'dried up' (i.e., water levels were actually only lowered below some pump intakes). Such problems have so far been handled without any recourse to litigation, primarily because water needs have not been great or because alternative aquifers or permeable zones within the Tertiary Limestone Aquifer or other aquifers were available. *Where alternative water sources are not readily available (in much of the coastal area) or are not used, interference problems will become more serious as the aquifer continues to be developed in both Georgia and the Low Country area.*

One of the most important benefits of hydraulic data is in calculating the effects of a proposed ground-water withdrawal on water levels, specifically water levels of the Upper Hydrogeologic Unit. Thus, ground-water hydrology techniques exist that can be used in predicting potential effects. These hydraulic calculations are often complicated and time-consuming and can be greatly expedited by using digital models. The USGS model of the Tertiary Limestone Aquifer in the Savannah area (Counts and Krause, 1976) has not yet been extended into most of the Low Country area. However, we understand that the five-year regional aquifer system study of the Tertiary Limestone Aquifer being conducted by the USGS will expand modeling capability into areas where it is most urgently needed (Johnston, 1978).

OTHER EFFECTS

Two effects of intensive ground-water withdrawals from the Tertiary Limestone Aquifer have been discussed in published reports on the Savannah area; thus, we are obligated by the S. C. Ground Water Use Act to review them. These effects are (1) dewatering of the aquifer and (2) land-surface subsidence. Closely allied is the problem of land-surface collapse which often occurs in connection with aquifer dewatering and subsidence.

AQUIFER DEWATERING

When water levels in an artesian aquifer are drawn below the top of the aquifer (i.e., below the upper confining bed), the aquifer will be dewatered in the center of the cone of depression. The potential problem of aquifer dewatering of the Tertiary Limestone Aquifer has been briefly mentioned in several USGS reports (Counts and Donsky, 1963, p. 87; McCollum and Counts, 1964; and Counts and Krause, 1976, sheet 3).

According to Counts and Donsky (1963) and McCollum and Counts (1964), the pumping water level in the center of the cone of depression at Savannah was nearing the top of the Tertiary Limestone Aquifer at Savannah in 1959 at a pumping rate of about 62 Mgd. They believed that if the pumping rate were increased to 125 Mgd with the same distribution of pumping that existed when they did their study, the top of the aquifer would soon be dewatered over a few square miles in the center of the cone of depression. Therefore, they recommended that future pumping centers should be more widely spaced if the situation was to be avoided.

In 1970, pumpage at Savannah had increased to 75 Mgd and water levels near the center of the cone of depression were only about 60 feet above the top of the aquifer--at 210 feet below msl (Counts and Krause, 1976). Information on water use provided by Georgia officials indicates that pumpage at Savannah could be as high as 90 Mgd for certain periods. Georgia officials are concerned with aquifer dewatering in the Savannah area, and they have adopted the policy of not allowing any additional ground-water pumpage near the center of the cone of depression (John Fernstrom, written communic., 1978).

The only dewatering that would affect the Low Country area of South Carolina, resulting from the current pumpage at Savannah, would be a relatively small area of southwestern Jasper County; therefore, future large, concentrated ground-water withdrawals from the Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer near the center of the cone of depression should be discouraged. *We are not suggesting the prohibition of moderate withdrawals that are properly planned--only the concentration of large, high-capacity wells in a very small area.*

While we do not wish to speculate beyond the technical data available, it should be stressed that large, improperly planned, ground-water withdrawals from the Upper Hydrogeologic Unit that are concentrated in a small area in other parts of the Low Country area could potentially cause aquifer-dewatering problems. Because of the nature of ground-water flow in the Upper Hydrogeologic Unit, dewatering problems would likely be most severe near the pumping center and decrease rapidly outward. We do not necessarily know how far out dewatering would extend from the pumping center in areas where hydrologic data are currently inadequate (mainly in Hampton and Colleton Counties and northern Jasper County). *Based on current amounts of pumpage and distribution of pumping centers, aquifer dewatering is not a problem in the Low Country area at this time.*

SUBSIDENCE AND LAND-SURFACE COLLAPSE

Subsidence is the slow or gradual lowering of the land surface due to deformation of materials comprising an aquifer or "compaction" of overlying confining beds. Subsidence commonly occurs where pumpage from an underlying artesian aquifer causes large water-level declines. In South Carolina, this phenomenon was reviewed by Siple (1967, p. 80-81) in connection with drawdowns resulting from pumpage of the Tuscaloosa Aquifer System at the Savannah River Plant.

Land-surface subsidence in connection with ground-water withdrawals from the Tertiary Limestone Aquifer at Savannah were reviewed by Davis, Small, and Counts (1963) of the USGS. They found that subsidence of the land surface overlying the cone of depression at Savannah was approximately 3.5 inches from 1918 to 1955. Counts and Krause (1976) stated that if pumpage at Savannah increases significantly above the 1970 rate (75 Mgd), the water level at the center of the cone of depression at Savannah may decline below the top of the Tertiary Limestone Aquifer (210 feet below msl) which would result in dewatering of the aquifer (specifically, the Upper Hydrogeologic Unit) and possible land subsidence, a situation that should be avoided.

We do not believe that land-surface subsidence is now a problem in the Low Country area influenced by the Savannah pumpage (i.e., southwestern Jasper County). As far as subsidence becoming a problem in the future, this will depend both on actions by Georgia officials in regard to water-use permitting, and whether large pumpage centers are located in southern Jasper County. In other parts of the Low Country area, the technical data needed to properly evaluate subsidence are not currently available. *The geologic framework in parts of the area is such that land-surface subsidence is a possiblity if large improperly planned ground-water withdrawals are made.*

Similar to subsidence, is land-surface collapse which is the sudden lowering of the land surface. Land-surface collapse problems associated with the Tertiary Limestone Aquifer have occurred in some areas of nearby Dorchester County, in Berkeley County (Spigner, 1978) and in southwestern Georgetown County (Spigner and others, 1977) where the Tertiary Limestone Aquifer occurs near (within 50 feet of) land surface. The mechanisms of land-surface collapse were reviewed by Spigner (1978) and will not be repeated here.

As far as we know, land-surface collapse problems have not occurred, or at least have not been reported, in the Low Country area. *However, there are areas in Colleton and Hampton Counties and southern Allendale County and near Beaufort where the geologic framework is favorable to the occurrence of land-surface collapse.* These areas are where confining beds overlying the Upper Hydrogeologic Unit are thin--such as over the axis of the Beaufort Arch (See fig. 7) and in northern Hampton and Colleton Counties. Currently, there are no extremely large, concentrated ground-water withdrawals in the area where the geologic framework is favorable to land-surface collapse. As long as the potentiometric surface of the Tertiary Limestone Aquifer remains sufficiently above the bottom of overlying confining beds, land-surface collapse will probably not occur. However, the effects of large concentrated ground-water withdrawals must be properly evaluated prior to commencing such withdrawals. With the proper hydrogeologic information prior to such large concentrated withdrawals, this problem can usually be prevented.

SALT-WATER CONTAMINATION

DEFINITION AND GENERAL EXTENT

Salty or highly mineralized water occurs in one or more aquifers of each major aquifer system in the South Carolina Lower Coastal Plain. Some of this mineralized ground water is naturally-occurring "saline formation water" that "encroached" or entered these aquifers in the geologic past. In other areas, aquifers have been contaminated by man's activities. The problem of salt-water contamination of the Tertiary Limestone Aquifer has received considerable attention by federal and state hydrogeologists working in the Beaufort-Savannah area; therefore, the mechanism of salt-water movement into and through the Upper Hydrogeologic Unit, and the methods of detecting salt-water contamination are now fairly well understood by hydrogeologists.

For the purpose of the capacity-use program of the SCWRC, "salt-water contamination" is the condition where chloride concentrations exceed background chloride concentrations normally found for a given aquifer. As explained later, the lateral and especially the vertical variations in concentrations of chloride (and other chemical constituents) in S. C. Coastal Plain aquifers are poorly known at the present time. Since the Low Country Study was the first ground-water study of the area in 20 years, a complete and comprehensive analysis of the distribution and actual movement of salt water in the Tertiary Limestone Aquifer was simply beyond the scope of this study. The data needed to accurately "map" the vertical and lateral distribution and actual movement of salt water in the Tertiary Limestone Aquifer is being collected as part of the planning-level ground-water study now underway by the SCWRC. For the purpose and scope of the capacity use investigation, however, we are satisfied that the data are adequate. Thus, in this report (which is not a technical report), we have the job of oversimplifying a very technical concept in a few paragraphs.

For drinking-water supplies, the secondary drinking-water maximum concentration limit (MCL) for chloride is 250 mg/L, and for total dissolved solids is 500 mg/L (U. S. Environmental Protection Agency, 1974). These limits cannot be used to define salt-water contamination caused by salt-water encroachment or intrusion. Obviously, concern about salt-water contamination must be long before chloride concentrations reach or exceed 250 mg/L because some industrial, agricultural, and other uses have a much lower tolerance level than these limits.

Investigations pertaining to salt-water contamination of the Tertiary Limestone Aquifer spanning a period of forty years in the Savannah-Low Country area were briefly reviewed in the "Introduction". In addition to the most recent report by Hayes (1979), other reports that contain historical data or pertinent discussions pertaining to salt-water contamination of the Tertiary Limestone Aquifer are those authored by Duncan (1972), Back and others (1970), McCollum and Counts (1964), Counts and Donsky (1963), Siple (1956; 1960b), and Mundorff (1944). Some miscellaneous data that have a bearing on salt-water contamination of the Tertiary Limestone Aquifer in the Beaufort area are contained in a series of consulting, administrative, or open-file reports listed in "Selected References". The technical ground-water investigations, primarily by the USGS, span a period of over forty years; thus, there are few 'technical revelations' we could add here that have not been covered at one time or another.

Chloride and dissolved solids values, published or included in various administrative and file reports on the Tertiary Limestone Aqufier in coastal Beaufort County, have essentially been on water samples from wells completed in the Upper Hydrogeologic Unit. Much of the historical water-quality data that was collected from many wells in the past (i.e., prior to the Low Country Study) was from wells where well construction or other data (sometimes even accurate location) were lacking. Without knowing the *exact position and source* of a water sample, such a chemical quality analysis is usually of limited value for proper hydrogeologic interpretation of salt-water contamination or for ground-water management purposes. Therefore, for coastal Beaufort County alone, much effort during the Low Country Study was expended in establishing the areal distribution of chloride in the Upper Unit (fig. 14 and Hayes, fig. 22). As pointed out by Hayes (1979, p. 73), the most accurate way to determine the relation between chloride concentrations and depth is by taking water samples at different depths (i.e., multi-depth sampling) in a well. In order to establish vertical distribution of chlorides, multi-depth samples were collected in as many wells as time and funding would permit, and several test wells were installed that could be used for multi-depth sampling (see fig. 14). Therefore, for the first time, we have begun to map both the lateral and vertical distribution of salt water in the Tertiary Limestone Aquifer.

The Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer is the only source of fresh ground water in large areas of the coastal Low Country area. Chloride concentrations of uncontaminated fresh water from the Upper Unit range from less than five to about 25 mg/L (Hayes, 1979, p. 73). This

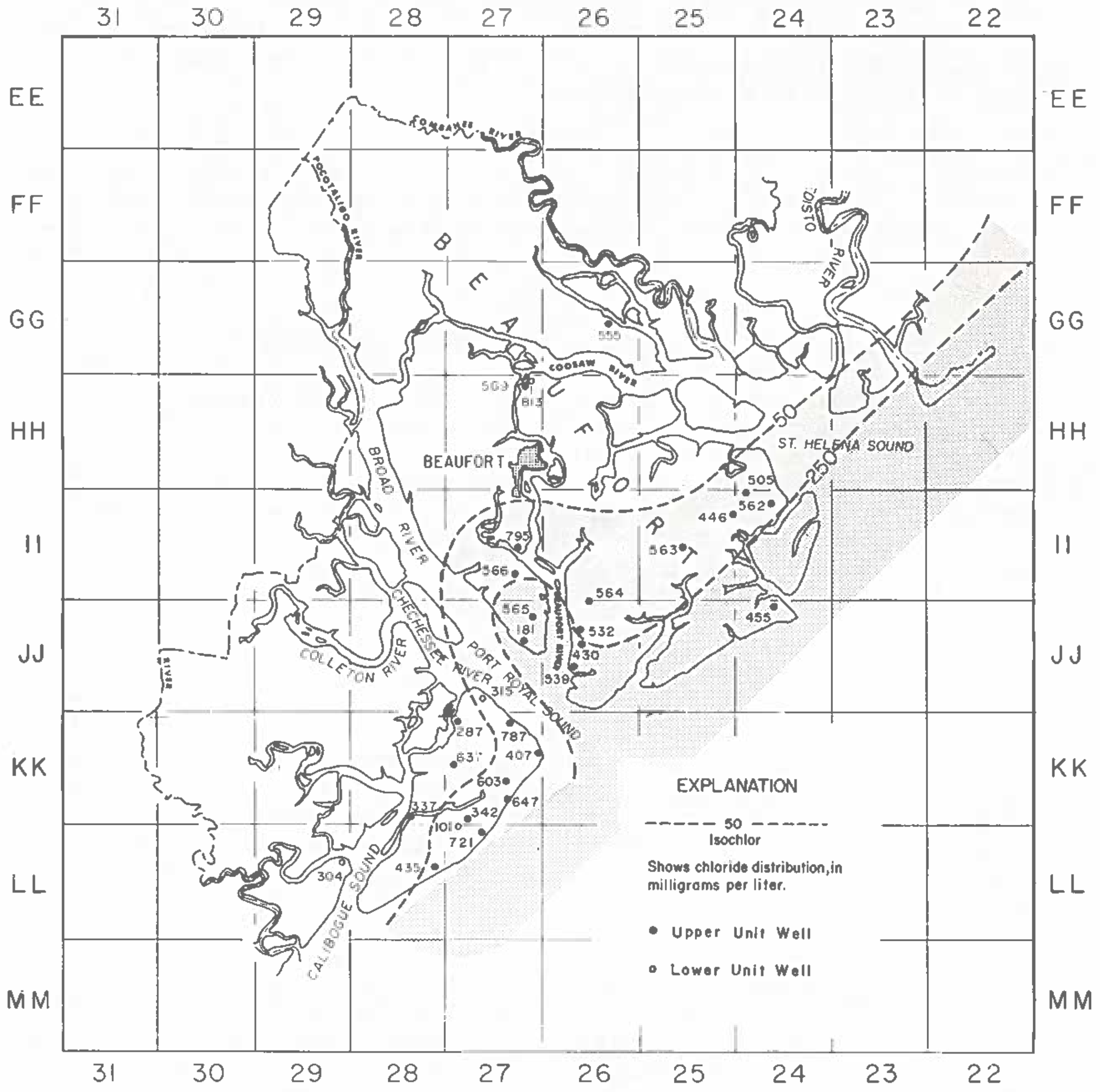


FIGURE 14. MAP SHOWING APPROXIMATE EXTENT OF CHLORIDE CONTAMINATION IN UPPER HYDROGEOLOGIC UNIT OF THE TERTIARY LIMESTONE AQUIFER.

range generally applies to the *upper part of the Upper Hydrogeologic Unit only,* because it has been shown by multi-depth sampling that *chloride and dissolved solids concentrations increase with depth in the Tertiary Limestone Aquifer.* In the immediate Savannah area, Counts and Donsky (1963, p. 69) believed that chloride concentrations in ground water from the Tertiary Limestone Aquifer that are in excess of 15 mg/L appeared to be indicative of contamination by salt water. Most of their data were apparently from the Upper Hydrogeologic Unit.

Figure 14 illustrates the area of the coastal Low Country where chloride concentrations in ground water from the Upper Hydrogeologic Unit exceed 50 mg/L, an arbitrary value chosen for convenience of illustration. The Upper Unit throughout large portions of Beaufort Country and to the northeast at Edisto Beach (Colleton County) and Edisto Island (Charleston County) has been contaminated by salty water.

As reviewed earlier in this report, deeper aquifers below the Tertiary Limestone Aquifer contain mineralized water (but not necessarily high in chloride) in some areas, primarily in the coastal Low Country area (fig. 3). This mineralized water is naturally occurring; therefore, man's influence had little to do with the initial emplacement or movement of mineralized water into these deeper aquifers. These aquifers are 'contaminated' and may contribute to salt-water contamination of other aquifers containing fresh water by interaquifer transfer, a process discussed later in this section. However, the major focus will be on the mechanism of salt-water contamination of the Tertiary Limestone Aquifer.

MECHANISMS OF SALT-WATER CONTAMINATION

The various natural and man-induced mechanisms responsible for salt-water contamination of the Tertiary Limestone Aquifer in the Low Country area are (1) natural contamination by ancient sea water, (2) lateral encroachment and intrusion, (3) vertical leakage, (4) salt-water upconing, and (5) interaquifer transfer by well construction and improper well abandonment.

Even prior to the investigation of Warren (1944) and Mundorff (1944), it was generally known that the Tertiary Limestone Aquifer in some areas contained ancient sea water that entered the aquifer in the geologic past. The most popular theory is that sea water entered the aquifer during sea-level fluctuations in Pleistocene time. Thus, much of the salt water, especially that in the Lower Unit of the Tertiary Limestone Aquifer, is ancient sea water that has not been completely "flushed" from the aquifer by fresh-water discharge. Regardless of its original source, this ancient saline formation water has been and is now a source of contamination to other parts of the aquifer that have long contained fresh water.

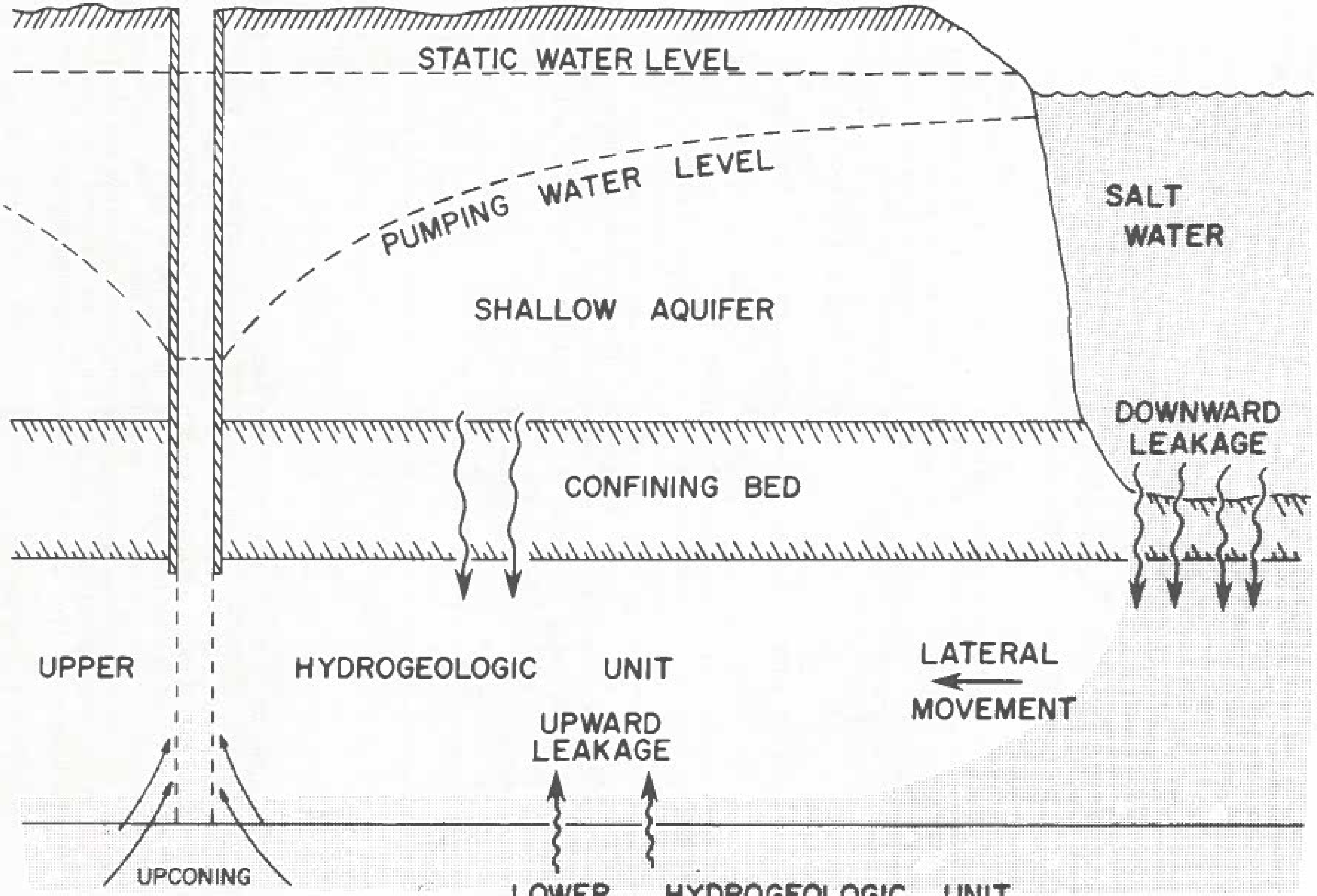


FIGURE 15. DIAGRAM ILLUSTRATING MECHANISMS OF SALT-WATER CONTAMINATION.

The four mechanisms now responsible for salt-water contamination are illustrated schematically in figure 15. In each mechanism, the problem is related to hydraulic gradient or head differentials; that is, water must move laterally or vertically--under either a natural, or man-induced stress (i.e., pumping). One or more of these mechanisms often exist in the same general area, making it difficult to determine exactly which mechanism locally has the greatest influence on the salt-water contamination problem. On Hilton Head Island, for example, all four mechanisms have been identified as contributing to salt-water contamination of the Upper Hydrogeologic Unit.

LATERAL ENCROACHMENT

The lateral movement of salt water from areas already containing saline formation water or from areas where confining beds are absent under salty surface-water bodies has been identified by several USGS hydrologists as the largest contributor to salt-water contamination of the Tertiary Limestone Aquifer. After fairly intensive study over a period of four years and much historical data available from earlier studies by the USGS, and from multi-depth information obtained from 8 test wells, Counts and Donsky (1963, p. 75) concluded that this was the most likely source of salt-water contamination in the Tertiary Limestone Aquifer between the Port Royal Sound area and Savannah. As Count and Donsky (1963, p. 76) predicted: Whatever its source, the salt water "...is surely moving toward Savannah, and if pumping continues at or above the present rate (that is, 62 Mgd in 1959), salt water will eventually contaminate the aquifer to the center of the cone of depression."

With additional water-quality and hydraulic data, McCollum and Counts (1964) provided a more detailed account of the lateral movement of salt water in various permeable zones of the Tertiary Limestone Aquifer in the area between Port Royal Sound and Savannah. On figure 6, modified from McCollum and Counts' plate 1, the positions of fresh and salt water in various permeable zones are illustrated. McCollum and Counts concluded that salt-water contamination of the Upper Unit at Hilton Head Island (their Zones 1 and 2) was a mixture of ancient saline formation water and recent sea water, and that salt water in their lower 3 zones was saline formation water.

Using a Carbon 14 age-dating technique, Back and others (1970) supported earlier conclusions that salt-water contamination of the Tertiary Limestone Aquifer in the Hilton Head to Beaufort area was both modern (less than 5,000 years old) and ancient sea water (more than 20,000 years old) and mixtures of the two. They showed that on Hilton Head Island, the oldest ground water (20,000 years old) occurred in the Lower Hydrogeologic Unit and the youngest ground water occurred in the Upper Hydrogeologic Unit, with intermediate ages in between. The youngest ground water sample was obtained from a well tapping the Upper Hydrogeologic Unit at Parris Island, thus supporting earlier conclusions that modern salty water had entered the upper part of the aquifer at Parris Island.

Hayes (1979) provided additional data on salt-water contamination of the Upper Hydrogeologic Unit. He defined, for the first time, the zone of diffusion (i.e., the zone where fresh and salty ground water mixes) in the Upper Hydrogeologic Unit between Hilton Head and Parris Island (see figs. 9 and 10). Thus, Hayes concluded that salt water in the Upper Hydrogeologic Unit beneath Port Royal Sound represented lateral encroachment of salt water from the Parris Island area. Therefore, with the proper water-quality and other data collected over a period of time, the lateral encroachment front (zone of diffusion) can be mapped in areas southwest of the Broad River-Port Royal Sound.

Rate of Lateral Encroachment.--There have been several calculations of the rate of salt-water encroachment made by the USGS. McCollum and Counts (1964) revised earlier calculations by Counts and Donsky, and presented data indicating that the rate of ground-water movement in the Upper Unit of the Tertiary Limestone Aquifer (at a pumping rate of 62 Mgd in 1962) would be about 210 feet per year at Daufuskie Island. Using the same formula, but with different porosity values, Hayes (1979) calculated that the encroachment boundary in the upper permeable zone northeast of Hilton Head Island (see fig. 10) would move from 140 to 370 feet per year, at gradients of 1.5 and 4.0 feet per mile, respectively. These calculations by the USGS were cautiously made and with proper justification on the basis of several factors. Several of the most important factors are: the hydraulic gradient (which is directly and most importantly dependent upon pumpage); proper or improper well location, spacing, and construction; future ground-water developments in Savannah and in the Low Country; and if and how the states manage the ground-water resources.

The rate of lateral encroachment is primarily dependent upon the hydraulic gradient (slope) of the potentiometric surface, the hydraulic characteristics (hydraulic conductivity and thickness), and porosity of water-bearing zones within the Tertiary Limestone Aquifer. *The most important of these is the hydraulic gradient which is directly related to pumpage, and the only one of the factors over which man has any control.* An increase in pumpage will result in a corresponding increase in hydraulic gradient and thus an increase in the rate of salt-water encroachment.

Hydraulic gradients are determined by monitoring water levels in a series of observation wells completed in the Tertiary Limestone Aquifer (specifically in the Upper Unit). The USGS model of the Tertiary Limestone Aquifer does not 'calculate' the rate of salt-water movement. However, it can 'predict' the hydraulic gradients caused by an increase, decrease, or adjustment of pumping. Thus, this model could be beneficial to any ground-water management program concerning the control of salt-water encroachment in the Savannah-Low Country area.

LATERAL INTRUSION

As pointed out by Hayes (1979), salt-water intrusion is the small scale, temporary movement of salt water. Such contamination may be for only short periods of time; then as pumpage is reduced or stopped, hydraulic gradients are reversed and the salty water may retreat from a pumping well. There have been a number of wells completed in the Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer that have been contaminated in this manner. Examples of this type of salt-water contamination in coastal Beaufort County (Port Royal Island and vicinity) were cited by Mundorff (1944), Siple (1960b), and more recently by Hayes (1979).

There are several areas on Port Royal Island where wells have been contaminated by intrusion in the past. By and large, these wells or well fields were first located near fresh-salt-water interfaces. Thus when one or more wells in a well field was excessively pumped, one or more wells became contaminated. Even though contamination may have been only temporary, and chlorides were not too high (i.e., perhaps still less than 250 mg/L) increases in chloride caused water-treatment or other problems. Wells in the old Jericho Well Field (SCWRC Grid 27II) owned by the MCRD were believed by Mundorff (1944) to have been contaminated in this manner. Several City of Beaufort wells were also contaminated by intrusion, and as pumpage was ceased, chloride concentrations decreased. Many other examples of salt-water contamination by intrusion are discussed in some detail in SCWRC Report No. 9; thus, further discussion is unnecessary here.

Areas where wells in the Upper Unit have been contaminated by or are particularly susceptible to further lateral intrusion are in coastal Beaufort, Colleton, and Charleston Counties. *Especially around the periphery of the 50 mg/L chloride isochlor in figure 14, or in areas between the 50 and 250 mg/L isochlors, the Upper Hydrogeologic Unit is particularly susceptible to salt-water intrusion (and encroachment).* Thus, a large area is subject to this type of salt-water contamination. There is a rather obvious point to be made upon comparison of the potentiometric (water-level) map (fig. 13) with figure 14. The direction of salt-water movement southwest of Port Royal Sound and Broad River is southwestward toward Savannah. *Therefore, with potentiometric heads already at or slightly below msl, there is going to be minimal temporary retreat of salt water once a 'new area' of the Upper Unit is contaminated.* Thus, southwest of the Broad River-Port Royal Sound, intrusion in effect equals regional encroachment.

Northeast of Port Royal Sound, on St. Helena, Ladies, and Edisto Islands, fresh water in the Upper Unit is currently subject to lateral intrusion more than 'regional encroachment'. The potentiometric head of the Upper Unit in these areas is at (or slightly above or below msl). *Therefore, pumping, well design, location, and construction must be closely and carefully planned in these areas to protect this aquifer and the wells of existing water users who depend upon fresh water from the Upper Unit.*

Intrusion, to be sure, is a form of 'encroachment', but ground-water management methods differ in the effective control of the two types of lateral salt-water contamination. The encroachment of salt water southwest of Port Royal Sound, among other factors, is closely linked to the pumpage at Savannah (and Hilton Head Island). Salt-water intrusion northeast of Port Royal Sound is also linked, overall, to the Savannah and Hilton Head pumpage but in a less direct manner. Both encroachment and intrusion are related, either directly or indirectly to pumpage throughout the extent of the Tertiary Limestone Aquifer in the Savannah-Low Country area. Thus, the 'retreat' of salt water away from well fields, especially from the Upper Unit will be less and less as pumpage continues or increases in a large area. As mentioned in the 'Introduction' of this report, the lack of any effective controls on pumpage or other ground-water management measures were large factors in the decision to seek a surface-water source for Beaufort and military installations in the 1950's (Bowen, 1956).

VERTICAL MOVEMENT

The vertical movement of salty water <u>into</u> water-bearing zones of the Tertiary Limestone Aquifer has two movement components, downward and upward, and both can occur at the same time. This ground-water movement is called 'leakage' and in the Low Country-Savannah area occurs <u>through</u> (but can also be from release of storage in) confining beds into water-bearing (permeable) zones. The movement must be from one low-pressure zone or aquifer, through confining beds (or from release of storage in adjacent confining beds) into another zone or aquifer having a lower artesian pressure.

There are certain methods used by ground-water hydrologists to calculate or reasonably estimate the amount of vertical leakage into a leaky artesian aquifer. However, it is extremely difficult to accurately separate the downward and vertical leakage components for a given aquifer and area.

As previously discussed, most ground-water pumpage from the Tertiary Limestone Aquifer is from wells in the Upper Hydrogeologic Unit; therefore, this zone has a lower potentiometric head than Lower Unit aquifers and in some places a lower head than that of overlying shallow aquifers. In areas near salty surface-water bodies (where upper confining beds are relatively permeable or absent) where the potentiometric head of the Upper Unit is drawn below mean sea level, it is the overlying salt water that exerts the downward pressure tending to force or 'squeeze' this salty water into the Upper Unit.

Downward Leakage

Of all the mechanisms of salt-water contamination in the Low Country area, the downward vertical movement of salt water, downward leakage, is perhaps the most difficult to accurately evaluate. Salt-water contamination of the Upper Hydrogeologic Unit by downward movement can occur from two sources of salt water: (1) From salty surface-water bodies such as the tidal rivers and estuaries in the coastal area, and (2) From shallow aquifers containing salty water. Of course, both sources can collectively contribute salty water. Accurate documentation of downward leakage from either source, especially from downward leakage of salty surface water, is extremely difficult to obtain.

In areas where confining beds exist between shallow aquifers and the Tertiary Limestone Aquifer, downward movement of ground water occurs by leakage through the confining beds. In areas where confining beds do not exist, this downward movement of salty water might be considered 'direct recharge' to the aquifer, although the term leakage is more descriptive of the slow process. We understand how someone could get the erroneous impression that downward movement in areas where confining beds do not exist occurs by rapid 'pouring-in' type movement. However, in the Port Royal area, for example, one would have to neglect hydraulic gradient--something that simply cannot be done if downward leakage is properly evaluated.

Although water-quality data (specifically, in this case, chlorides) in shallow aquifers are admittedly poor, it is generally recognized that high chloride concentrations in shallow aquifers primarily occur in the vicinity of salty surface-water bodies. Inland from these salty surface-water bodies, shallow aquifers would not contribute chlorides (unless from domestic or industrial sewage or other sources of pollution) to the Tertiary Limestone Aquifer. Therefore, in connection with the salt-water contamination of the Tertiary Limestone Aquifer by downward leakage, salty surface-water sources are by far the most important consideration.

The factors governing the rate of downward leakage are (1) the physical characteristics of the confining beds (i.e., thickness and vertical permeability) overlying the Upper Unit, and (2) the potentiometric head of the Tertiary Limestone Aquifer and the elevation of this head relative to msl, or relative to the potentiometric head of an overlying shallow aquifer. As long as the potentiometric head in the Tertiary Limestone Aquifer remains above msl, there will be a net movement of water from the aquifer into the salt-water rivers and estuaries.

The downward vertical leakage (referred to as 'seepage' by some) of salty water into the Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer has been the subject of considerable debate both in the eastern Chatham County, Georgia area and the Port Royal, South Carolina area. *The principal question in both areas has concerned the hydraulic effectiveness of the confining beds overlying the Tertiary Limestone Aquifer in preventing the downward movement of salty water from the extensive salt-water rivers and estuaries into the aquifer.*

At least five technical publications have been written that either directly or indirectly address the question concerning the rate of downward leakage of ground water through confining beds overlying the Tertiary Limestone Aquifer in the Savannah-Low Country area. In the immediate

Savannah area, the publications of Counts and Donsky (1963) and Furlow (1969) specifically addressed the question concerning the rate of downward leakage. In the Port Royal, South Carolina area, the reports by Duncan (1972) and Colquhoun (1972) addressed the physical characteristics of the confining beds, but did not address the role and importance of hydraulic gradient. Hayes (1979) addressed both the physical characteristics of the confining beds and the role of hydraulic gradient.

The same type of problems and hydrogeologic investigations are contained in several publications of the Pamlico River estuary area in Beaufort County, North Carolina (Nelson and Peek, 1964; Jacob and others, 1967; Peek and others, 1971; Peek and Nelson, 1975; and North Carolina Department of Natural Resources and Economic Development, 1974). These investigations by hydrogeologists in North Carolina are the most comprehensive investigations conducted on salt-water contamination of the Tertiary Limestone Aquifer in the Southeast. These reports and personal contact with North Carolina officials have been extremely beneficial in our investigation and analysis of salt-water contamination in the Low Country area.

In Chatham County, the questions of salt-water contamination by vertical leakage involved a proposed open-pit phosphate-mining operation which would require partial removal of a bed of commercial-grade phosphate in the Duplin Formation, part of the confining beds over the Tertiary Limestone Aquifer. An open-pit operation would also involve the removal of a certain thickness of the underlying Hawthorn Formation, also part of the confining beds. Georgia officials were concerned that partial removal of confining beds might allow the downward leakage of salty surface water through the confining beds (whose thickness would be reduced) into the Tertiary Limestone Aquifer. They requested a study of the potential environmental effects of the proposed mining operation. A preliminary geologic study by Carver (1968b) preceded a study by Furlow (1969) who provided more hydrogeologic data concerning the amount of downward leakage of salt water that was 'naturally' occurring, and the amount that should be expected if the mining operation were allowed. Using the average vertical permeability value of 0.0096 gpd/ft^2 for confining beds (determined on core samples), a confining bed thickness of 40 feet, and a hydraulic head differential of 15 feet, Furlow calculated a vertical leakage factor of approximately 0.0036 gpd/ft^2 (equal to 100,300 gpd/mi^2). Furlow calculated that 160 gpd of ground water per acre of mine area would enter the Tertiary Limestone Aquifer by downward leakage through the confining beds. Considering the amount of fresh ground water moving laterally through the upper part (actually the Upper Unit) of the Tertiary Limestone Aquifer in the Savannah area, Furlow concluded that the amount of salty water that would enter the aquifer by vertical leakage (160 gpd/acre) would have minimal effects on chloride concentrations in wells that supplied the City of Savannah.

Counts and Donsky (1963, p. 78) used a vertical permeability value of 0.001 gpd/ft^2, a confining bed thickness of 150 feet, and calculated that the downward leakage at the center of the Savannah cone of depression in 1959 (at a pumping rate of 62 Mgd) was about 37,000 gpd/mi^2; and 8 to 10 miles away at Daufuskie Island, South Carolina (where hydraulic gradients of the

Upper Unit of the Tertiary Limestone Aquifer were less) downward leakage was about 9,300 gpd/mi^2. Based on these data, Counts and Donsky concluded that at Savannah in 1959 (1) the rate of salt-water movement through confining beds was small in comparison to the lateral movement of ground water through the Tertiary Limestone Aquifer, and (2) the comparatively small amount of salt water discharged (i.e., 'leaking') into the aquifer had no noticeable effect on the quality of ground water in the Tertiary Limestone Aquifer.

In the Beaufort area, the concern with contamination by downward leakage from salty surface-water bodies has centered on the possible effects of previous dredging and requested future dredging of certain shipping channels. Proper calculation of downward leakage of salt water in the Beaufort, South Carolina area is more complicated than in Chatham County, Georgia because the hydrogeology is more complicated. For example, as previously discussed, in some areas (e.g., at Hilton Head Island) there is a leaky but generally effective confining bed over the Upper Hydrogeologic Unit (see fig. 10). However, there are no effective confining beds overlying the Upper Hydrogeologic Unit in other areas (figs. 16 and 17). In addition, the hydraulic gradient of the Tertiary Limestone Aquifer in the immediate Beaufort area is currently very small, and water levels in Tertiary Limestone Aquifer wells are strongly influenced by tidal fluctuations.

Calculating the quantities of vertical leakage in the Beaufort area is much too complicated to discuss fully or illustrate properly in this report. Nevertheless, (although we believe it is probably beyond the scope of this report) we believe the technical data collected during the study and during the studies mentioned above allow a more realistic appraisal concerning the question of dredging at Port Royal.

At this time, there are two aspects to the dredging question at Port Royal: (1) The requested deepening of the Turning Basin at the S. C. State Docks from 24 feet to 27 feet below MLW (mean low water), and (2) Deepening of the entrance navigation channel in the Beaufort River southeast of the Turning Basin (SCWRC, 1972). It was shown during the Port Royal Sound Study and by test drilling that an effective confining bed is not present over the Upper Unit in portions of the Turning Basin (see fig. 16). It has been shown that the Upper Unit at Parris Island already contains salt water. It has also been shown that salt water is present in the Upper Unit under the Beaufort River and Battery Creek and under Port Royal Sound northeast of Hilton Head Island (figs. 9 and 10). *Thus, the critical factors concerning the effect of dredging in the Turning Basin and the amount anticipated in the entrance navigation channel in the Beaufort River is primarily the potentiometric head and hence the hydraulic gradient of the Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer. The effectiveness or ineffectiveness of the confining beds in preventing downward leakage is important, but has perhaps received a little too much emphasis at the exclusion of potentiometric head and other hydrogeologic factors.*

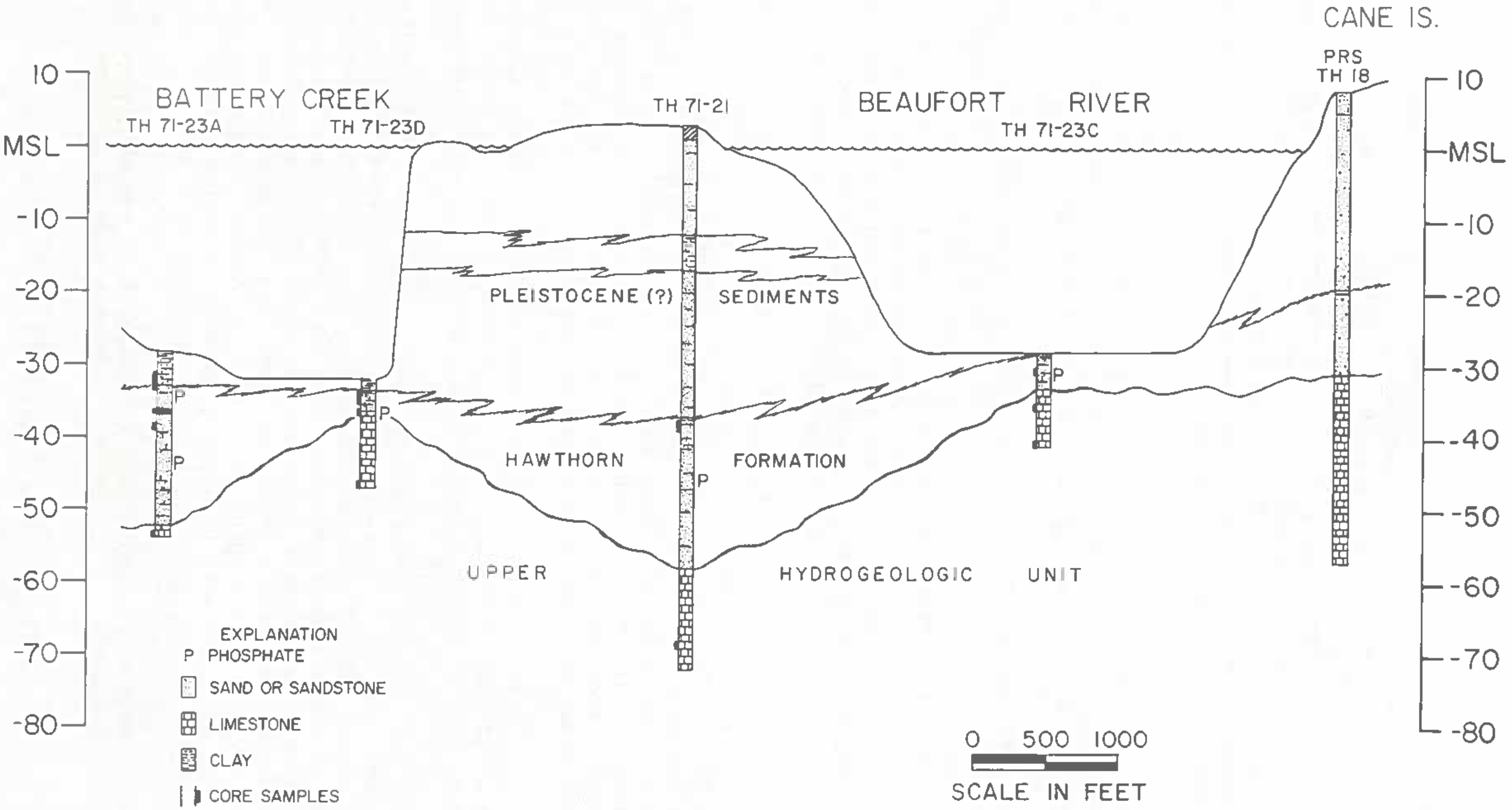


FIGURE 16. HYDROGEOLOGIC CROSS-SECTION OF THE PORT ROYAL AREA.

Water level data collected during the Low County Capacity Use Study indicated that the zero (mean sea level) potentiometric contour of the Upper Unit in December, 1976 paralleled the Broad River-Port Royal Sound (fig. 12). As previously discussed, the relative 'stabilization' of the zero contour indicates that salt water is slowly encroaching toward the southwest (i.e., toward the center of major pumping at Savannah). *Thus, the control of pumpage and maintenance of the potentiometric surface of the Upper Unit of the Tertiary Limestone Aquifer above or as much above msl as possible, especially in coastal Beaufort County, is the most critical factor in slowing or preventing further lateral salt-water encroachment toward Savannah to the southwest. Salty water already present in the Upper Unit under Port Royal Sound and Parris Island (fig. 10) is the foremost threat to fresh water in the Upper Unit in southwestern Beaufort County (specifically Hilton Head Island)--not any salt water that may enter the Upper Unit from Battery Creek and the Beaufort River at Port Royal.*

The effect of dredging in the Turning Basin on fresh water in the Upper Unit in areas north (Port Royal Island) and east (Ladies Island) of the Turning Basin must also be considered now and in the future. As shown in figure 17, there is little or at least no 'effective' confining bed over the Upper Unit in the Beaufort River north of Port Royal. Similarly, test drilling at Beaufort (Bft-801) and test drilling conducted at the Beaufort Marina (well Bft-559) indicates a similar lack of effective confining material over the Upper Unit.

As shown at least as early as Mundorff (1944), *prior to dredging activities*, a Beaufort City well was contaminated by lateral salt-water movement from the Beaufort River when the potentiometric head of the Upper Unit was drawn below msl. Thus, whether future dredging is allowed or not, there is still going to be downward leakage of salty water into the Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer in the Beaufort-Port Royal area if the potentiometric head of the Tertiary Limestone Aquifer is drawn below msl. Therefore, the same conclusion is drawn: *The potentiometric head of the Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer and the position of this potentiometric head relative to msl is the primary controlling factor concerning lateral salt-water movement and downward vertical leakage in the area from Port Royal to Beaufort.*

Our conclusions are that pumpage, well design, location, and spacing are the most important factors that should be closely monitored and regulated properly to prevent vertical and lateral salt-water contamination of fresh water in the Upper Unit. Many residents of the Beaufort area, including those on much of Ladies and St. Helena Islands now obtain their drinking water from the Beaufort-Jasper Water Authority. Regardless of this availability, a number of residents in these areas obtain their drinking-water supplies from wells in the Upper Unit; and the aquifer is extensively utilized for agricultural irrigation. Therefore, the fresh water in the

Upward Leakage

Ground water in the Tertiary Limestone Aquifer can 'leak' or move upward only if (1) artesian pressure (head) in a lower aquifer system (Black Mingo) or lower water-bearing zone of the Tertiary Limestone Aquifer is greater than the head of an overlying water-bearing zone, and (2) there is a 'leaky' or ineffective confining bed separating two permeable zones; or (3) there is a natural break or discontinuity in the confining bed separating the two permeable zones, or (4) wells are drilled that create a hydraulic interconnection through the confining bed so that the two water-bearing zones become interconnected (inter-aquifer transfer). Three types of hydrogeologic data are needed in order to document upward leakage of salty or mineralized ground water: (1) Water-quality data from the upper fresh-water zone, and (2) Potentiometric head measurements from both zones, and (3) Data on vertical hydraulic conductivities (permeabilities) of intervening confining beds.

It has been shown from multi-zone test wells that ground water in the lower part of the Upper Unit (i.e., Zone 2 of McCollum and Counts, 1964) and in the Lower Unit has a greater head (but not much greater) and is more mineralized than ground water in the upper part of the Upper Unit at Daufuskie and Hilton Head Islands (Counts and Donsky, 1963; McCollum and Counts, 1964). The multi-aquifer observation well station installed on the northeast end of Hilton Head Island (Bft-786, -787, -788) indicates that chloride concentrations in the lower part of the Upper Hydrogeologic Unit (well Bft-786, see fig. 10) are greater than chloride concentrations in the upper part of this unit (well Bft-787). Although several more multi-zone test wells are needed to accurately calculate the amount of upward leakage that is taking place, proper hydrogeologic interpretation of the data available now can provide a reasonable evaluation of upward leakage in southwestern Beaufort County, the area where upward leakage would cause the most problem.

Hayes (1979,) p. 69) mentioned that on Hilton Head Island, the "...vertical upward movement of underlying salty connate water is contributing to the salt-water encroachment problem." Additional test wells may indicate other areas where mineralized ground water from the lower part of the Upper Hydrogeologic Unit is moving upwards and is contributing to the salt-water contamination of the Upper Unit. *A cautious interpretation is made from the data available that because horizontal permeabilities of the Upper Unit are so much greater than vertical permeabilties, it is unlikely at this time that upward vertical leakage 'significantly' contributes to the salt-water contamination of the Upper Unit.*

Reasonable hydrogeologic interpretations have shown that highly mineralized ground water occurs in strata immediately underlying the Tertiary Limestone Aquifer (that is, in the Black Mingo Aquifer System). Data on the distribution of this mineralized water and potentiometric head of the Black Mingo are so meagre that, at the present time, it cannot be absolutely shown for certain whether upward leakage of this mineralized water into the Tertiary Limestone Aquifer occurs in the Low Country area. However, as noted previously, Hayes (1979) stated that artesian pressures in the Black Mingo Aquifer System are about 30 psi in some wells in Hampton and Colleton Counties. Therefore, if similar artesian pressures exist in the Black Mingo in the coastal Low Country area, there could be some upward leakage from the Black Mingo *into the Lower Unit* of the Tertiary Limestone Aquifer. Information collected by Counts and Donsky (1963, p. 76-77) led to their conclusion that the upward movement of mineralized ground water from aquifers underlying the Tertiary Limestone Aquifer in the immediate Savannah area was "an unlikely cause of serious salt-water contamination of the principal artesian (Tertiary Limestone) aquifer".

Concerning the question of upward leakage, the following conclusions are made: (1) *Upward vertical leakage from the lower part of the Upper Unit or from the Lower Unit is probably contributing to the salt-water contamination of the Upper Unit, although it is probably not causing 'serious' contamination (when compared to contamination by lateral movement and downward leakage of salt water); and (2) We agree with Counts and Donsky that not enough hydraulic data are available to accurately determine if natural upward leakage is contributing significantly to the salt-water contamination problem, particularly in the coastal Low Country area.*

SALT-WATER UPCONING

Fresh-water aquifers can become contaminated by a mechanism known as 'salt-water upconing' or 'upconing intrusion', which is in actuality a 'vertical' movement (does have a horizontal component also), and thus similar in one respect to upward leakage. This type of salt-water contamination commonly occurs in areas where an aquifer (or one permeable zone of an aquifer) contains saline water overlain by fresh water. If a well penetrating this aquifer or permeable zone is drilled too deep or is pumped at an excessive rate, either or both of these factors can cause the 'upconing' of salt water into the well (see fig. 15). Therefore, a single well or an entire well field could become contaminated as a result of salt-water upconing.

In the Low Country area, the most likely areas of salt-water upconing would be where the Upper Hydrogeologic Unit contains fresh water underlain by salt water near the bottom (see fig. 9, for example). Data available at this time indicates that the Upper Unit at Hilton Head, St. Helena, and Ladies Islands is particularly susceptible to salt-water upconing. Hayes (1979, p. 69) mentioned that vertical upward movement of underlying salty connate water at Hilton Head Island is contributing to the salt-water encroachment problem. Thus, the concentration of improperly designed large-capacity wells in a small area could cause or contribute to salt-water upconing. Controls on the spacing, depth, and pumping rate of wells (especially large-capacity wells) are critical factors in preventing upconing and in protecting fresh water in the Upper Unit. Thus, individual

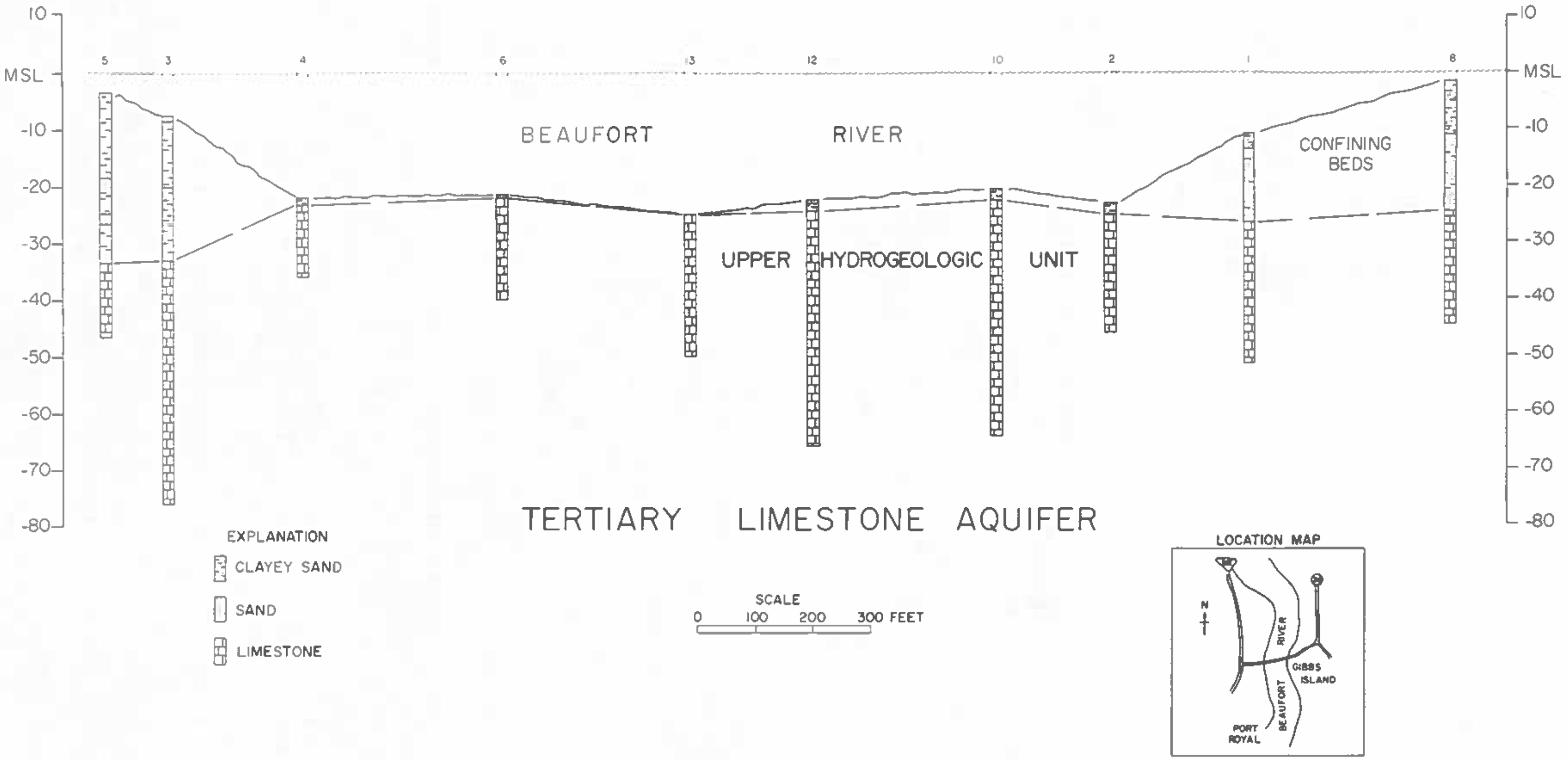


FIGURE 17. GEOLOGIC CROSS-SECTION OF THE TERTIARY LIMESTONE AQUIFER, PORT ROYAL.

Upper Unit is a valuable resource for these and other potential ground-water users, *and the aquifer should be protected from over-development and salt-water contamination.*

The possibility of downward movement of salty water from shallow aquifers, either by leakage or by direct recharge into the Tertiary Limestone Aquifer in the Beaufort area, was mentioned by Siple (1960b) and Hayes (1979). In order for downward leakage of ground water from shallow aquifers into the Tertiary Limestone Aquifer to occur, the following two conditions are necessary: (1) The potentiometric surface (head) in shallow aquifers must be greater (relative to msl) than the potentiometric surface of the Upper Hydrogeologic Unit; (2) Confining beds must be sufficiently 'leaky' (i.e., dependent upon thickness and vertical hydraulic conductivity).

Mundorff (1944) and Siple (1956; 1960b) suggested that vertical downward leakage contributed to the salt-water contamination of this aquifer in the Beaufort area. Siple (1956) suggested that downward 'seepage' of salty or brackish water could occur in the area near Burton, and he suggested that the presence of 'sinks' in coastal Beaufort County could represent breaks in the confining beds overlying the Tertiary Limestone Aquifer. Information collected from one test well (Bft-801) during the Low Country study supports Siple's suggestion that these 'sinks' represent areas of vertical leakage and thus an avenue of recharge into the Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer.

Hayes (1979) estimated that approximately 500 gpd/mi^2 of ground water (most of this would be fresh water) was moving from overlying shallow aquifers into the Upper Unit of the Tertiary Limestone Aquifer in the Beaufort area. He estimated that this would amount to about 5 to 10 Mgd in the four-county area. Therefore, in areas where shallow aquifers have higher heads than the Upper Hydrogeologic Unit and contain salty water, downward leakage could contribute to salt-water contamination of the Upper Unit. However, if 500 gpd/mi^2 is a reasonable estimate, then downward leakage of salty water <u>from shallow aquifers</u> would not constitute a large quantity compared to other sources of salt-water contamination of the Upper Unit.

In summary of downward leakage, it is concluded that the downward leakage of salty surface water and salty water in shallow aquifers does contribute in some measure to salt-water contamination of the Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer. The greatest contribution is from salt-water streams and tidal rivers in coastal Beaufort County where the Upper Hydrogeologic Unit is not everywhere separated from overlying salty water by an effective confining bed. The quantity (or rate of movement) of salty water entering the Upper Unit is dependent primarily on the potentiometric head of the Upper Unit and the thickness and vertical permeability of confining beds. The potentiometric head is dependent on ground-water pumpage. As pumpage increases, and the potentiometric head is lowered below sea level, salty surface water will continue to 'leak' downward into the Upper Unit.

water users may be 'their own worst enemy' if their wells are drilled too deep or are pumped excessively.

As previously mentioned, the Upper Hydrogeologic Unit behaves hydraulically as a confined, diffuse-flow aquifer over an area measured in square miles. Locally, on a scale measured in hundreds of square feet, the Upper Unit is hydraulically more complex; and data are currently insufficient to accurately (to our satisfaction) estimate the true potential of salt-water upconing. As more hydrogeologic data on the Upper Hydrogeologic Unit become available, it will be possible to more accurately predict areas having the potential for salt-water upconing. This lack of proper data underscores the need for more attention to proper well design and to collecting proper hydrogeologic data when constructing water wells that tap the Tertiary Limestone Aquifer.

There are many (albeit small and localized) areas of coastal Beaufort and Colleton Counties where salt-water upconing has probably occurred in the past and can occur in the future. *With proper controls on well depth, discharge, and well spacing, such problems can be prevented or at least lessened. In addition, the proper reporting of well construction data on all wells that are drilled into and through the Upper Unit is of utmost importance, and cannot be stressed too strongly.*

WELL CONSTRUCTION

Defective or improperly-cased wells can contribute to salt-water contamination in the following ways: (1) By creating hydraulic interconnection of aquifers or permeable zones with different heads and water quality--these head differentials causing either upward or downward movement; (2) Defective well casings, which are not properly grouted into the top of the Tertiary Limestone Aquifer, resulting in salty water moving downward from a shallow aquifer (with a high head) containing salt water into the Tertiary Limestone Aquifer; (3) Defective well casings of abandoned, improperly grouted wells that extend into deeper aquifers containing salt water; and (4) Wells that are simply drilled too deep into aquifers containing salty or mineralized water.

There is some published information on well-construction problems in the Beaufort area. Mundorff (1944) mentioned several examples, and he believed that there was a good possibility that the old Jericho Well Field owned by the MCRD was contaminated in part by defective wells. Siple (1956) also believed that there were many examples of such contamination in the Beaufort area. Hayes (1979, p. 63) mentioned two such examples (well Bft-494, and Bft-811) and stated that such wells "can pose a serious threat to the principal artesian aquifer" (p. 66). He recommended that wells be properly plugged with grout before being abandoned, and suggested the extension and proper grouting of casing *into* the Upper Hydrogeologic Unit of the aquifer.

There are also many discussions of well construction problems in memoranda and administrative files of the MCRD at Parris Island. The questionable accuracy of some of this information sometimes prevents it from being used to accurately pinpoint the exact source of certain problems.

In the Low Country, primarily in the Beaufort area (where the most hydrogeologic data are available), there are several known examples, and many other suspected cases where improperly constructed wells and/or defective well casings are causing or are believed to be causing salt-water contamination of the Tertiary Limestone Aquifer. However, the extent and degree of seriousness of these well-construction problems are not known in detail for several reasons: (1) Lack of accurate well-construction records by water-well contractors (no requirements for keeping such records); (2) Many of these are small-diameter wells that have been abandoned (some for many years) for one reason or another (no well-abandonment legislation), and it is now often impossible to get accurate information on the wells; (3) Many abandoned wells have been located, but many have simply not been properly scheduled (i.e., completion of water-well report form); (4) Without the proper historical data, it is usually and often impossible to determine if a well is improperly constructed or whether the aquifer already contained salt water when the well was drilled; and (5) Lack of water-quality and water-level data from wells in the shallow aquifers or in deeper artesian aquifers.

Therefore, at this time, it is impossible to say how much of a problem improperly constructed, improperly cased, and improperly abandoned wells are in the Low Country area; and how much they may be contributing to the salt-water contamination of the Tertiary Limestone Aquifer. However, there are literally hundreds of drilled wells on Port Royal Island and other areas around Beaufort alone and many of these wells could be causing problems. Many, perhaps even hundreds of these wells have been simply covered over, rarely abandoned properly, and forgotten by the owner. During the Port Royal Sound Study conducted during the early 1970's, approximately 100 gamma logs were run in abandoned, unused wells in coastal Beaufort County that were once used for domestic, public, or other water supply (USGS, unpublished file data). Several hundred unused, abandoned wells were also located during the Low Country Capacity Use Study that could be utilized as observation wells or as other hydrogeologic data points. There are many more wells that have not been accurately located. Thus, the sheer number of wells would tend to indicate some problems that simply have not been documented. For many years, even in the Low Country area, many persons have believed 'the deeper the well, the better'. Therefore, wells are often drilled too deep (into salty water) in many areas--even though the technical data may be available to prevent such mistakes.

We would add a word of caution concerning well-construction problems: In designing and constructing a well, there are many factors that must be considered by the person designing the well and by the well-drilling contractor; and it must be remembered that many wells were constructed in the Low Country area long before there were any hydrogeologic investigations, and before information was available on proper well-design and construction techniques. Therefore, it would be technically unfair in this report to attach a responsibility for these problems. Except for authorities granted in the S. C. Ground Water Use Act, South Carolina has never had water-well standards legislation and there have essentially been no controls on well depth and construction methods; thus, many wells are poorly designed or are simply drilled too deep in some areas.

Considering the entire Low Country area, a hydrologist, a well-drilling contractor, or well owner may define 'serious' in different ways. It would probably be a correct evaluation that, compared to the other mechanisms of salt-water contamination, improper abandonment and lack of proper plugging of abandoned wells have been less 'serious' than the other mechanisms. However, it may locally be a very serious problem to an individual well owner who has a well drilled and to his dismay finds that the aquifer under his property has been contaminated by an improperly abandoned well of a previous or nearby well owner.

As part of a ground-water management program, we would strongly recommend the initiation of proper well-abandonment regulations under the authority granted by the S. C. Ground Water Use Act. To some, the proper plugging of a few improperly abandoned wells may seem like 'fighting a forest fire with a garden hose'; and perhaps their argument is correct in one sense. Without initiation of controls on pumpage and other recommendations in this report, it would indeed be 'fighting a forest fire with a garden hose'.

However, it must be remembered that an uncapped, abandoned well can too easily be a disposal mechanism for all types of pollutants, some even dangerous. At least as a minimum measure, unused abandoned wells should be capped with a relatively inexpensive cap when the well is not being used. Therefore, in many cases the proper abandonment could be the registering of abandoned wells with the SCWRC and the installation of a relatively inexpensive cap on the well.

SUMMARY AND CONCLUSIONS ON SALT-WATER CONTAMINATION

The sources of salt water in the aquifers in the Low Country area have been fairly well documented on a regional basis and in parts of coastal Beaufort County. The mineralized ground water in deep artesian aquifers and the Lower Hydrogeologic Unit of the Tertiary Limestone Aquifer is ancient sea water (or 'saline formation water') that has been incompletely 'flushed out' by fresh-water discharge. The Upper Unit of the Tertiary Limestone Aquifer and shallow aquifers near salt-water bodies also contain recently-intruded sea water (less than 5,000 years old), derived mainly from the tidal rivers and estuaries.

Salt-water contamination of the Tertiary Limestone Aquifer is a major problem in the Low Country area. Five major mechanisms of salt-water contamination have been identified. The four mechanisms related to man's activities that are presently of concern include: (1) Lateral movement by encroachment and intrusion; (2) Vertical movement by downward or upward leakage; (3) Upconing; and (4) Well-construction practices. These mechanisms are closely interrelated and detailed hydrogeologic data are required in order to determine which mechanism is the greatest cause of the problem in a specific area. Effective control or prevention of salt-water contamination depends on proper separation and evaluation of these various mechanisms.

It has been documented that in large areas of coastal Beaufort County and southern Colleton County (especially at Edisto Beach), the Upper Hydrogeologic Unit of the aquifer has been contaminated both from natural and man-induced causes. It has been documented that saline water in the Upper Unit and in permeable zones (aquifers) within the Lower Unit in southwestern Beaufort County is moving, slowly, toward the cone of depression generated by the large ground-water withdrawals at Savannah. In the last fifteen years, increased pumpage from the Upper Unit in the Low Country (especially in southwestern Beaufort County) has exerted an increased influence on the rate of lateral salt-water encroachment toward Savannah. All estimates of the rate of lateral salt-water encroachment made by hydrologists with the USGS agree within reasonable limits. The greatest of these estimates indicates that southwestward movement is very slow--approximately 370 feet/year at a hydraulic gradient of 4 feet/mile. Even if these estimates are in error by 100 percent, the rate still indicates slow movement.

Salt-water contamination of the Tertiary Limestone Aquifer is related primarily to ground-water pumpage. This contamination is also closely linked to other technical problems identified in this report: Well design, construction, location and depth and the construction of wells or test holes in deeper or in overlying aquifers. The problem is also linked to certain 'administrative' problems, such as technical data transfer and uncoordinated water-supply development.

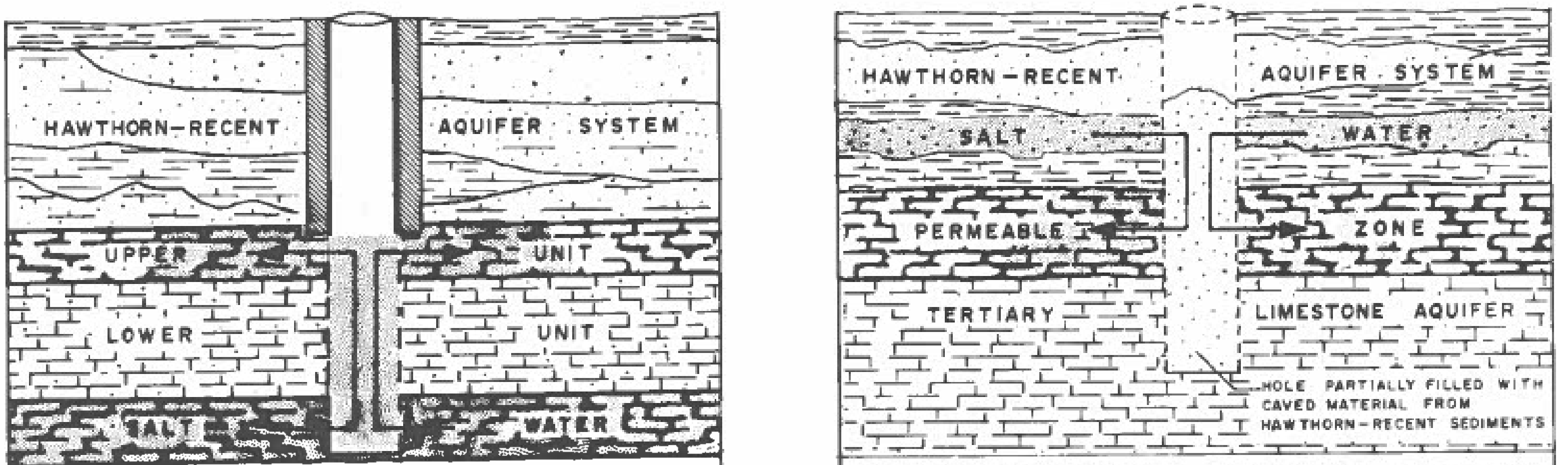
These interrelated causes of salt-water contamination mean that there is no easy, simple solution to the control of salt-water contamination. *Therefore, any ground-water management program that will be successful in managing available fresh-water supplies in the Tertiary Limestone Aquifer must have the following elements:* (1) *Accurate technical data;* (2) *Authority to regulate and control pumpage, well spacing, well depth, and methods of construction (in all aquifers--not just the Tertiary Limestone Aquifer);* (3) *Flexibility--a management method used in one area is not necessarily needed in another area;* (4) ***Continual monitoring** of both potentiometric heads (water levels) and water quality at properly located, designed, and constructed monitor wells; and* (5) *Continual coordination with personnel responsible for ground-water management in Georgia.*

In our opinion, the technical data indicate that the problems of salt-water contamination of the Tertiary Limestone Aquifer alone are sufficiently serious to justify the declaration of a capacity use area, and initiate a comprehensive ground-water management program. These data do not indicate that salt-water contamination of the Tertiary Limestone Aquifer is an 'unsolvable problem' and that we have to accept progressive salt-water contamination of a fresh-water aquifer. The technical data do indicate a slow movement of salt water toward the southwest in southwestern Beaufort County. Lateral movement is very slow; thus, ground-water management options are available. *If nothing is done, and we are lulled into a false sense of security, the technical data indicate that we are not addressing the problem.* As briefly summarized in this report, Georgia officials have already initiated certain ground-water management methods to alleviate and prevent additional water-level declines in the immediate Savannah area. With a proper and realistic approach, we believe that solutions are available that will require coordinated, positive approaches on the part of both South Carolina and Georgia officials. *Therefore, we believe that ground-water management should not be postponed in the Low Country area.*

INTERAQUIFER TRANSFER

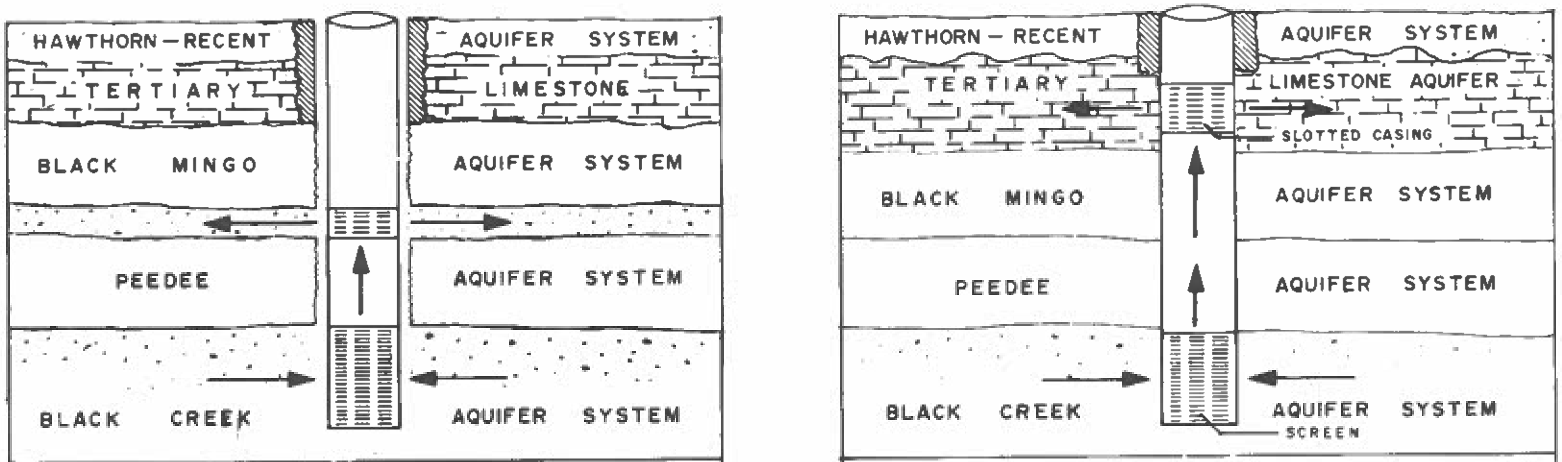
Interaquifer transfer is the process by which water in an aquifer occuring under a high artesian pressure (head) may move into another aquifer of lower artesian head (fig. 18). Although confining beds normally separate and prevent (or 'retard') the interchange of ground water between aquifers, the construction of a well can penetrate and establish hydraulic interconnection of aquifers. With the establishment of hydraulic interconnection and if sufficient pressure differentials between aquifers exist, the well may provide a conduit for water of inferior quality to move vertically (upward or downward) and contaminate a fresh-water aquifer. Actual documentation of interaquifer transfer requires information on potentiometric heads of two or more aquifers and certain well-construction information on wells penetrating these aquifers.

In the Low Country, interaquifer transfer can occur from one sand aquifer into another sand aquifer through screens opposite these aquifers (generally deeper aquifer systems); or by transfer of ground water from a sand aquifer into an adjacent limestone aquifer; or transfer through an open-hole (uncased) well drilled through two limestone aquifers. As mentioned previously, the Lower Hydrogeologic Unit of the Tertiary Limestone Aquifer and the Black Mingo, Peedee, Black Creek, and Tuscaloosa Aquifer Systems are not at this time *used* extensively in the Low Country area. Because these aquifers have not been extensively utilized, few potentiometric head data are available from abandoned (unused) wells in these deeper aquifers. Therefore, only a few interaquifer problems associated with these aquifers have been properly documented at this time. However, as shown by Hayes (1979), in much of the area ground water in Lower Unit



A. ABANDONED OR NON-PUMPING WELL IN LOWER UNIT OF THE TERTIARY LIMESTONE AQUIFER

B. DOWNWARD TRANSFER, ABANDONED, UNPLUGGED TEST HOLE



C. LOSS OF ARTESIAN PRESSURE, ABANDONED WELL

D. UPWARD TRANSFER FROM SAND AQUIFER INTO TERTIARY LIMESTONE AQUIFER

FIGURE 18. DIAGRAM ILLUSTRATING MECHANISMS OF INTER-AQUIFER TRANSFER

aquifers and underlying aquifer systems (especially the Black Mingo, Black Creek, and Tuscaloosa) is under considerable artesian pressure, and in parts of the coastal area these aquifers contain salty or mineralized water. Therefore, reasonable application of hydrogeologic principles indicates that any improperly constructed or abandoned well penetrating these aquifers will (1) pose a potential source of contamination to other aquifers by means of interaquifer transfer of water, and (2) cause loss of pressure in the higher head aquifer.

There is some information indicating that the interaquifer (or 'interzone') transfer of water has occurred in wells completed in different aquifers within the Tertiary Limestone Aquifer and in deeper aquifers. As discussed and illustrated earlier, the various permeable zones in the Tertiary Limestone Aquifer in the coastal Low Country area contain different concentrations of chloride and dissolved solids. If wells are drilled into a higher-head salt-water bearing aquifer in the Lower Unit, fresh water in the Upper Unit could become contaminated. Information from open-file and consulting reports indicates that this problem has occurred on Port Royal Island and on Parris Island. These problems were briefly reviewed in the previous section on 'Well Construction' in reference to salt-water contamination in the coastal Low Country area.

Interaquifer (or 'interzone') transfer is believed to be occurring in other areas of the Low Country. For example, in northern Beaufort and in Jasper, Hampton, and Colleton Counties, some wells have been drilled below the Upper Unit into the Lower Unit of the Tertiary Limestone Aquifer. There are some areas where the potentiometric heads of these Lower Unit aquifers are greater than the potentiometric head of the Upper Unit. However, casing is usually extended only to the top of the Upper Unit and the open-hole section of the well may extend through and hydraulically connect several, perhaps many, water-bearing zones. If wells are drilled deep into the Lower Unit, a flowing artesian well can be obtained in some areas of Hampton and Colleton Counties. In some cases, the flow is not what it should be because some of the pressure is lost in an upper, lower-head zone.

A turbidity problem involving possible interaquifer transfer has been identified in several areas in South Carolina and recently in the Low Country area. This problem concerns 'turbidity' of ground water caused by precipitation of small crystals of calcite or aragonite in ground water in the vicinity of well screens. The exact geochemistry of this process is still not fully understood at present, but apparently can be caused by several mechanisms. One mechanism involves the interaction of a calcium bicarbonate-type ground water with a sodium-bicarbonate type ground water either during or after well-completion operations. When these two types of ground water are mixed in the subsurface in the vicinity of the well borehole, ion exchange occurs as calcium ions are exchanged with sodium ions, and a calcium carbonate precipitate (calcite or aragonite) forms. The problem can occur when calcium bicarbonate-type water from the Tertiary Limestone Aquifer is mixed with a sodium bicarbonate-type water in deeper aquifers, specifically in the Black Creek Aquifer System. The problem can also occur during drilling operations if a calcium-base drilling mud is used and intermixes with a sodium bicarbonate-type ground water (Allen Zack, oral communication, 1978). When the well is pumped, the precipitate (calcite or aragonite) produces a 'cloudy' appearance or turbidity problem. In the Low Country area, this problem has probably occurred at several locations, and has been reported from a public-supply well drilled into the Black Creek Aquifer System at Estill in Hampton County.

Once the turbidity problem occurs, it is often difficult, time consuming, or costly to completely remove the precipitate. Prolonged pumping has been successful in correcting the problem in several wells in Williamsburg County (Johnson, 1978). In other cases, vigorous well development operations with packers and high-velocity jetting may be practical. Often, the water clears up after only a few minutes of pumping from the well. Therefore, another relatively inexpensive solution has been to install a 'blow-off' valve, pump the water to waste until clear, then pump into the distribution system.

The general mechanisms repsonsible for this problem have been identified. However, the lack of geochemical data at this time prohibits an adequate appraisal of the problem or predict, except in general terms, where this turbidity problem may occur in the future. In the Low Country as a whole, this 'turbidity' problem is not believed to be serious at this time. Fortunately, this problem can be prevented with proper technical data and care in designing and constructing wells. However, in the future, any proposed well that is going to be drilled deep enough to penetrate several aquifers should be properly evaluated and designed to prevent this problem.

The artesian pressures of fresh-water aquifers in the Low Country are extremely valuable 'water quantity resources' that should be properly managed and utilized. With available information, it is presently unknown if interaquifer transfer of ground water is causing 'serious' problems with artesian pressure losses or water-quality impairment of fresh-water aquifers. However, reasonable application of hydrogeologic principles indicates that interaquifer transfer is a problem and could cause severe ground-water quantity and quality problems if wells continue to be drilled without proper consideration of interaquifer transfer. Therefore, any well that is going to penetrate several aquifers should be evaluated in terms of possible interaquifer transfer effects. If interaquifer transfer of ground water becomes widespread, artesian pressures of a high-pressure aquifer would decrease through time; artesian pressure would be bled off; and interaquifer transfer would presumably cease.

As discussed by Hayes (1979) and summarized earlier in this report, artesian pressures in the Black Mingo and deeper aquifer systems in Hampton and Colleton Counties range from 30 psi to more than 60 psi at land surface. These artesian pressures are ground-water resources that should be properly utilized and managed. As mentioned previously in the "Aquifer Systems" section of this report, interaquifer transfer can be utilized as a ground-water management tool. Properly-constructed wells in some areas could be utilized to re-pressure an overlying or underlying aquifer. Therefore, proper utilization of interaquifer transfer could be a ground-water management asset rather than a liability. However, without proper management, these resources will not be available for utilization in the long term.

WATER QUALITY PROBLEMS

DATA AVAILABILITY AND TRANSFER

As summarized previously in this report, aquifers in the deeper artesian aquifer systems and shallow aquifers are not currently utilized to a great extent. Therefore, the lack of wells means that the water-quality characteristics of these aquifers have not yet been determined, except in a few areas. Because the Tertiary Limestone Aquifer is so extensively utilized in the Low Country area, more chemical quality data have been collected from wells in this aquifer. The most water-quality data available are from the Upper Hydrogeologic Unit in the Beaufort area. Throughout the Low Country as a whole, the water-quality characteristics of this aquifer system are not yet known in detail. *Therefore, we consider the lack of water-quality knowledge a water-quality problem.*

There are several reasons for this lack of water-quality knowledge which are related to (1) expense of accurate water-quality data collection and analysis, (2) difficulty in obtaining representative water-quality samples, and (3) problems concerning data 'transferrability'. A water-quality analysis of even the common chemical constituents in a water sample is expensive; thus, economics often dictates how many analyses are made in a given area, especially during a reconnaissance-level ground-water study. Therefore, one of the objectives of any reconnaissance-level ground-water study is to determine data availability and to determine where additional data are needed. Then water-quality data are refined in a planning-level study with emphasis placed where most needed.

A water sample from a multi-aquifer well (i.e., one withdrawing water from more than one aquifer or permeable zone) is frequently not representative of the quality of water from a single aquifer or permeable zone tapped by the well. *Therefore, the proper down-hole sampling equipment must be available in order to obtain a truly representative water sample.* When possible during the Low Country study (and within the budget available), multi-depth water samples were obtained with a borehole water sampler in order to determine the relation between water quality and depth. At the present time, planning-level investigations are hampered because no state agency has the proper sampling equipment to obtain representative water-quality samples.

Another problem concerning water-quality accuracy from existing and newly constructed wells is related to the lack of well construction data. If the proper well construction data are not available, water-quality analyses from the well are sometimes of limited value for hydrogeologic interpretation; and frequently such analyses, if a water-quality problem exists, offer little clue to the proper solution of the problem.

The transferrability of water quality data in South Carolina is often hampered by (1) the lack of standardized sample-collection techniques, (2) concern over quality control, and (3) lack of proper sample-point description. These problems are not unique to the Low Country area and are no more severe here than in other areas. Nevertheless, these factors do contribute to the lack of knowledge which is a 'water-quality problem'.

In terms of the capacity use investigation, this lack of knowledge has not seriously hampered hydrogeologic evaluation. *However, the administrative factors that contribute to this problem should be solved, with a sense of urgency, and with proper coordination among all state, federal and local agencies involved in collection, analysis, distribution (i.e., transfer), or utilization of water-quality data.*

TERTIARY LIMESTONE AQUIFER

As previously mentioned, the chemical quality of ground water from the Tertiary Limestone Aquifer System is so variable and there are currently a limited number of multi-depth analyses. Therefore, in the Low Country area as a whole, generalizations concerning water quality in the four-county area are difficult to make. The majority of chemical analyses that are available are from wells open to the Upper Hydrogeologic Unit, primarily in Beaufort County. Water from the Upper Unit throughout the Low Country area is generally of good quality and suitable for most uses except in areas where salt-water contamination has occurred. The water is characteristically low in iron, dissolved solids, and varies from soft to moderately hard. Aside from salt-water contamination, other water-quality problems are the presence of hydrogen sulfide and iron bacteria. The presence of iron bacteria in wells could be considered as contamination since these bacteria are not normally considered to occur naturally in ground water.

Hydrogen sulfide is a gaseous compound having the characteristic odor of rotten eggs. Its presence in ground water is due primarily to the anaerobic decomposition of naturally deposited organic material. Hydrogen sulfide in ground water does not usually constitute a health hazard, but it can impart a very unpleasant odor to the water. Water from the Tertiary Limestone Aquifer contains hydrogen sulfide in many areas of the Low Country. Counts and Donsky (1963) suggested that the hydrogen sulfide occurs in the uppermost part of the aquifer. They remarked that several wells on Hilton Head Island cased to a depth of 63 to 84 feet had a high concentration of hydrogen sulfide in the water, whereas a few wells with the casing set deeper had less concentrations. This range of casing depths on Hilton Head Island would be for wells completed in the Miocene and Oligocene limestones, which would explain the high concentration of hydrogen sulfide. Therefore, there is some indication that well construction (i.e., amount of casing) may be in part responsible for this water quality problem. *As previously mentioned, the thin Miocene Tampa Limestone unit in southwestern Beaufort County is likely, in part, responsible for the higher than normal concentration of hydrogen sulfide.* If this is true, then 10 to 20 feet of additional casing may mean a considerable improvement in water quality. Additional investigation may show the problem to be more widespread and related to other factors.

Iron bacteria are organisms that oxidize and precipitate dissolved iron and manganese. The process produces accumulations of slimy, jell-like material that can cause clogging of well screens and, thus, slow the flow of water into a well. In addition, the organisms are a nuisance in that they clog pipes and cause staining in household fixtures and appliances. Although iron bacteria are apparently not harmful to an individual's health, once a well is contaminated with the organism, it can be difficult to completely disinfect the well. In the Low Country area, the occurrence and problems of iron bacteria in wells have not been studied in detail. However, many residents have complained of having these problems. For example, in an area two miles north of the town of Hampton, residents in a subdivision experienced severe problems with iron bacteria contamination of their wells, and the residents reported that this problem occurs in nearby areas. The problem is usually aggravated by the fact that most well owners are not able to properly diagnose the problem because these bacteria can easily be mistaken for silt or suspended solids in the water; thus, the installation of a filter system proves ineffective in eliminating the problem. *It is recommended that more data be collected on the extent and severity of iron bacteria problems in the Low Country area in order to provide water users with the technology needed to eliminate the problem.*

GROUND-WATER POLLUTION

The SCWRC is required by the S. C. Ground Water Use Act to consider "the physical and chemical nature of any impairment of the aquifer adversely affecting its availability or fitness for other uses (including public use)". However, a detailed analysis of ground-water pollution from various 'man-made' sources was not a specific objective of the Low Country Capacity Use Investigation. Ground-water pollution investigations, by their very nature, can involve many weeks or months of study, very detailed and expensive water-quality testing, and can easily involve expenditures beyond our Low Country budget. In addition, we believe such investigations would be unnecessarily duplicative because the detection, analysis, and control of ground-water pollution in South Carolina are the reponsibility of the SCDHEC.

As previously mentioned, during the latter stages of the capacity use study the SCDHEC conducted several ground-water pollution investigations to determine the extent of ground-water pollution of shallow aquifers within the Low Country. We provided hydrogeologic data to SCDHEC personnel conducting these studies and coordination was also maintained with the SCDHEC District Engineer. The reports of these studies have not yet been released by the SCDHEC. We were not notified of any serious cases of ground-water pollution that would necessarily have a direct bearing on the preparation of this report.

As noted earlier, the Hawthorn Formation and overlying sediments contain shallow aquifers in some areas. Where these aquifers occur near land surface, they may be susceptible to pollution. Should shallow aquifers become polluted in areas where local recharge is occurring, the polluted water could also percolate downward and contaminate the Tertiary Limestone Aquifer. As reviewed previously, the most prominent area of local recharge (or leakage) is in the vicinity of the MCAAS (fig. 12). Therefore, pollution of shallow aquifers in this area could also result in the pollution of the Tertiary Limestone Aquifer.

Potential sources of pollution in the coastal area are the many 'sinks' in southern Beaufort County which, in part, represent areas where confining beds are missing. Thus, these areas should be avoided, if possible, in the siting of potential waste-disposal facilities, particularly heavy metals or potentially hazardous wastes.

As reviewed previously, little information is available on the quality of ground water in shallow aquifers within the Hawthorn-Recent Aquifer System. As of October 15, 1978, the SCDHEC had installed a total of 82 test wells in shallow aquifers in the coastal parts of Beaufort and Colleton Counties that are being monitored to determine possible ground-water pollution (SCDHEC, 1978, table 2). At present, conclusions from this regional investigation are preliminary and the final report is to be released in mid-1980 (Donald Duncan, SCDHEC, oral communication, 1979). *However, a preliminary progress report (SCDHEC, 1978) indicates that shallow aquifers have been polluted in some areas of coastal Beaufort County, and other potential cases of pollution have been identified by the SCDHEC. With proper investigation, various potential sources of ground-water pollution can be avoided, or waste-disposal sites can be located in more hydrogeologically suitable areas.*

ADMINISTRATIVE PROBLEMS

There are several problems concerning ground-water management in the Low Country that have a direct bearing on the technical problems identified in this report. We prefer to call them 'administrative problems', but they are, in several respects, technical problems. These problems are (1) technical data acquisition and technology transfer, (2) uncoordinated water resources development and (3) economics and financing of ground-water management.

TECHNICAL DATA ACQUISITION AND TECHNOLOGY TRANSFER

In formulating an effective plan for understanding and managing ground-water resources, full consideration must be given to the hydrogeology of all aquifers and economic and cultural development within the area involved. This can only be accomplished by obtaining adequate technical data from the field. Such information includes the depth, thickness, lateral extent and composition of aquifers and the quality of water in each aquifer. A complete evaluation must be made of each aquifer's hydraulic properties (transmissivity, storage) direction and rate of ground-water movement, upward and downward leakage, and areas of natural recharge and discharge. In addition, water levels, water quality, pumping patterns, and water use are subject to change with time as ground-water development progresses. These changes must be measured and technical data continually updated in order to predict long-term trends and to avoid potential problems. The relationship between surface- and ground-water resources must also be defined, evaluated and understood.

In the Low Country area, there is a strong need for the continual acquisition of these ground-water data. The collection of reliable data has to be an integral part of any program concerning the management and protection of ground-water resources.

At present, there are few requirements for reporting any hydrogeologic data to a state agency. Currently, there are minimal requirements for the submission of even well-construction data to a state agency. Conservatively speaking, a state agency probably receives no data on 75 percent of wells drilled in the Low Country area. If the proper information was submitted on only 50 percent of the wells drilled, it could potentially save thousands of dollars and man-hours. Perhaps more importantly (and many examples could be cited), a seemingly unimportant piece of information may at some later date save a potential water user hundreds or perhaps thousands of dollars for an unnecessary expense. Problems discussed in this report should clearly indicate that future development of ground water without accurate hydrogeologic data reporting will contribute to additional problems involving interference, waste, and improper development of the resource.

The problems concerning inadequate ground-water data reporting were reviewed in connection with declaration of the Waccamaw Capacity Use Area (Spigner, Stevens, and Moser, 1977). Similar requirements for reporting technical data in the Low Country area should be implemented, as has been done in the Waccamaw Capacity Use Area. It would be unacceptable for someone to construct a surface-water intake on a stream without knowing the water-quality and flow characteristics of the stream. Yet, in the case of ground-water intakes (i.e., the well), proper development has too often been left to chance or best-guess estimates. We believe that the State of South Carolina can no longer afford to do so. Many man-hours have been spent in collecting technical data that otherwise would have been lost had we not made the effort. We have found that such efforts will save water users and prospective water users thousands of dollars at some time in the future.

A problem directly related to an inadequate data base is the problem of maintaining a well-trained staff of ground-water personnel. We believe that the advantages of maintaining well-trained ground-water hydrologists and technicians in local (Regional) offices have been well documented in other states and by the SCWRC in South Carolina. In many instances, potential ground-water development problems have been avoided because the proper hydrogeologic information was available to prospective water users, consulting engineers, well-drilling contractors, and local officials. Such information must be accurate and timely supplied, which requires well-trained personnel. Without proper training of ground-water personnel, it is difficult to maintain the 'continuity' of a good ground-water program.

In the Low Country area and other areas of South Carolina, the cooperative program of the SCWRC and USGS to provide technical ground-water data has been an effective means for obtaining an initial ground-water data base. Another advantage, in our opinion, has been the training benefits derived through this cooperative program. After this initial investigation phase (Phase I of the Low Country Capacity Use Investigation), we believe it would be a sound investment for the State of South Carolina and the SCWRC to maintain a proper ground-water data base and provide a comprehensive investigative, technical assistance, and ground-water management program. We feel that the benefits of a ground-water program conducted from a regional office have already been substantial, and local legislative leaders and officials have been very supportive of maintaining a regional ground-water office in the Low Country area.

Any ground-water management program needs certain 'tools' in order to collect proper and accurate hydrogeologic data. *We believe that one of the best investments for the State of South Carolina, the SCWRC, and for the ground-water resources would be the purchase of a geophysical logger.* Proper geophysical logs are the 'soul' of a ground-water program, especially in the Coastal Plain where most ground-water knowledge must be obtained from the analysis of borehole geophysical logs. We believe the economic benefits provided by a geophysical logger to ground-water users and prospective ground-water users in South Carolina would far outweigh the cost. As mentioned in the "Introduction", the one geophysical logger owned by the USGS cannot possibly possibly cover even the coastal counties where we currently have ground-water projects underway, much less the remainder of the Coastal Plain and the Piedmont. We believe that a properly equipped geophysical logger should be viewed as an asset rather than as a cost liability to the State.

UNCOORDINATED DEVELOPMENT

Local water-resources planning and management ranges from water-supply evaluation and planning for a single well (or surface-water intake), to evaluation and planning for a well field. Regional planning and management must consider water district, county-wide, river-basin, and finally statewide or multi-state problems and needs. It has been shown in this report how the development of a single large-capacity well field can influence regional planning and management decisions for an entire river basin, county, or multi-county area. Thus, it is important that effects of all future water-supply development that takes place in the basin or area should be evaluated in terms of the effects that the development will have on existing wells, well fields, or surface-water supplies. Obviously the reverse is true also--the potential effects that an existing well or well field will have on future wells or well fields throughout the basin or region should be evaluated.

In the Low Country-Savannah area, one problem that has occurred in the past is what we refer to as 'uncoordinated development' of both the surface and ground-water resources. We consider the uncoordinated development as an administrative problem, but it should most definitedly be considered as a technical one. Future water-resources development in the Low Country and adjacent areas must be evaluated on both a regional multi-state (in this case two states) and on a local basis.

THE REGIONAL INTERSTATE PICTURE

Most water users in the Low Country and adjacent areas in South Carolina and Georgia have in the past considered their own immediate, or possibly their future needs when they developed their water supply. However, proper and adequate consideration has rarely been given to existing and future water-supply needs of other water users. This problem is certainly not unique to the Low Country-Savannah area. Such single-purpose water-supply development and planning, which has long been avoided in 'water-deficient' western states for many years, has been a common occurrence in the 'water-rich' eastern states. However, eastern states have painfully learned that *water resources are a 'renewable resource' only if they are prudently managed and protected.*

It has been shown in several reports that pumpage from the Tertiary Limestone Aquifer at Savannah has caused water-level declines in parts of Beaufort and Jasper Counties and is contributing to the salt-water contamination of the Tertiary Limestone Aquifer. Obviously, when these large ground-water withdrawals began, the Low Country area and the Savannah area were much more rural and sparsely populated than they are now. Thus, it could be said that there was little 'serious' adverse effect on water users and the Tertiary Limestone Aquifer itself--until pumpage at Savannah exceeded about 40 Mgd, the maximum withdrawal rate estimated by the USGS that would prevent salt-water encroachment. However, the growth and water needs of Beaufort County in particular, have increased since the early 1960's, and pumpage at Savannah alone has long exceeded 40 Mgd. Therefore, any new anticipated ground-water development from the Tertiary Limestone Aquifer in the Low Country, South Carolina area and adjacent areas in South Carolina and Georgia must be undertaken with proper consideration for existing and possible future uses of ground water.

Such consideration is important in the entire Low Country area and a large area of coastal Georgia. As shown by several investigations, ground-water development anywhere in the Low Country, particularly in Hampton, Jasper, and northern and southwestern Beaufort County will, in some measure, affect the future availability of ground water from the Tertiary Limestone Aquifer. In addition, any future ground-water development from this aquifer in a large area in the Lower Coastal Plain of Georgia will, in some measure, affect the future availability of ground water from this aquifer in adjacent South Carolina. 'How much' effect these ground-water developments will have must be determined or at least estimated by the hydrologist, and someone must decide if such development will 'seriously' jeopardize existing water uses or the aquifer. There are, of course, many complex and interrelated factors in water management that must be evaluated. Their evaluation is often not easy; and often all the technical data may not be available for the proper evaluation of these factors when decisions are needed. However, these water-management decisions must be made--with proper consideration and evaluation of the 'regional interstate picture'.

THE REGIONAL BASIN PICTURE

Neglecting, for discussion purposes, ground and surface-water development in adjacent Georgia, there has been other uncoordinated water-supply development in the Savannah and adjacent ACE (Ashley, Combahee, Edisto) River Basins. In the past, uncoordinated water-supply development has probably not caused serious water-use conflicts because withdrawal uses of ground and surface water in the Low Country area, as a whole, have not been large. However, in addition to drinking water (which must, of necessity, be considered first), other water needs such as agricultural (stock and irrigation), industrial, recreational, and fish and wildlife propagation needs must be considered; and available supplies must be conjunctively utilized by these sometimes conflicting uses. *Therefore, single-purpose water-supply planning will not suffice if the surface and ground-water resources of the Low Country area (and South Carolina in general) are going to be properly managed to provide the long-term water-supply needs of these diverse users.*

The Savannah and Edisto Rivers are the only streams in the Low Country area that have sufficient fresh-water discharges to sustain extremely large withdrawal uses of water. In terms of streamflow, the Savannah River has sufficient fresh-water discharge to supply additional large withdrawals. At USGS gaging station No. 1985 at Clyo, Georgia (fig. 11), the lowest mean daily flow for the period of record (1929-33; 1937-current) is 1,950 cfs (1,260 Mgd), and the 10-year, 7-day low flow ($7Q_{10}$) is 5,800 cfs (3,747 Mgd) for the period of record. Thus, discharge above the Beaufort-Jasper Water Authority intake in Jasper County is sufficient to sustain large withdrawal uses without causing serious upstream salt-water encroachment. Therefore, the quality of Savannah River water (which depends, of course, on streamflow and other factors) is presently of primary consideration in the water-supply planning and management of this river basin.

The Edisto River has a much lower fresh-water discharge and can not sustain 'extremely large' additional withdrawal uses without careful planning. The lowest mean daily discharge of the Edisto River near Givhans (USGS gaging station 1750, fig. 11) for the period 1939 to the present was 349 cfs (275 Mgd). This river currently supplies the municipal water needs for the cities of Charleston and Orangeburg, and several smaller municipal withdrawals on tributary streams. The average daily demands of Charleston and Orangeburg in 1975 were approximately 70.0 Mgd, and the estimated average daily withdrawals from the Edisto River by other municipal and industrial users approximated 8.5 Mgd (Duke, 1977). Since 1975, there have been a number of irrigation systems installed in the Edisto River Basin that withdraw substantial quantities of water from the Edisto or its tributaries. In addition, the City of Walterboro and Colleton County have been granted a 'legislative right' to withdraw a certain quantity of water for municipal needs from the Edisto River, although neither has exercised that right (and neither is likely to in the forseeable future). The Edisto River is also an important source of fresh water for certain non-withdrawal uses such as fish and wildlife propagation and recreation.

These streamflow and water-use data indicate that known withdrawal uses in the Edisto River Basin at and above the Charleston municipal intake, may already exceed 40 percent of the lowest mean daily discharge of the River at Givhans (275 Mgd). Therefore, future withdrawal uses of water from this river basin, in addition to affecting existing or identified potential surface-water users, will also have some influence on ground-water supply planning and management in the Low Country and adjacent areas. Without careful basin-wide planning and management, the Edisto River cannot be necessarily relied upon as a replacement for ground water in the Low Country area. Certainly the flow is sufficient now to replace all ground-water withdrawals, but what future development can be anticipated?

An important concept in total water-resources planning and management is an understanding of the relationship between surface and ground-water resources. In past years, this has been all but neglected in South Carolina, mainly because knowledge of our ground-water resources has lagged so far behind our knowledge of surface-water resources. In most so-called 'comprehensive' plans, ground-water resources have not received the proper attention, often being only briefly mentioned or reviewed in a 'natural resources' section. It must be realized that in most areas, and in southwestern South Carolina in particular, there is an intimate relationship between surface and ground water. Many of the streams that originate within the ACE and the lower Savannah River Basins are sustained by ground-water discharge during low-flow periods. Thus, the development of ground-water supplies in the lower reaches of streams will have some effect on the flow characteristics of streams in the area. Conversely, water-supply developments (either surface or ground water) in the upper reaches of the Savannah, Edisto, and Combahee and other streams must be considered in water planning and management of the lower reaches of these streams in the Low Country area.

THE LOCAL PICTURE

The development of ground water within the four-county Low Country area has most often occurred with little or no coordination among users. In many instances, wells for water users have been located with little or no consideration given to the effects that this new well or wells will have on existing wells. Considering the Low Country area as a whole, this has not been a serious problem because of the relatively small ground-water pumpage and the sparsely settled, rural nature of the area. In addition, in much of Hampton County and northern Colleton County more than one aquifer has been available for development. However, in Jasper County and in most of Beaufort County the Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer is the most readily available, economic source of fresh ground water. Consequently, the effects of uncoordinated ground-water development among water users that utilize the Upper Unit are the most noticeable on Port Royal, Ladies, St. Helena, and Hilton Head Islands. In these areas, it is common for one water user to locate a new well close to an existing well of an adjacent landowner.

The competition among several water users including public supply, industrial uses and commercial and agricultural irrigation has already become noticeable, especially on Hilton Head Island. At this time, the problem has not reached 'the crisis' stage; *but in the absence of proper management, at some point in time water-use conflicts are going to occur.* This problem is especially compounded in coastal Beaufort County because ground-water users that tap the Upper Hydrogeologic Unit of the Tertiary Limestone Aquifer must also be acutely aware and watchful of salt-water contamination.

This lack of coordination, an administrative problem, is directly related to the technical problems summarized in this report. Proper coordination is especially important where aquifer permeabilities are low, or where salt-water contamination problems and large water-level declines are occurring or are likely to occur in the future. *Often, modification in well design or location, or other ground-water management measures can be utilized to lessen the impact of one withdrawal on another.*

ECONOMICS AND FINANCING OF GROUND-WATER MANAGEMENT

Public concern for environmental protection and management of ground-water resources has historically been less than concern for protection and management of surface-water and other natural resources. Perhaps, in part because of this attitude, expenditures for ground-water evaluation, planning and management programs in the United States have been small in comparison to the value of ground water and in comparison to expenditures for protection and management of other natural resources. Historically, this lack of funding for ground-water programs has been an administrative problem, especially in the Southeast where ground water has too long been considered a 'priceless resource', free for the taking, and somewhat 'insulated' from problems. In addition, various federal financial-assistance programs for local ground-water supply development projects have historically been underfunded because of lack of recognition by federal authorities. Therefore, economic and social conditions and attitudes are as much a part of ground-water managment as the technical aspects of managing this resource.

The average citizen, quite understandably, has a general lack of knowledge of and appreciation for the value of ground water. It is difficult for this citizen to appreciate the costs and efforts in protecting and managing ground-water resources. Even though ground water may be the major source of water supplies in a particular region, the largest expenditures by a large margin have generally been devoted to environmental protection of surface water in this region. We believe these imbalances in concerns and expenditures for ground-water programs are administrative problems that have a direct bearing on ground-water management in the Southeast, South Carolina, and the Low Country area, and on certain conclusions and recommendations contained in this report.

What is the value of ground water in the Low Country area? What is the potential value of a ground-water supply that can be depended upon to meet both the short-term and long-term needs of a municipality, an industry, or a farmer wishing to begin supplemental irrigation? What is the current value of ground water to an existing public, rural-domestic, industrial, or agricultural water user? Could the value of a ground-water supply be equated to the value of an equivalent supply from surface-water resources? Are fresh surface-water supplies readily available to water users in the Low Country? Are they economically available? What is the cost of replacing a ground-water supply that has been, for most practical purposes, rendered unusable? Is ground water a dependable source of supply? If I drill a well, how can I be sure that another well owner is not going to interfere with my water supply?

These are not 'hypothetical' questions, but are questions that have been asked, and are constantly being asked by water users in the Low Country area. Each of the questions has been posed more than once, sometimes many times, to the authors of this report. The questions can not be answered in this report because many of the questions are interrelated, and there are no simple answers that could include all the various water-user/water-supplier viewpoints in the Low Country and in the adjacent Savannah area. However, we would suggest several thoughts that may put the value of ground water in the proper perspective.

In the opinion of the user who purchases water from a public-supply system, the value of ground water may not be greater than the cost of his monthly water bill. However, the value of ground water is much greater to the water user dependent upon his own private well for a water supply. To an industrial or public-water supplier dependent on ground water, the value would vary considerably, depending on whether he had an alternate supply available. The readily available ground-water supplies for industrial, agricultural and municipal water users in the Low Country-Savannah area have been extremely valuable in our opinion, and obviously in the opinions of these water users. In Savannah alone, from 75 to 90 Mgd of ground water is pumped from the Tertiary Limestone Aquifer for industrial and public drinking-water supplies. Therefore, regardless of various opinions, ground water is one of the most valuable natural resources in the Low Country-Savannah area.

For citizens in the Low Country area, various administrative and financing problems are associated with obtaining funding for either surface or ground-water supply projects (such as the construction of a new municipal well field, for example). All water users are faced with increasing construction and energy costs. Rural families dependent upon private wells for their water supply face the same costs; without financial assistance, these families may not be able to afford tap-on fees and monthly water bills, even if a public drinking-water supply were available to them. Public drinking-water suppliers (whether their source of supply is from surface or ground-water) face increasing costs for equipment, water treatment (especially for surface-water supplies), construction of new or replacement and repair of distribution lines. Farmers utilizing, or wishing to utilize, ground water for supplemental irrigation face many increasing capital costs for machinery, energy, and well construction.

There should be no question that the value of ground water to the Low Country area would justify greater state and federal expenditures for ground-water management. However, we realize that current economic conditions are such that there are no easy solutions to obtaining additional funding for local ground-water development projects, and for ground-water investigation, planning and management programs. Federal financial assistance for local or state ground-water development, planning and management programs is available through several federal-state cooperative programs. However, it has been increasingly difficult to obtain additional federal funding because of the difficulty in obtaining state and local matching funds.

The financial assistance programs that will be of greatest benefit over the long term will be those that (1) properly recognize the value of ground water and need for its proper investigation, utilizaton and management, and (2) provide funding assistance for a state-acceptable ground-water management program, based on state (rather than national) guidelines. As ground water becomes less of a 'mysterious resource' to the average citizen, awareness and concern for its protection and management will increase; and greater levels of funding will be obtained. However, until greater levels of funding become available, the difficulties in properly funding ground-water management programs will be those of recognition and setting of priorities by those federal, state and local agencies directly responsible for ground-water protection and management.

Any ground-water management program must consider all these economic problems and conditions, and it must have the flexibility to adjust to these various needs and conditions. A ground-water management program must also recognize that ground-water management methods cannot be applied uniformly and inflexibly over an entire county or region and certainly not statewide or nationally. Therefore, the hydrologist or any other 'water manager' must always be acutely aware of these local economic problems and conditions when recommending solutions and ground-water management alternatives. As discussed in the following section of this report, the SCWRC is required by the S. C. Ground Water Use Act to consider economic as well as environmental factors in the application of ground-water management methods in a designated capacity use area.

GROUND-WATER MANAGEMENT PROGRAMS

REVIEW REQUIREMENT

The S.C. Ground Water Use Act requires a review of existing measures to control or solve ground-water use problems of an area that are identified during a capacity use investigation. This, in effect, requires a review and evaluation of all local, state, or federal ground-water management measures or programs, either regulatory or voluntary, that could provide solutions to the problems.

In regard to state and federal laws and ground-water programs, these have been reviewed in several publications. In the report on the capacity use investigation of Horry and Georgetown Counties (SCWRC Rept. No. 129), a thorough appraisal of these ground-water programs was provided. We do not feel it necessary to repeat these here, since there have been no substantiative changes in state or federal ground-water laws or regulations since completion of that report.

A recent review of state and federal programs was completed by Harris and Ferguson (1978) as part of the Statewide Non-Point Source Pollution (208) Report. In addition, a brief but thorough discussion of ground-water programs in southeastern states by ground-water officials responsible for those programs, was included in a document compiled by A. D. Park (1979) entitled, "Groundwater in the Coastal Plains Region, A Status Report and Handbook." (Copies can be obtained from the SCWRC).

In regard to local programs, a review of local laws and ordinances in the Low Country area has been made. Contacts were made with local city and county government officials and with the staff of the Low Country Council of Governments. Municipal and county officials expressed either lack of authority, desire, or expertise to undertake the kind of program that would be required to manage ground-water resources.

Our conclusions are that there is no local, state, or federal law that could, or is designed to adequately address all of the ground-water problems summarized in this report, or none that are unnecessarily duplicative of authorities granted to the SCWRC by the S.C. Ground Water Use Act.

GROUND-WATER USE LEGISLATION

While not required by the S.C. Ground Water Use Act, we feel that it would be beneficial to review ground-water management legislation in several other southeastern states. While the purposes and objectives of such legislation are known to the Commissioners, it is important that local officials and others understand the objectives. In addition, since several ground-water problems discussed in this report are interstate in nature, Georgia's ground-water management program is important to any ground-water management program that may be initiated in the Low Country area.

Reasonable interpretation of any capacity use type legislation should clearly indicate that the basis of such legislation is ground-water management. It is definitely not "crisis" or "last-resort" type legislation because ground-water management options decrease if problems become critical.

The basic element of all ground-water use type legislation is, like most natural-resources legislation, a permit system. A permit must be obtained prior to beginning any ground-water development activities. However, prior to granting a permit to withdraw ground water, the potential effects of the proposed withdrawal must be evaluated. Therefore, it is not a "basic-data collection" program because much of the basic hydrogeologic data needed to evaluate a proposed ground-water development must be available to the regulating authority. Certain hydrogeologic data must be collected by the water user or his contractor prior to, during, and after any well-construction activities that will enable proper decisions to be made by the regulating authority. The collection of proper data, prior to expenditures for a proposed ground-water use, will insure that unnecessary expenditures are not made by a water user.

All Southeastern Atlantic States now require ground-water use permits, either in the entire state or in designated "capacity use", "critical", or "ground-water management" areas (fig.19). Most southeastern ground-water officials dislike the term "capacity use" or "critical" because of the seemingly ominous implications of the terms. Indeed, the term "capacity use" unfortunately has in some states too easily been misinterpreted by some to mean that aquifers are "at capacity" and that no more ground-water withdrawals are possible. To the contrary, with the establishment of proper ground-water management programs, additional ground-water withdrawals are possible in most ground-water management areas that have been established in the Southeast.

In Georgia, water-use permits for the entire state are issued by the Georgia Department of Natural Resources, Environmental Protection Division, located in Atlanta. The State of Florida is subdivided into five Water-Management Districts that are responsible for managing both surface and ground water. Each of these Water-Management Districts issues ground-water use permits or is in the process of initiating permitting systems. Similarly, in North Carolina and Virginia, regional offices are responsible for evaluating the effects of a proposed ground-water use, and water-use permits are issued from the central office of the state agency.

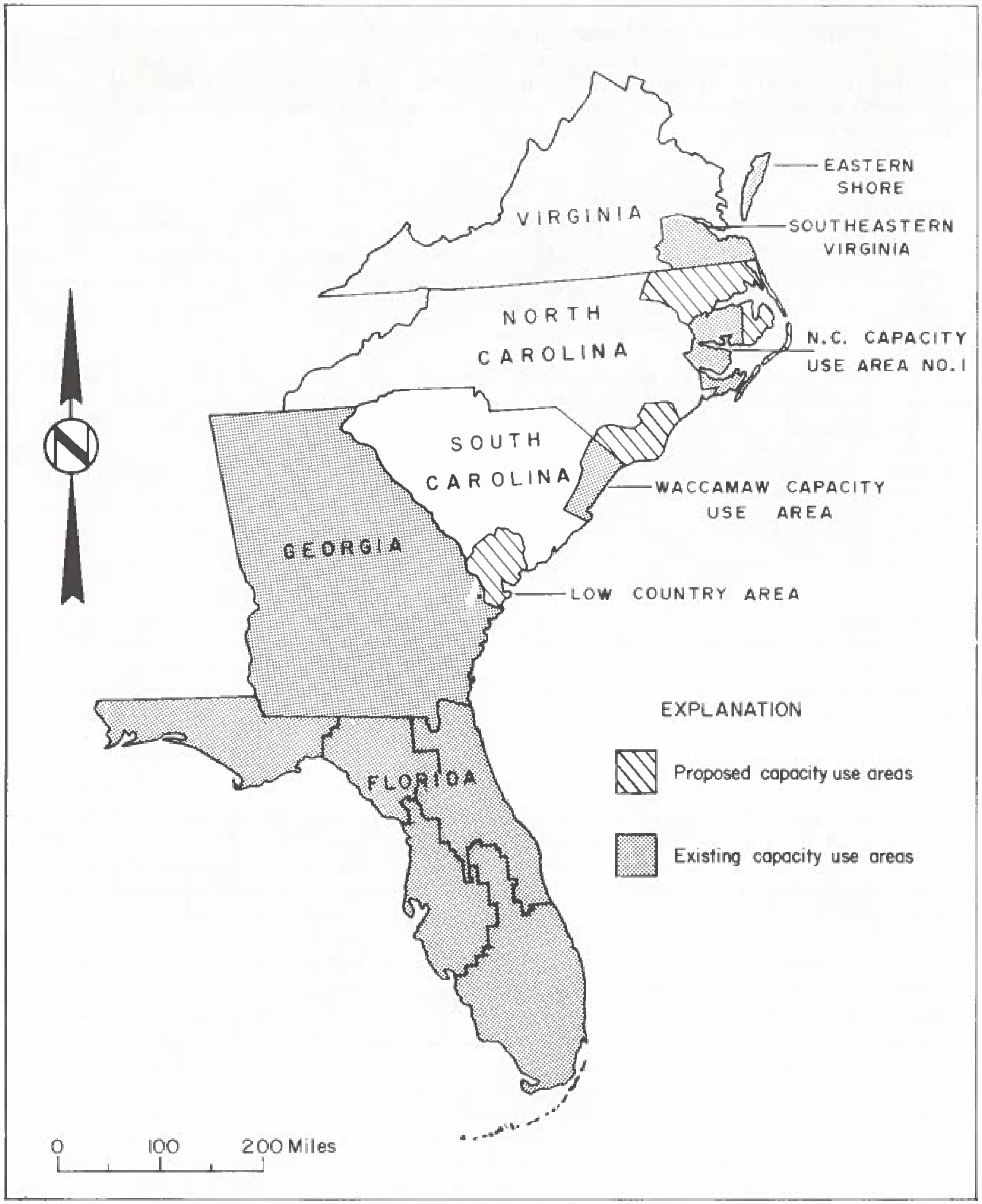


FIGURE 19. GROUND-WATER MANAGEMENT AREAS IN THE SOUTHEAST.

It is especially pertinent in this report to review the ground-water use legislation and programs of Georgia because we have problems in common; and to review the program in North Carolina because ground-water problems in their one declared capacity use area are similar, in several respects, to those in the Low Country area.

Georgia

Georgia's Ground Water Use Act of 1972 was amended in 1973, and the entire state, in effect, became a "capacity use area". In addition, a water-use permit is now required in order to withdraw 100,000 gpd or more from surface as well as ground-water sources.

According to officials with the Georgia Department of Natural Resources, since their ground-water regulations are so new, a fair evaluation of the program can not as yet be made. These officials indicate that an inadequate staff, inadequate technical data, and lack of an effective program of training ground-water hydrologists have been troublesome problems. Since Georgia's water-use regulations pertain to the entire state, additional staff and funding are needed to properly administer the program.

Georgia officials indicate that ground-water management programs are being initiated in areas where large, concentrated ground-water withdrawals are being made from the Tertiary Limestone Aquifer System. One of these areas is the Savannah area, where additional ground-water withdrawals from the Tertiary Limestone Aquifer are being critically reviewed by the Environmental Protection Division.

North Carolina

The North Carolina Water Use Act of 1967 applies (as in Georgia) to both surface and ground-water withdrawals. However, in North Carolina the institution of a water-use permit system is dependent (as in S. C.) upon the declaration of a capacity use area. One capacity use area has been declared, and several other capacity use investigations are underway (fig. 19).

There are several important differences in the ground-water management programs of North Carolina and the programs in South Carolina and Georgia. For many years, the state of North Carolina has had ground-water legislation that the states of South Carolina and Georgia have not had. North Carolina has long had water-well standards legislation, a well-drillers liscensing act, and has required that a well-completion report be submitted on every well drilled in the state. Thus, the ground-water program of North Carolina is years ahead of similar ground-water programs of South Carolina and Georgia. Legislation in North Carolina is only partly responsible for their success in developing an effective ground-water program. For many years, North Carolina has had much greater state expenditures for their ground-water programs. Three well-drilling rigs and a properly-equipped geophysical logger have provided information and management capability that South Carolina and Georgia have not had.

The hydrogeology of N.C. Capacity Use Area No. 1, centered on Beaufort, County, N. C., is very similar to the Beaufort County, S. C. area. A shallow artesian limestone aquifer (the Castle Hayne Aquifer), hydrogeologically similar to the Tertiary Limestone Aquifer of South Carolina, is overlain by confining beds (Pungo River Formation) which are hydrogeologically similar to the Hawthorn Formation. Beds of phosphate are being commercially mined from the Pungo River Formation, part of the confining bed overlying the Castle Hayne Aquifer. In order to mine these phosphate resources, the underlying Castle Hayne Aquifer must be depressured (i.e., dewatered) in order to reduce artesian pressures below the base of the large open-pit mines. These dewatering operations began in July 1965, prior to the passage of the N. C. Water Use Act of 1967.

The Castle Hayne Aquifer is the major source of fresh-water supplies in this area, and the large ground-water withdrawals have "dried up" (caused a large pressure-reduction in) many wells and have caused progressive salt-water intrusion of the Castle Hayne Aquifer (Peek, 1969; Peek and Nelson, 1975). The environmental consequences of this dewatering were in part responsible for the passage of the N. C. Water Use Act in 1967, and declaration of a capacity use area in 1968. However, according to a report by the N.C. Department of Natural Resources and Economic Development (1974, p.48), there have been minimal attempts at developing ground-water management measures in the area, despite recommendations concerning several measures that could be initiated. It has been fortunate that the Beaufort, County, N. C. area is as rural and sparsely populated as it is; otherwise, the environmental damage to water users and to the Castle Hayne Aquifer would be even more serious (H. M. Peek, NCDNRCD, oral communication, 1978).

Our purpose is not to criticize or to judge decisions made by N. C. officials. There are many factors that they must have had to consider, and the decisions were undoubtedly difficult. Whatever the reason, there are important lessons to be learned from North Carolina's experience. State officials have at least had the benefit of sound professional advice from their state ground-water hydrologists, and once decisions were made, they were able to at least mitigate adverse environmental damage. Similar ground-water management decisions are now facing South Carolina and Georgia officials in regard to the Low Country and adjacent Savannah areas. Georgia officials have already made one major decision--the declaration of a capacity use area and institution of water-use permitting.

S. C. GROUND WATER USE ACT AND GROUND-WATER MANAGEMENT PROGRAM

The S. C. Ground Water Use Act of 1969 is similar to the N. C. Water Use Act of 1967 and the Virginia Ground Water Use Act of 1973 in that "capacity use" or "critical use" areas must be declared prior to the initiation of a water use permitting system. The legislative intent of these acts is clear--to protect aquifers (i.e., the source of ground-water supplies) and ground-water users from adverse effects of ground-water development (this may be pumping for supply purposes or "pumping" for wasteful purposes, such as unused flowing artesian wells).

After declaration of a capacity use area, Section 49-5-60(h) of the Act requires the SCWRC to consider nine factors in regard to water-use permits that in reality are the very basis of ground-water management. For all practical purposes, these factors must be considered before a capacity use area is declared. These factors, used by the Geology-Hydrology Division as a guide in conducting a capacity use investigation, are:

(1) *"The number of persons using an aquifer and the object, extent and necessity of their respective withdrawals or uses."*

This requires a ground-water use inventory, and a continual update of water use. In evaluating the necessity of a particular use, the SCWRC must consider economic and other factors that may influence or have a bearing on the value of that use to a particular water user. Because the value of a particular use depends on so many factors, this is perhaps one of the most difficult decisions in water-resources management.

(2) *"The nature and size of the aquifer."*

Although not specifically defined in the Act, "nature" is interpreted to mean the hydrologic characteristics of the aquifer and the quantity and quality of ground water contained in that aquifer. "Size" is the thickness and lateral extent. Where aquifers cross county boundaries or state boundaries (as in the Low Country), the thickness and lateral extent of aquifers must be considered in these areas also.

(3) *"The physical and chemical nature of any impairment of the aquifer, adversely affecting its availability or fitness for other uses (including public use)."*

Therefore, the SCWRC must consider all physical and chemical impairment of the aquifer. These "impairments" could include salt-water contamination, ground-water pollution, or other types of contamination. As previously mentioned, ground-water pollution studies conducted by the SCDHEC are important sources of information, and any sources of pollution, or potential sources of pollution, must be considered in evaluating a proposed ground-water withdrawal.

(4) *"The probable severity and duration of such impairment under forseeable conditions."*

Because the movement of ground water is so slow, once an aquifer is contaminatd or polluted it may take hundreds of years for contaminants or pollutants to be flushed from an aquifer. Thus, for all practical purposes, some contamination is "forever". For this reason, it is important to protect fresh-water aquifers from potential sources of contamination or pollution.

(5) *"The injury to public health, safety, or welfare which result if such impairment were not prevented or abated."*

Many factors enter into an evaluation of short-term and especially the long-term effects of contamination or pollution, and the possible injury to public health, safety, or welfare if the impairment of an aquifer were not prevented or abated. One of the most important factors is recognition of the role of prevention of such impairment. It is very difficult, sometimes impossible, to remove certain types of contaminants or pollutants from aquifers. To the contrary, pollution of some rivers, for example, may be only of short-term duration which may interrupt the use of that stream for only a matter of hours or perhaps days.

> (6) *"The kinds of businesses or activities to which the various uses are related."*

Consideration must be given to water use, factor number (1) above.

> (7) *"The importance and necessity of the uses claimed by permit applicants (under this section), or of the water uses of the area (under Section 49-5-50) and the extent of any injury or detriment caused or expected to be caused to other water uses (including public use)."*

This is a part of water use and requires that the SCWRC consider not only the technical but other environmental and economic factors concerning a proposed ground-water use. Not only existing, but potential damage to the aquifer or water users, must be considered. Thus, the long-term effects of ground-water development must be anticipated.

> (8) *"Diversion from or reduction of flows in other water courses or aquifers."*

The effects of ground-water withdrawals from one aquifer on another aquifer must be evaluated as well as the effects on surface-water supplies. Reduction of artesian pressures in aquifers must be considered.

> (9) *"Any other relevant factors."*

As a discretionary factor, this could include most anything not included in the other eight factors.

The Ground Water Use Act is a "technical assistance" act because an important aspect of ground-water management is accurate, timely technical assistance. In many instances, the proper technical assistance at the right time is an important way of avoiding or preventing improper ground-water development.

The S.C. Ground Water Use Act also contains provisions to prevent or abate salt-water encroachment--which involves several aspects of proper ground-water management measures discussed previously in this report. Preventive or abatement measures that may be initiated include reduction of ground-water withdrawals, rearrangement of pumping centers, utilization of other fresh-water aquifers or saline-water aquifers for a particular purpose, requiring conjunctive use of surface-and ground-water resources, plugging and abandonment of wells, and other factors. As outlined previously in this report, the control of salt-water contamination of an aquifer may be fairly simple or extremely complicated. The primary factor in the control of salt-water contamination is the control of hydraulic gradient which is related directly to ground-water withdrawals.

CONCLUSIONS AND RECOMMENDATIONS

After careful consideration of the data collected during the Low Country Capacity Use Investigation, and data collected by the SCWRC, USGS, and others prior to this investigation, the following conclusions and recommendations are submitted to the Commission for consideration.

Surface water is currently not utilized to a large extent for water supplies in the Low Country area. Since most streams in the coastal area either contain salty water or have insufficient fresh-water discharge, there are few withdrawal uses of fresh water from these streams. Thus, several water users have had to resort to interbasin transfers from the Savannah or Edisto Rivers. Approximately 5 Mgd are withdrawn from the Savannah River and transported via canal to the Beaufort area by the Beaufort-Jasper Water Authority; and approximately 75 Mgd are withdrawn from the Edisto River and transported via underground tunnels to the Charleston area by the Charleston Water Works.

Ground water is by far the most important source of water supplies for public, rural-domestic (private), industrial, and agricultural supplies in the Low Country area. This ground water is obtained from six major aquifer systems that are now supplying or are capable of supplying from small to large ground-water supplies. These are, from the surface downward, (1) shallow aquifers within the Hawthorn Formation and unnamed Pleistocene deposits, included in the Hawthorn-Recent Aquifer System in this report; (2) the Tertiary Limestone Aquifer; (3) the Black Mingo Aquifer System; (4) the Peedee Aquifer System; (5) the Black Creek Aquifer System; and (6) the Tuscaloosa Aquifer System.

In order of their current utilization for ground-water supplies, the most important are the Tertiary Limestone, the Black Creek, the Black Mingo, and the Tuscaloosa Aquifer Systems. The Tertiary Limestone Aquifer is currently the most heavily developed aquifer system throughout the area as a whole. Aquifers within the deeper artesian aquifer systems are primarily utilized in Hampton and Colleton Counties, and to a much lesser extent in coastal Beaufort County. The Peedee Aquifer System is not known to yield large quantities of ground water to wells in the area; and if used at all, it is probably developed with overlying or underlying aquifer systems. Shallow aquifers occur in some areas in the Hawthorn Formation and (or) Pleistocene deposits and are tapped by small-diameter, shallow wells used primarily for rural-domestic supplies in Jasper County and in some areas of Beaufort County; however, these shallow aquifers are relatively thin, laterally discontinuous, and relatively untapped. The major functions of these shallow sediments are as a confining bed over the underlying Tertiary Limestone Aquifer, and as a source of recharge by the process of downward leakage.

The estimated total ground-water withdrawals in the four-county area is an average of about 50 Mgd. However, much of this total includes ground water withdrawn for commercial and agricultural irrigation, and only a fraction of the flowing artesian wells in the area have been properly inventoried. Thus, the total ground-water withdrawals during certain periods could easily range from about 30 Mgd to as much as 70 Mgd. It is believed that most of the flowing artesian wells that have been inventoried in Hampton and Colleton Counties tap the Black Mingo Aquifer System. However, in some areas, these wells tap water-bearing (permeable) zones in the middle and lower parts of the Tertiary Limestone Aquifer.

The largest ground-water withdrawals (approximately 35 Mgd) in the Low Country area are from the Tertiary Limestone Aquifer. This aquifer is the most economical source of large quantities of good-quality water throughout much of the area. Present information indicates that there is no alternative source of good quality ground water in much of Beaufort County and the southern portions of Jasper and Colleton Counties. Deeper artesian aquifers are utilized to some extent in Hampton and Colleton Counties, primarily by industries and municipalities. However, in Beaufort and southern Colleton Counties, these deeper aquifers either contain mineralized water; are not as productive; or they occur at greater depths and their utilization is not as economical as that of the Tertiary Limestone Aquifer. *Therefore, the Tertiary Limestone Aquifer is almost exclusively utilized as a source of fresh-water supplies in much of the Low Country.* The largest withdrawals from this aquifer (25 Mgd) are in Beaufort County, where approximately 10 to 15 Mgd are used for commercial and agricultural irrigation. The Tertiary Limestone Aquifer is also extensively (many wells) but not heavily utilized throughout the remainder of the Low Country area. In the Savannah area, approximately 75 to 90 Mgd of ground water are withdrawn from the Tertiary Limestone Aquifer by 21 water users, mainly for industrial and public water supplies. Contacts with Georgia and USGS ground-water officials indicate a lack of accurate water-use reporting, and to date they have not conducted a thorough water-use inventory. Thus, pumpage from the Tertiary Limestone Aquifer in Chatham County alone may periodically exceed 90 Mgd.

There are several major problems occurring now in the Low Country area, and others that are likely to become serious if the ground-water resources are not properly managed. These problems have been categorized as 'technical' and 'administrative' in this report, but their separation has been primarily to facilitate orderly discussion. They are, in fact, closely interrelated.

As summarized in this report, the major technical problems are related to ground-water withdrawals from the Tertiary Limestone Aquifer. Documented problems that are directly related to these withdrawals include (1) regional water-level declines (loss of artesian pressure) throughout large areas of the Low Country and adjacent counties in Georgia, (2) progressive salt-water contamination of this aquifer in parts of the coastal area, (3) local well interference where water levels are lowered below some pump intakes, (4) interaquifer transfer resulting in local artesian pressure losses in wells and water quality impairment. Potential problems that could result from improper well design, location, and spacing include (1) subsidence of the land surface, which has occurred in the Savannah area, (2) local dewatering of the Tertiary Limestone Aquifer, and (3) land-surface subsidence and collapse if certain conditions are created.

The problems are related to varying degrees, and the solution of one problem would permit the solution of another problem. *The one factor common to all of the problems is hydraulic gradient, which is related to ground-water withdrawals.* Of course, some of these problems have been more serious in some areas than in others. As summarized in this report, the 'seriousness' of a ground-water problem ranges from loss of a ground-water supply to little more than aggravation. Recognizing that the degree of 'seriousness' of a water problem is highly subjective, we have tried to evaluate the degree of seriousness on the basis of technically-documented facts rather than speculation.

Ground-water pollution of shallow aquifers has occurred in some areas and locally poses a potential threat to the Tertiary Limestone Aquifer. Several cases of ground-water pollution have been intensively investigated by the SCDHEC, and other cases are being investigated at the present time. The final results of these investigations have not been released by the SCDHEC. Therefore, we have not speculated in this report on the results of these investigations.

The major problem in the Low Country area is unregulated, uncoordinated pumpage. Closely linked to the 'technical' problems associated with this pumpage are several 'administrative' problems. In effect, there is no ground-water management in the Low Country area.

At the present time, almost anyone can drill a well pretty much where they wish and pump how much they wish. There is essentially no control on well depths and type of well construction. There are no controls on amount of ground-water pumpage, water levels, and well location and spacing. The only existing controls on well location or construction are for wells utilized for public drinking-water supplies. These requirements pertain primarily to the quality (potability) of ground water which must meet certain minimum drinking-water standards established by the U. S. Environmental Protection Agency.

There are no requirements, or minimal requirements for collecting and reporting certain technical data to a state agency. Many types of data should be submitted prior to any well-construction activity so that a prospective withdrawal can be evaluated as to its possible effects on existing water users or on the aquifer.

Other types of hydrogeologic data should be collected and submitted to the proper authority, either during or immediately after well-construction operations. These requirements are important for several reasons: (1) In many cases, the collection of proper data by a prospective water user, his consultant, or well-drilling contractor prior to beginning a proposed withdrawal will save a prospective water user hundreds or perhaps even thousands of dollars for an unnecessary expense. (2) The collection of proper hydrogeologic data during well-construction operations would save the well owner money; it would insure protection for the well owner and well-drilling contractor should questions arise concerning the adequacy of well-construction in obtaining the desired quantity and quality of ground water. (3) Accumulated hydrogeologic and well-construction data will be properly stored and evaluated so it can be utilized by the water users, consultants, future water users, well-drilling contractors, or any other individual requesting the information. (4) The continual evaluation of these data by state hydrologists would insure that ground-water knowledge of the area is accumulated for utilization by the general public, prospective water users, and others.

As required by the S. C. Ground Water Use Act, an assessment has been made of existing methods to solve or minimize water-use problems short of declaring a capacity use area. These ground-water management methods consist of both regulatory and voluntary methods.

There is no local, state, or federal law or regulation which is capable of providing appropriate remedies for the ground-water use and management problems outlined in this report. Contacts with local government agencies indicate a lack of authority, funding, personnel, and technical expertise to carry out a ground-water managment program. There have been no substantiative changes in state or federal law since completion of our first capacity-use report that merit detailed review in this report, because none that we know of would be unnecessarily duplicative of authorities granted to the SCWRC by the S. C. Ground Water Use Act.

In connection with voluntary ground-water management methods, it would indeed be a fortunate circumstance if all ground-water users and potential ground-water users in both South Carolina and Georgia, and others involved in designing and constructing wells, could agree on proper ground-water development and management methods. While 'voluntary' sounds good (and indeed proper coordination among various ground-water users would be ideal), it has not been done in the past. However, we believe it must be done in the future.

One aspect of 'voluntary' ground-water managment is a sound technical assistance program, and the SCWRC, SCDHEC, and USGS are committed, in our opinion, to providing the best technical assistance possible in assisting existing and prospective ground-water users. Indeed, these technical assistance efforts have in the past prevented many problems. However, the State can only do so much in terms of technical assistance; and the State can not and should not be reasonably expected to provide all services that logically must be provided by the water user or potential water user. *Thus,* *our conclusion regarding voluntary ground-water management methods is that they could not possibly provide solutions to all of the problems and potential problems identified in this report.*

A ground-water management program is urgently needed in the Low Country that will provide for the orderly development of the ground-water resources, and aid in eliminating some of the current problems, or preventing them from becoming worse; and in preventing future water-use conflicts, waste, and overdevelopment. We believe the following specific recommendations are needed to help solve or, at least, alleviate the problems arising from the development of the ground-water resources and are herein submitted for consideration by the Commission.

Declaration of a Capacity Use Area: which would include all of Beaufort, Jasper, Hampton, and Colleton Counties, and Edisto Island (Charleston County). Recommended boundaries of the proposed Low Country Capacity Use Area are shown on figure 20.

Much consideration has been given to recommending the declaration of a larger capacity use area to include recharge areas of the Tertiary Limestone Aquifer in adjacent Allendale, Bamberg, and southern Orangeburg Counties. There would be several advantages to doing this in regard to ground-water management. However, there are several reasons, both technical and administrative, why we do not recommend the declaration of a larger capacity use area at this time: (1) With the technical data presently available on these recharge areas, we do not feel that ground-water development from the Tertiary Limestone Aquifer in Allendale, Bamberg, and southern Orangeburg Counties 'significantly' affects artesian pressures of this aquifer in the Low Country area at this time. We are now in the process of refining hydrogeologic data in these areas, and we believe that through a good technical assistance program, potential problems can be avoided. In addition, the high-capacity wells in these areas are primarily completed in deeper artesian aquifers. Ground-water development from these deeper aquifers should have little effect on the overlying Tertiary Limestone Aquifer, unless interaquifer transfer becomes a problem. (2) Administratively, with the current level of funding for our Capacity Use Program, funding and personnel constraints would limit the effort needed to manage a larger capacity use area. (3) The current needs of ground-water management efforts in the Low Country area, especially in the coastal area, are so great that a large area could not be managed without additional funding and manpower. Therefore, the recommended boundaries are somewhat of a compromise between good ground-water management practices and current administrative constraints. However, we believe our recommendations are adequate to provide for proper ground-water management.

Although not specifically required by the S. C. Ground Water Use Act for this report, we would recommend that the following ground-water management methods be instituted if a capacity use area is declared. If the Low Country area is declared a capacity use area, we would recommend adoption of the same type of ground-water management regulations that have been promulgated for the Waccamaw Capacity Use Area. Copies of these regulations, which were approved on June 22, 1979, are available from the SCWRC upon request.

1. *Regulations to limit ground-water withdrawals in areas where the supply is limited or where it has been documented that the movement of poor quality water is degrading a fresh-water aquifer:*

As discussed and illustrated in this report, there is no question that in some areas it will become necessary to limit the quantity of ground water withdrawn from the Tertiary Limestone Aquifer in order to protect the aquifer from further salt-water contamination, and (or) to protect water users. The State of Georgia has already established pumpage limitations in the Savannah area of Chatham County, and Georgia officials are not permitting additional ground-water withdrawals in that area.

2. *Regulations related to well spacing, construction, and abandonment; proper testing of aquifers during well-construction operations; and the proper reporting of all such data:*

Reasonable application of these ground-water management "tools" would be of enormous benefit in preventing further salt-water contamination, and interaquifer transfer; and in preventing needless expenditures for unnecessary ground-water or surface-water development activities. By controlling well spacing and design, excessive water-level declines can often be prevented, thus decreasing the threat of salt-water contamination by lateral encroachment and intrusion, upconing, and interaquifer transfer. Improper well abandonment may not be completely stopped by requiring well-abandonment permits, but it can at least be reduced in the most critical areas. The proper reporting of hydrogeologic data will enable the ground-water data base to be refined and expanded so as to insure the most reliable information.

3. *Ground-water monitoring program:* A ground-water monitoring program is needed to measure continuing changes in water levels and water quality. Long-term records of these measurements, correlated with accurate water-use and other data, provide the most reliable information on the capacity of aquifers to sustain long-term withdrawals. The SCWRC test wells completed during phase I of the Low Country Capacity Use Investigation are available for future monitoring. However, it is estimated that a minimum of an additional 20 properly constructed multi-aquifer test wells will be necessary to establish an adequate ground-water monitoring network in the coastal area of the Low Country. These test wells would be in addition to test wells needed for special studies in local areas.

4. *Water conservation measures:* Each ground-water user should be encouraged to limit ground-water development activities to actual needs, and to make concerted efforts to reduce water requirements as much as technically and economically feasible. The State of Georgia has already done so in the Savannah area, encouraging water-requirement reduction and the recycling of water.

5. *Water users should be required to use the water of lowest quality available that is, or can feasibly be made, suitable for a particular purpose.* For example, for certain water uses that do not require drinking-water quality, a ground water of lower quality could be utilized and thus conserve higher-quality ground water.

6. *Measures should be instituted that would provide for the best practical management of the ground-water system and cause the least interference with existing water users.* Such measures would include careful consideration of well or well-field placement, proper well spacing, and the establishment of "optimum practical" pumping rates and pumping water levels. In short, prior to permitting a certain withdrawal, the water user should be required to consider the best location for a well, which may not necessarily be his most economic location. One area in particular which this is already critical is in southwestern Beaufort County (specifically on Hilton Head Island). The concentration of extremely large-capacity wells without proper spacing and depth control that are to be completed in the Tertiary Limestone Aquifer should be prohibited. Again, prohibition of future ground-water withdrawals from this aquifer, even in coastal Beaufort County, is unrealistic and not supported by the technical data. We are recommending careful consideration of these withdrawals. For example, if it is shown that two properly-spaced lower capacity wells can replace one large-capacity well, then this would be the proper alternative.

7. *If a capacity use area is declared, we would recommend that no well in coastal Beaufort County (especially southeast of the Coosaw River), regardless of capacity or purpose, should be drilled without first obtaining a permit from the SCWRC under the provisions of Section 49-5-40(a)(2) of the Ground Water Use Act.* The primary concern is not necessarily the quantity that may be withdrawn through a small-diameter well, but the possible contribution to salt-water contamination if the well were improperly constructed. If a reasonable need could not be shown, and the proper well-construction criteria could not be adherred to then the well should not be permitted.

8. *Measures for proper monitoring:* There are some areas, southwest of the Broad River for example, where prospective water users wishing to install a large-capacity well or well field should bear the cost of one or more observation wells if it is deemed necessary. For example, if a water user wished to locate a large-capacity well in close proximity (within 2,000 feet) of a known fresh-salt-water interface (or a suspected interface), he should be required to install a minimum of one salt-water monitor well. The State of S.C. should not be expected to do this; we have neither the funding, equipment, nor the personnel budget to do so. Obviously, the greater the quantity of ground-water use requested, the greater the need for monitoring. It is entirely possible, or even probable, that one relatively inexpensive small-diameter (four inch) test well may save a prospective water user from an unnecessary large expense.

Two other recommendations should be considered, and are strongly recommended whether or not a capacity use area is declared.

1. *Maintain the SCWRC Regional Office in Beaufort, South Carolina:* This office will serve the proposed Low Country Capacity Use Area (if declared) as well as Allendale, Bamberg, and Barnwell Counties. The duties of personnel assigned to this office will include carrying out the administrative responsibilities necessary to manage the proposed capacity use area (if declared) as well as carrying out a comprehensive ground-water research and technology transfer program to assist existing and prospective ground-water users. The ground-water program conducted from this office will be directed towards providing an adequate ground-water research program consisting of the collection and evaluation of basic hydrogeologic data pertaining to the occurrence, movement, availability, and chemical quality of ground water. As such data become available, they will be interpreted and evaluated and reported immediately by direct oral communication, and letter-type reports; and these data will be published by the SCWRC on a regular basis.

2. *Establish a formal Interstate Ground-Water Committee composed of representatives from South Carolina and Georgia:* Insomuch as the impact of ground-water withdrawals does not stop at state boundaries, a technical ground-water committee, composed of hydrologists from South Carolina and Georgia, should be created immediately. Because both Georgia and South Carolina rely heavily on the Tertiary Limestone Aquifer in the Low Country-Savannah area, several problems involving water rights are becoming more apparent as the demand for ground water increases. A Technical Ground-Water Committee could serve as a source of communication whereby joint efforts could be made by qualified ground-water personnel to seek practical solutions to present technical problems and future water-supply needs of the area.

It should be re-emphasized that the ground-water resources of the Low Country area, as a whole, can sustain much greater development. Deep artesian aquifers below the Tertiary Limestone Aquifer in Hampton County, much of Colleton County, and possibly in northern Beaufort and Jasper Counties are capable of supplying much greater quantities of fresh, good-quality ground water to properly constructed wells. If the ground-water resources of the Tertiary Limestone Aquifer are properly managed, this aquifer system is also capable of additional development. As mentioned in the "Introduction", this report, as required by a State law, has concentrated on problems that require the application of proper ground-water management. *Therefore, it would be erroneous and totally misleading for this report to be utilized to suggest that ground water is an undependable resource.* On the other hand, we hope that we have not left the reader with the impression that the problems are not serious. *To the contrary, without proper management, ground-water management options now available may not be available in the short term and certainly not over the long term.*

FIGURE 20. BOUNDARY OF PROPOSED LOW COUNTRY CAPACITY USE AREA.

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Table 1. Summary of hydrogeologic data on SCWRC test holes, Low Country area

								HYDROGEOLOGIC DATA AVAILABLE								
SCWRC Well No.	USGS Well No.	Latitude Longitude	Elevation Land Surf. in Feet Above MSL	Total Depth (Feet)	Casing Diam. (in)	Casing Depth (ft)	Date Drilled, Driller	Aquifer	Drillers Log	Lithologic Log	Geologic Samples	Geophys. Logs	Discharge Water Level (Discharge Test)	Chemical Analysis (Type Lab)	Use of Well	Comments
27KK-b2 (TH 8)	BFT-787	32°14'56" 80°41'57"	12.0	240.0	4 PVC	126.4 (80' GROUT)	3/9/76 SOUTH GA. PUMP CO.	TLA UPPER UNIT	X			G,CAL C,T	NO	USGS(C) MULTI DPETH	OBS UPPER UNIT TLA	HILTON HEAD IS. MULTI WELL STATION. LOG BY M. CANNON; NO CTGS, SEE BFT-786. MONITOR ZONE DIFFUSION (SEE FIG. 11). ADR RECORDER-UPPER UNIT.
27KK-b3 (TH 9)	BFT-788	32°14'56" 80°41'57"	12.0	100.0	4 STL	72.0 (60' GROUT)	3/11/76 SOUTH GA. PUMP CO.	HAW-THORN	X			G	NO Q PIEZO. DATA ADR RECORDER	USGS(C)	OBS HAW-THORN	HILTON HEAD IS. MULTI-WELL STATION. LOG BY M. CANNON; NO CTGS, SEE BFT-786. ADR RECORDER-HAWTHORN AQUIFER.
26FF-e1 (TH 10)	COL-92	32°39'42" 80°39'20"	12 (TOPO)	600.0	4 PVC	96.1 (60' GROUT)	3/17/76 SOUTH GA. PUMP CO.	TLA LOWER UNIT	X		CTGS TO T.D.	E,SP, G,CAL	PUMP TEST (2.0 HRS) Q/s=2.0	USGS(C) MULTI DEPTH 2/23/77	OBS TLA UPPER UNIT	HWY. 17-ROADSIDE PARK;SEE FIG. 9. CURRENT-M TEST. ESTM. OF TRANS. LOWER UNIT (1,800 SQ. FT./DAY). QW at 600' (FRESH) CTGS TO SCGS.
28EE-g1 (TH 11)	COL-93	32°43'50" 80°48'20"	42 (TOPO & B.M. ESTM.)	400.0	4 PVC	22.0 (22' GROUT)	3/19/76 SOUTH GA. PUMP CO.	TLA LOWER UNIT (LPZ)	X		CTGS TO T.D.	E,SP, G,CAL	NO	NO	OBS TLA UPPER UNIT	NEAR JONESBORO SCH. ON SO. SIDE CO. RD. 395-STATE RIGHT/WAY. LOG BY SPIGNER/HAYES. CTGS TO SCGS.
25GG-d1 (TH 12)	COL-94	32°34'05" 80°33'29"	10 (TOPO)	600.0	4 PVC	84.0 (36' GROUT)	3/31/76 SOUTH GA. PUMP CO.	TLA LOWER UNIT (LPZ)	X (PAR)		CTGS TO T.D.	E,SP, G,CAL	AQUIFER TEST (2.0 HRS) BY RANSOM Q/s=4	USGS(C) (DHS) USGS	OBS TLA	WIGGINS BOAT LDG. AT COMBAHEE R. ON COL. CO. PROP. NEAR WELL 25GG-d2 (OBS. WELL FOR A.T.). ESTM. TRANS. LOWER UNIT(7,200 FT.SQ/D). SPIGNER LOG TO 320 FT. CTGS TO SCGS.
25EE-d1 (TH 13)	COL-95	32°44'37" 80°33'09"	15 (TOPO)	141.0	NONE	NONE	3/31/76 SOUTH GA. PUMP CO.	TLA LOWER UNIT	X		CTGS TO T.D.	G	NO	NO	DES	EAST BANK ASHEPOO R. AT HWY 17 BRDG; STATE RIGHT/WAY. SEE FIG. 8. SPIGNER LOG. CEMENT GROUTED 0-141 FT. CTGS TO SCGS.
24EE-c1 (TH 14)	COL-96	33°44'11" 80°27'09"	10 (TOPO)	604.0	4 PVC	94.6 (36' GROUT)	4/5/76 SOUTH GA. PUMP CO.	TLA LOWER UNIT	X		CTGS TO T.D.	E,SP, G,CAL	PUMP TEST (2.0 HRS) Q/s=4	YES	OBS TLA	WEST BANK LDG-JACKSONBORO BOAT RAMP; EDISTO R. ON COL. CO. PROP. NEAR FLOW ARTES. WELL 24EE-d2. SPIGNER LOG. SEE FIG.8. CURRENT-M TEST. CTGS TO SCGS.

Table 1. Summary of hydrogeologic data on SCWRC test holes, Low Country area

								HYDROGEOLOGIC DATA AVAILABLE								
SCWRC Well No.	USGS Well No.	Latitude Longitude	Elevation Land Surf. in Feet Above MSL	Total Depth (Feet)	Casing Diam. (in)	Casing Depth (ft)	Date Drilled, Driller	Aquifer	Drillers Log	Lithologic Log	Geologic Samples	Geophys. Logs	Discharge Water Level (Discharge Test)	Chemical Analysis (Type Lab)	Use of Well	Comments
26AA-11 (TH 15)	COL-97	32°02'51" 80°35'56"	80 (TOPO)	500.0	4 PVC	132.0 (40' GROUT)	4/7/76 SOUTH GA. PUMP CO.	TLA LOWER UNIT	X		CTGS TO T.D.	E,SP, G,CAL	NO Q ADR RECORDER	NO	OBS TLA LOWER UNIT	INTERSEC. HWY 45 & 61 ON STATE RIGHT/WAY.
30AA-s1 (TH 16)	COL-98	33°01'55" 80°56'42"	84 (TOPO)	303.0	NONE	NONE	4/9/76 SOUTH GA. PUMP CO.	TLA LOWER UNIT	X		CTGS TO T.D.	E,SP, G,CAL	NO	NO	DES	INTERSEC. HWY 64 & 641 ON STATE RIGHT/WAY. LOWER UNIT TEST HOLE. ABN. & CEM. GROUTED.
32BB-i1 (TH 17)	HAM-72	32°58'43" 81°06'51"	115 (TOPO)	880.0	4 PVC	162.0	JAN-FEB,1977 SOUTH GA. PUMP CO.	TLA UPPER UNIT	X	LOG TO T.D.	CTGS TO T.D.	E,SP, G	NO	NO	OBS TLA UPPER UNIT	INTERSEC. CO. RD. 248 & 13 ON STATE RIGHT/WAY. BLACK MINGO TEST; WELL CAVED AT 551 FT. PALEO. WORK BY SCGS/W.M. ABBOTT. TD IN KPD. DRILLER & LITH. LOGS BY C. RANSOM.
31CC-j5 (TH 18)	HAM-73	32°53'05" 81°00'11"	75 (TOPO)	200.0	4 PVC	60.0	JAN-FEB,1977 SOUTH GA. PUMP CO.	TLA LOWER UNIT	X	LOG TO T.D.	CTGS TO T.D.	E,SP, G,CAL	PUMP TEST (0.25 HR) Q/s=5	USGS(C) 2/23/77	OBS TLA UPPER UNIT	INTERSEC. HWY 63 AND RD. 13 ON STATE RIGHT/WAY. LITH. LOG BY C. RANSOM.
31CC-m4 (TH 19)	HAM-74	32°52'42" 81°02'24"	135 (TOPO)	200.0	4 PVC	110.0	JAN-FEB,1977 SOUTH GA. PUMP CO.	TLA LOWER UNIT	X	LOG TO T.D.	CTGS TO T.D.	E,SP, G,CAL	PUMP TEST (0.25 HR) Q/s=5	NO	OBS TLA UPPER UNIT	N. OF INTERSEC. HWYS. 363 & 63 ON STATE RIGHT/WAY. LITH. LOG BY C. RANSOM.
29DD-f2 (TH 20)	HAM-76	32°48'21" 80°54'35"	70 (TOPO)	216.0	4 PVC	94.0	JAN-FEB,1977 SOUTH GA. PUMP CO.	TLA LOWER UNIT	X	LOG TO T.D.	CTGS TO T.D.	E,SP, G,CAL	PUMP TEST (0.25 HR) Q/s=2	NO	OBS TLA UPPER UNIT	NW INTERSEC. CO. RDS. 13 & 42. LITH. LOG BY C. RANSOM.
29EE-h4 (TH 21)	HAM-77	32°43'30" 80°52'49"	50 (TOPO)	153.0	4 PVC	80.0	JAN-FEB,1977 SOUTH GA. PUMP CO.	TLA LOWER UNIT	X	LOG TO T.D.	CTGS TO T.D.	E,SP, G,CAL	PUMP TEST (0.25 HR) Q/s=17	USGS(C) 2/23/77	OBS TLA UPPER UNIT	N. INTERSEC. CO. RDS. 65 & 44 ON STATE RIGHT/WAY. LITH. LOG BY C. RANSOM.

Table 1. Summary of hydrogeologic data on SCWRC test holes, Low Country area

SCWRC Well No.	USGS Well No.	Latitude Longitude	Elevation Land Surf. in Feet Above MSL	Total Depth (Feet)	Casing Diam. (in)	Casing Depth (ft)	Date Drilled, Driller	HYDROGEOLOGIC DATA AVAILABLE							Use of Well	Comments
								Aquifer	Drillers Log	Lithologic Log	Geologic Samples	Geophys. Logs	Discharge Water Level (Discharge Test)	Chemical Analysis (Type Lab)		
29EE-p3 (TH 22)	HAM-78	32°41'31" 80°54'47"	80 (TOPO)	200.0	4 PVC	120.0	JAN-FEB,1977 SOUTH GA. PUMP CO.	TLA LOWER UNIT	X	X	CTGS TO T.D.	E,SP, G	PUMP TEST (0.25 HR) Q/s=33	NO	OBS TLA UPPER UNIT	SE SIDE CO.RD.286 AT MCPHERSONVILLE CHURCH.ON STATE RIGHT/WAY. LITH. LOG BY C. RANSOM.
31DD-n1 (TH 23)	HAM-79	32°47'09" 81°03'29"	95 (TOPO)	219.0	4 PVC	124.0	JAN-FEB,1977 SOUTH GA. PUMP CO.	TLA UPPER UNIT	X	X	CTGS TO T.D.	G,CAL	PUMP TEST (0.25 HR) Q/s=16	NO	OBS TLA UPPER UNIT	NW INTERSEC. HWY 278 & CO. RD. 51 ON STATE RIGHT/WAY. LITH. LOG BY C. RANSOM.
33CC-p2 (TH 24)	HAM-80	32°53'57" 81°14'14"	105 (TOPO)	60.0	4 PVC	60.0	JAN-FEB,1977 SOUTH GA. PUMP CO.	TLA UPPER UNIT	X	X	CTGS TO T.D.	G	PUMP TEST (1.0 HR) Q/s=36	USGS(C) 1/14/77	OBS TLA UPPER UNIT	SW INTERSEC. HWY 321 & CO. RD. 21 AT DUKES ON STATE RIGHT/WAY. LOST CIRC. AT 30 FT. LITH. LOG BY C. RANSOM.
33FF-p2 (TH 25)	HAM-81	32°36'25" 82°14'38"	75 (TOPO)	260	4 PVC	132	JAN-FEB,1977 SOUTH GA. PUMP CO.	TLA LOWER UNIT	X	X	CTGS TO T.D.	G,CAL	PUMP TEST (0.21 HR) Q/s=52	NO	OBS TLA UPPER UNIT	NE INTERSEC. HWY 321 & CO. RD. 20 IN GARNETT ON STATE RIGHT/WAY. LITH. LOG BY C. RANSOM. SCWRC REPT. 9, FIG. 7.
26HH-b4 (TH 26)	BFT-813	32°29'31" 80°41'13"	7.97	824.0	4 STL	200	MAR.,1977 SOUTH GA. PUMP CO.	TLA LOWER UNIT	X	X	CTGS TO 820 FT	STD,E, SP,G, CAL	NO	NO	OBS TLA LOWER UNIT	BRICKYARD PT.-LADIES IS.;SEE SCWRC REPT. 9,FIG. 8.LITH. LOG C. RANSOM. CURRENT-M TEST; DRILL CTGS-SCGS. PROPOSED BLACK MINGO TEST BUT WELL CONS. PROBS. LIMITED TD.
27EE-s5 (TH 27)	HAM-83	32°41'52" 80°51'04"	45 (TOPO)	156	4 PVC	88	AUG., 1976 C. RANSOM SCGS	TLA LOWER UNIT	X	X	CTGS, AND CORE (P)	E,SP, G	PUMP TEST (0.25 HR) Q/s=30 C. RANSOM	NO	OBS TLA UPPER UNIT	YEMASSEE-ADR RECORDER. LITH. LOG-A.J. ZUPAN, SCGS. CTGS DISCARDED; SEE FIG. 9. CURRENT-M TEST.
33CC-w6 (TH28)	HAM-82	32°51'09" 81°12'23"	125 (TOPO)	200	4 PVC	98	8/18/76 C. RANSOM SCGS	TLA LOWER UNIT	X	X	CTGS, CORES (PAR)	G,CAL	PUMP TEST (0.25 HR) Q/s=16	NO	OBS TLA UPPER UNIT	HAMPTON CO. LANDFILL. COOP. WITH LCOG 208 PROJECT.

Table 1. Summary of hydrogeologic data on SCWRC test holes, Low Country area

								HYDROGEOLOGIC DATA AVAILABLE									
SCWRC Well No.	USGS Well No.	Latitude Longitude	Elevation Land Surf. in Feet Above MSL	Total Depth (Feet)	Casing Diam. (in)	Casing Depth (ft)	Date Drilled, Driller	Aquifer	Drillers Log	Lithologic Log	Geologic Samples	Geophys. Logs	Discharge Water Level (Discharge Test)	Chemical Analysis (Type Lab)	Use of Well	Comments
27II-L6 (TH 29)	BFT-800	32°22'25" 80°41'35"	10.85	94.0	4 PVC	45	7/22/76 C. RANSOM SCGS	TLA UPPER UNIT				E,SP, G,CAL	OBS. WELL AQ. TEST AUG. 76	USGS(C) MULTI DEPTH	OBS TLA UPPER UNIT	PORT ROYAL CLAY CO. TH NO. 4. LOC. 62 FT. NE BFT-795.
27HH-t1 (TH 30)	BFT-801	32°26'32" 80°40'40"	11.61	88	4 STL	60	OCT., 1976 C. RANSOM SCWRC	TLA UPPER UNIT				G,CAL	NO Q PIEZO DATA	NO	OBS TLA UPPER UNIT	CITY OF BEAUFORT NEAR CEMETARY. DRILLED CENTER "SINK," LOST CIRC. ADR RECORD FOR TEMP. PERIOD.
29GG-f2 (TH 31)	JAS-166	32°22'38" 80°54'38"	10 (TOPO)	200.0	4 PVC	105	OCT., 1976 C. RANSOM SCWRC	TLA UPPER UNIT	X	X	CONT. SPLT SPN. AND CORE	G,CAL	NO	NO	TEST TLA UPPER UNIT	DAWSON'S LANDING, COOSAWHATCHIE R. SCWRC OBS. WELL.
28LL-t1 (TH 32)	BFT-810	32°06'33" 80°49'22"	12.02	140.0	NONE	NONE	FEB., 1977 C. RANSOM SCWRC	TLA UPPER UNIT	X	X	CONT. SPLT SPN. AND CORE	G,CAL	NO	NO	TEST ABN	SW END HILTON HEAD IS. PLUGGED AND CEMENTED GROUTED.